Conference Proceedings

BEHAVE 2023

the 7th European Conference on Behaviour Change for Energy Efficiency

European Energy Network
A voluntary network of European energy agencies

Netherlands Enterprise Agency

Behave 2023
7th European Conference on Behaviour and Energy Efficiency

Foreword for BEHAVE 23 Conference Proceedings
Kristina Haverkamp, German Energy Agency (dena)

Dear readers,

It is my great privilege to introduce you to the official Proceedings of the 7th Behave Conference of the European Energy Network (EnR) in Maastricht. As President of this great European network, I am happy to present to you this collection of abstracts and papers as one more proof of EnR’s relevant and forward-looking work.

From Maastricht to Europe and beyond
Maastricht has gone down in history as a place of fundamental and forward-looking political decisions and, in particular, as a symbol of European cooperation. For it was here, more than 31 years ago, that the heads of state and government of twelve countries signed the Maastricht Treaty. The Treaty laid the foundations for the European Union in its present form. For example, today the Treaty is considered the birth certificate of our common European citizenship and our common currency.

To be quite precise, the Maastricht Treaty officially entered into force on November 1, 1993, and the European Union thus became a reality. That was almost exactly 30 years ago today. So you could say; time and place were quite appropriately chosen for a conference that is also committed to the idea of European cooperation and addresses important future challenges for the people of Europe and well beyond.

This year's Behave conference is themed "Scaling-up behaviour change in the light of the energy and climate crisis". The purpose of this conference is to help in shaping solutions to the major challenges posed by both the current climate and energy crises. Without question, the interlinking of these two crises and the solution of their complex problems pose enormous challenges for policymakers and for societies in Europe – and beyond.

Behavioural science, climate change and the energy transition
At the same time, the conference stands for an approach that could be given even more attention in science, but above all in practical politics. The conference places the findings of the behavioural sciences at its centre. It shows how these findings can be applied to practical policy and contribute to the decarbonisation of our societies.

It is now widely recognized in the scientific community that human behaviour change can be an effective component of systematic climate protection measures. Thus, insights from general behavioural science are today considered crucial for defining and implementing even more effective measures in energy and climate policy for the future. The scientific findings could find multiple applications in practice, whether in efficient energy use at the level of individual consumer households or in industry, in the area of public procurement, or in the topic of energy communities, to name a few examples.

For a long time, policymakers and researchers have also sought to incorporate behavioural science insights into climate policy discussions. But despite their well-known importance, these insights are still too rarely part of real policy practice.

Reinforcing the bridge between science and policymaking
Conferences like Behave 2023, which bring together researchers and decision-makers from politics and business, are therefore indispensable for transferring the findings of the behavioural sciences into practical action. The Behave conference is dedicated to this transfer from theory to practice in about 50 sessions. The more than 200 abstracts submitted and the more than 50 papers submitted demonstrate the great interest in the diverse topics of the conference.

I am convinced that this conference can reinforce the much-needed bridge between science and political practice and contribute to new effective climate protection measures. I wish you much pleasure and new insights. Let this special read encourage you to European cooperation and to solve our common problems!

Foreword for BEHAVE 23 Conference Proceedings
Rebecca van Leeuwen, Netherlands Enterprise Agency/ RVO

As Chair of the EnR Working Group Behaviour Change, I feel proud and privileged to have had the opportunity to lead this 7th edition of the BEHAVE Conference on 28th and 29th November 2023 in Maastricht, the Netherlands.

Changing the ways in which we consume energy has a significant and immediate impact on accelerating the energy transition, on increasing the energy resilience of Europe and beyond, and on tackling climate change and environmental degradation.

Behavioural change is becoming an increasingly important dimension in achieving quick and effective energy demand reductions across all sectors, in both the work place and at home. Simple measures such as awareness campaigns on switching off lights and electrical equipment, promoting alternative modes of transport or adjusting heating temperatures by 1 degree have already helped to achieve significant energy reductions, but we need to do more.

This edition focuses on scaling-up behaviour change in the light of the energy and climate crises. Topics covered a wide array of behaviour-related issues ranging from energy poverty, energy communities, demand flexibility in energy, acceptance and adoption of new sustainable technologies, industry, mobility, the built environment, retrofitting, peer to peer energy to the role of institutions in sufficiency policy, green jobs and skills, the role of the youth in the energy transition and more.

Useful insights from behavioural science and psychology on stimulating energy efficient behaviour are widely available. However, they need to be taken into account in a more consistent manner to fully guide the design of behavioural change campaigns and policy development at national, local and regional levels. This is why we brought together not only the social scientists to this event, but also policymakers, practitioners, representatives from industry and end-users to engage in dialogue, learn from one another and to apply the wonderful research carried out worldwide to real life situations.

We are extremely proud to have received so many great contributions (close to 200 abstracts and around 50 full papers) from many different countries all over Europe and beyond. BEHAVE 2023 was tailored to inspire and inform, bringing together diverse minds from the depths of scientific research to the strategies of policy-making. These conference proceedings comprise all abstracts and full papers received, all of which have been peer-reviewed by a Scientific Committee of members from universities all around Europe, the European Commission and a sustainable energy organisation in New Zealand.

Last but not least I would like to thank dena, Germany the EnR Presidency, my co-Chair Adrianna Threpsiadi from the Energy Saving Trust (EST) in the UK, the many EnR member energy agencies of the Organising Committee, and of course the EnR Working Group Chairs for their tremendous support and collaboration. I would also like to thank the members of the Scientific Committee in particular Marta Lopes, Thijs Bouman, Kaisa Matschoss and Paolo Bertoldi for all their hard work and support and colleagues involved in the IEA Technology Collaboration Programme (TCP) Users, in particular Chair David Shipworth and Head of the Secretariat Sam Thomas for their great cooperation. Finally I would also like to thank my team at the Netherlands Enterprise Agency/ RVO – Marlies Kok and Michel Handgraaf from the Behavioural Insights Team and Lucille Hulshoff, Charlotte de Jonge, Femke Ton and Jelmer Bennen from Events and Communications for making this conference a resounding success.

Foreword to the Proceedings of the BEHAVE 2023 conference "Scaling-up behaviour change in the light of the energy and climate crises"

Marta Lopes **Kaisa Matschoss** **Thijs Bouman**

BEHAVE 2023 is the 7th edition of the biannual EnR event focusing on the application of behavioural insights in policies, programmes and actions to foster energy efficiency and combat climate change. As an important conference for national energy agencies in Europe, BEHAVE provides a unique forum for policymakers, academics, industry and practitioners to share the latest insights, ideas and experiences to promote a more efficient use of energy and to reduce carbon emissions. BEHAVE 2023 hosts more than 400 participants, coming from all over Europe, as well as from other continents. Close to 200 abstracts and about 50 full papers were received.

The topics of the conference include a fair and inclusive energy transition (e.g., energy poverty, gender and generational fairness , green jobs, energy justice, hard to reach energy users), the public adoption of more sustainable energy behaviours (e.g., energy efficiency, energy conservation and curtailment, sufficiency, demand flexibility), the public engagement in energy solutions and policy making (e.g., energy communities, public participation, citizen science, peer-to-peer trading), interventions to promote or facilitate behaviour change (e.g., sustainable habits and practices, education, nudging, intermediaries), the role of technology and systems design in encouraging and facilitating behaviour change (e.g., acceptance and adoption of low-carbon technologies, energy labelling, green buildings, retrofitting, mobility and electric vehicles, decarbonising cities).

These proceedings display a vast variety of perspectives on behaviour change, which contribute to the energy transition and highlight the versatility and creativeness of potential solutions to address the multiple challenges in this realm. The contributions underline the need for changes in behaviours and practices to improve energy efficiency, shift to renewable energies, and engage in sufficiency in a just manner. We thank all authors and participants for their contributions, which we trust will provide an impetus to consolidate fruitful actions in this field.

On behalf of the Scientific Committee, we welcome you to BEHAVE 2023 and wish you a very successful conference!

Maastricht, 28-29th November 2023

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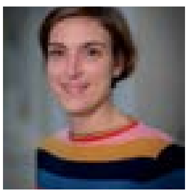

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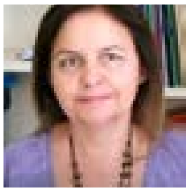

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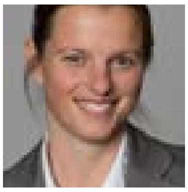

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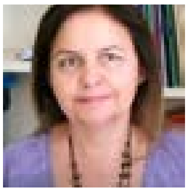

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Contents

ABSTRACTS

Behavioural Science for Energy Efficiency: Insights and Policy Recommendations from the NUDGE Project

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Keywords: Energy efficiency, Behavioural interventions, Nudging, Randomised Control Trials, Profiling, Sensor data, Survey data, Indoor Air Quality, Solar photovoltaic systems, Electric Vehicles, EV Charging, Educational interventions, Efficiency of gas-fired boilers

Abstract

This session highlights the key findings and policy recommendations derived from the Horizon 2020 project NUDGE, which explores the potential of behavioural interventions in promoting energy efficiency choices. The project has conducted an extensive assessment of nudging interventions through a series of randomized controlled trials (RCTs) spanning households, energy communities, and schools across five EU Member States.

Adhering to fundamental principles of behavioural science, NUDGE has utilized a wide range of methodologies and tools to analyse participant behaviour. This comprehensive approach has resulted in the development of user profiles, suggested nudges, and a systematic evaluation of their effectiveness. The project has relied on data gathered from user surveys and advanced sensors, including smart meters, apps, and indoor air quality sensors, during real-life field experiments.

The accumulated research and experimentation have culminated in the formulation of policy recommendations for both public and private sectors. NUDGE has played a vital role in assessing the potential inclusion of nudging interventions in the policy-making

toolbox of EU and national policy makers and stakeholders, offering valuable insights into their efficacy and limitations.

In this session, we will discuss the lessons learned from the project, highlight important findings, identify areas for further research, and present key policy recommendations. The session aims to foster dialogue and collaboration among researchers, policymakers, and stakeholders, enabling the translation of scientific insights into practical solutions for promoting energy efficiency.

BETTER ENGAGING UNDERSERVED ENERGY USERS: EARLY LEARNINGS FROM THE UNITED STATES AND CANADA

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Keywords: Equity, Energy Efficiency, Behaviour, Programme, Utility, Just Transition

Abstract

Utilities in the United States and Canada have increasingly been focused on how to better engage in energy efficiency programmes customers who are vulnerable or marginalized. One entity aiming to advance this cause is the Consortium for Energy Efficiency (CEE), a non-governmental organization (NGO) whose 76 energy efficiency programme administrator members direct approximately 70% of the $9.3 billion USD spent annually on energy efficiency in the United States and Canada. CEE launched the Center for Equity and Energy Behavior in 2022 to help ensure more equitable benefit from energy efficiency programmes and to more fully account for the multiple benefits of programmes for underserved customers. The Center seeks to address the reality that income eligible, low-English proficient, rural residential, and indigenous communities may not participate in—and benefit from—energy efficiency to the same extent as their counterparts. As an initial step, CEE recently completed an assessment of the energy equity efforts underway across the U.S. and Canada. We propose a presentation that provides an inventory and overview of the current work underway in North America to better engage vulnerable and underserved audiences in energy programmes. The focus would include which energy users are typically considered particularly vulnerable in this context, the most promising approaches for better engagement, and metrics used for measuring progress.

Exploring residential space use pattern: findings from a multi-country survey

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Keywords: Willingness to change, Occupant behaviour, Residential sector, Policy acceptance, Space use pattern

Abstract

The residential sector accounts for a large share of total energy consumption in the EU. The average floor area per capita has been steadily increasing over the recent decades, leading to higher energy demand due to the need for more building materials and more energy for heating and cooling. Certain groups, namely childless families, have the highest average floor area. A large saving potential therefore lies in the redistribution of the floor space, thereby reducing the need for new construction by avoiding the unnecessary consumption. Strategies such as moving, sharing and rearranging could facilitate this redistribution in the residential sector.

To provide an overview of the feasibility of such strategies, this paper examines the current behaviour of residents with regard to the use of residential space and the potential for change in this sector, using empirical data collected in a multi-country online survey conducted in Germany, Sweden, Poland and Portugal. In addition to analysing consumption patterns in the residential sector, the study examines the willingness of residence to change their space use and investigates the acceptance of specific strategies that could lead to a reduction in the need for new construction in the residential sector.

By providing insights from different geographical and cultural representatives of the EU, the results of the study could contribute to EU and national policy making. By focusing on the groups with the highest potential for savings, the study helps to design tailor-made and efficient solutions and to optimize effectiveness of the policies.

USER CENTRED DESIGN OF BUSINESS MODELS FOR ACTIVATION OF FLEXIBLE ELECTRICITY DEMAND

Experiences from a collaboration project between academia and the commercial and public sector

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Keywords: Flexibility, Demand response, Policy, Business models, Flexibility markets

Abstract

The electrification that takes place as part of the energy transition entails challenges related to power balance and grid capacity. According to the EU commission, flexibility services are crucial to meet the increasing share of renewables that is needed to meet climate goals. In the Swedish context it is also important to speed up the pace at which grid customers are connected in order not to slow down the electrification and societal development. Against this background the Swedish government has tasked four different authorities with creating the conditions for realizing the flexibility potential - in terms of demand response, energy storage and control of small-scale electricity production - in the energy system. Using methods that are inspired by user centred design, the overall goal of this project is to develop and test business models, in the form of market-based policy instruments for incentivizing flexibility, and thus pave the way for a more efficient use of local power grids. The aim is to increase knowledge about the approach of different actors to the capacity shortage in the grids, the drivers and barriers of flexibility providers and aggregators to be part of the solution, as well as the expedient design of flexibility markets and business models for increased flexibility at the demand side. The project is carried out in close cooperation between academia, industry and the public sector, which means that the development takes both commercial and technical conditions as well as the needs and preferences of various key players into account.

Local Energy for Sale: An Experimental Analysis of Consumers' Decision-Making in Peer-to-Peer Energy Trading Platforms

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Abstract

As energy markets are becoming more decentralised, energy trading platforms are emerging as a promising tool which can facilitate the integration and coordination of energy consumption, encouraging the use of renewable source of energy. Peer-to-peer energy trading platforms represent a new marketplace where consumers who can both generate and use their own energy (i.e. prosumers) are able to share part of their energy production with those who can be considered as traditional consumers. By empirical exploring three different European countries, Italy, Spain and the United Kingdom, we study the effectiveness of both economic and non-economic incentives in understanding consumers' willingness to pay for electricity in a platform. We collect our data making use of an incentivized online survey experiment. To determine if consumers will use the proposed energy platform to maximise their individual benefits in the form of electricity bill savings or if they will act pro-socially and maximise community benefits, we employ a set of contingent valuation experiments. We also explore how individuals' socio-economic characteristics, attitudes and behavioural biases affect their decisions and willingness to pay. In our findings emerges that determinants such as pro-environmental attitudes and wish for independence from the current electricity suppliers influence individuals' willingness to pay for electricity in the platform. Results also show that consumers exhibit pro-social behaviour in their pricing decisions, suggesting that the use of peer-to-peer energy trading platforms can be beneficial to all participants.

Keywords: Energy, prosumers, contingent valuation, survey-experiment

Policy implications of digitalisation pathways for lower energy demand

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Keywords: Digitalisation, ITC, pathways, energy demand

Abstract *Digitalisation has the potential to enable significant reductions in energy demand and greenhouse gas emissions. However, research suggests that this is not the current trajectory, as decarbonisation of supply and energy efficiency improvements are being outpaced by the rapid expansion of digital goods and services. Further, current market forces prioritise economic growth and overconsumption over energy savings and wellbeing. We have examined future pathways and scenarios which consider both digitalisation and transitions to sustainability [1]. We found that first, insufficient attention is paid to rebound effects of digitalisation, whereby efficiency improvements can drive higher levels of consumption. Second, different pathways have very different impacts for energy demand, well-being and other sustainability goals. We conclude that governance and policy must play a central role in directing the digital transformation towards sustainability.*

We now consider potential policy measures for digitalisation and energy demand in three areas – data; household devices; and transport. Building on the notions of responsible digitalisation and digitalisation sufficiency, we propose policy principles for steering digitalisation towards sustainability, and start to apply these principals to critique UK and EU policy, which despite strong legal frameworks on climate change mitigation, have a low interventionist approach to digitalisation and sustainability, avoiding questions relating to the use of these technologies and relying primarily on market mechanisms.

1. Bergman, N. & Foxon, T. J. Drivers and effects of digitalisation on energy demand in low carbon scenarios. Clim. Policy 1–14 (2022).

Heat pumps for domestic hot water in residential buildings: insights from a roll-out programme

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Keywords: heat pump, domestic hot water, energy transition, energy efficiency, behaviour

Abstract

Heat pumps are effective and efficient in producing heating/cooling from electricity. They are generally used to heat/cool buildings, but also to heat water, either as stand-alone water heating system, or as combination of water heating and space conditioning system.

Due to its high energy efficiency, heat pumps play a significant role in the energy transition towards decarbonisation of domestic hot water production.

The Portuguese Plan for the Promotion of End-Use Efficiency promotes measures to improve demand-side energy efficiency. A vast range of promoters can submit applications for funding, including retailers, transmission and distribution systems operators, consumer protection entities, associations of companies, associations of municipalities, energy agencies, and research and high education institutions.

A survey was applied to a sample of beneficiaries who had conventional electrical storage tank water heaters replaced with air source heat pump water heaters. The questions aimed at characterizing house typology and domestic hot water usage patterns, evaluating energy bill reduction perception, asserting the likelihood to invest in a heat pump without incentive, and identifying other energy efficiency measures implemented or planned.

The surveys found most users were satisfied with the new equipment and over 50% noticed an energy bill reduction. Most users had not implemented energy efficiency measures in the last two years, and of those who did LED lighting prevails. Nevertheless, almost 50% of the users reported this measure influenced the future decision of implementing other energy efficiency measures.

The need for fresh air: Is there a (mis)match between the technical and user requirements for mechanical ventilation systems in residential buildings?

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Keywords: Energy efficient buildings, ventilation behaviour, user requirements mechanical ventilation

Abstract

Decarbonizing the building sector goes along with an increasingly energy efficient building standard and therefore also, the use of mechanical ventilation systems. However, not many studies have examined whether actual ventilation behaviour and occupant requirements for mechanical ventilation in residential buildings match with the characteristics of ventilation systems. Energy efficiency of ventilation systems is usually described as the most important criterion in the technical requirements for ventilation systems (EU, 2014). However, previous studies have shown that there is a gap between the ventilation behaviour required to exploit the technical potential of mechanical ventilation systems and the actual behaviour (Lai et al., 2018). In this mixed-methods study, different types of ventilation behaviour, natural ventilation behaviour in general and tenants´ requirements and priorities for mechanical ventilation, were examined using qualitative interviews and an online questionnaire survey carried out in the German population (N = 952). The results show that ventilation behaviour differs between occupants and has habitual as well as goal-directed and situational components. Furthermore, we applied the technology acceptance model (TAM; Davis, 1989) for residents already using mechanical ventilation systems to examine our hypotheses that next to perceived ease of use and perceived usefulness, also technology complexity (Chin & Lin, 2016), past user experience and cleanliness concern (identified in qualitative pre-study) constitute additional predictors of attitude towards the mechanical ventilation systems. We conclude that (potential) users place importance on slightly different aspects than what has been focused on in the technical design requirements for ventilation systems. More user-centric designs are thus needed for energy transition.

How to Include Energy Sufficiency in EU Energy Policies?

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Keywords: EU energy policies, Sufficiency, energy conservation, Energy efficiency, Behaviour

Abstract

(max 250 words) The EU has set by law the target to be carbon neutral by 2050 and has adopted stringent targets for GHG emissions, renewable energies and energy efficiency for 2030.

It is important to note that the so called EU "Energy Efficiency" target a maximum energy consumption target for the EU and the EU Member States. The second point to note is that the previous 2020 target of -20% was reached through a combination of energy efficiency policies and the impact of the Covid-19 pandemic, and EU energy consumption has increased again in 2021.

Recently the dramatic invasion of Ukraine by Russia has further impacted the EU energy markets and policies, by increasing energy prices in particular for natural gas and as a response has triggered a fast, sharp and unprecedented reduction of gas consumption in the EU, showing new mechanisms to reduce energy consumption.

In recent years the energy efficiency policy research and debate has focused on the concept of sufficiency as a complementary concept to energy efficiency. Sufficiency has been recognised in the latest IPCC report as a key component to reach climate neutrality in 2050 complementing energy efficiency.

The key research question addressed in this paper is how the current EU energy and climate policies, in particular the EED, EPBD, Ecodesign, RED and Internal Market Directive address implicitly or explicitly energy sufficiency in relation to the 2030 and 2050 EU targets. Finally, the papers proposes solutions for the integration of sufficiency in EU energy and climate policies.

Supporting SMEs in net zero: A review of behavioural influences on decisions to invest in energy efficiency

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Abstract

Small and medium sized enterprises (SMEs) have an important influencing role and contribution to net zero, notably because they represent 99% of all businesses in the EU, with an estimated 400 million SMEs worldwide. However, opportunities for SMEs to improve energy efficiency (EE) and decarbonise are likely to differ across sectors.

This research, that was conducted as part of the H2020 project LEAP4SME, sought to understand how different SME stakeholders can influence decisions to invest in energy efficiency. It involved a Rapid Evidence Assessment (REA) and semi-structured interviews with SME experts. Twenty-six publications were selected for full review with information recorded on location, method(s), sample, sector, behavioural factors, SME policy and programme recommendations. The REA confirmed that sectors studied were heavily skewed towards energy-intensive manufacturing sectors, with a minority of studies on SMEs in horticulture, building/ construction, hospitality, and retail.

The research identified groups of factors that can influence SMEs propensity to implement energy efficiency measures. The first group is professional and industry-related factors such as participation in peer networks and memberships to trade associations. This can support SMEs through raising awareness of funding opportunities and promoting best practice among professional and/ or local businesses. The second group is individual owner/ manager and/ or employee attributes. For example, our research found that decisions to invest in energy efficiency can be related to sensitivity to issues such as climate change and sustainability, staff ambition and entrepreneurial mindsets. Other themes identified by the research included timing of engagement and support and the roles of different stakeholders. Recommendations for SME decarbonisation efforts are provided.

Keywords: SMEs; decarbonisation; energy efficiency; decision-making and behaviour.

“Energy is scarce. Let’s not waste it”. Findings and challenges of the Swiss energy saving campaign 2022/23 and beyond

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Keywords: Energy saving campaign; behavioural economics; stakeholder involvement; security of supply

Abstract

In response to the possible shortage of gas and electricity in winter 2022/23, many governments turned to energy savings campaigns. This presentation illustrates and analyses the new campaign launched in Switzerland on August 2022 “Energy is scarce. Let’s not waste it.” We summarise how the campaign used custom-tailored insights of behavioural economy for its design and subsequent improvements. The campaign advertised energy-saving tips for private households and operational optimisation measures in companies in order to realise immediate savings and prevent a shortage in electricity or gas during next winter. It also used a broad stakeholder approach, the so-called “Energy Saving Alliance” in order to engage organisations of the economy, civil society and the government of cantons and cities. The campaign was monitored and evaluated, showing an overall very high recognition of both the campaign and the topic of energy efficiency. The findings also allow to identify the main strengths and weaknesses, including where the readiness of people to take action increased significantly – and where it didn’t. The campaign continues to winter 2023/24 with additional elements, such as: gamification; efficiency in small and medium enterprises, in particular through modernising facilities and devices; further possible measures of local governments. It puts into discussion the challenges that remain, such as delivering prompt feedback to end-user on their savings, or on defining and measuring a quantitative aim of energy savings of the campaign.

HOME FOR THE COMMON FUTURE (HCF):

The use of home-meanings to promote domestic energy retrofit

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Keywords: domestic energy retrofit, motivation, home-meanings, perezhivanie, emotions, cognition

Abstract

*The promotion of energy retrofit to homeowners is an important policy strategy to reduce operational energy use in dwellings and mitigate climate change. Research and policy on the built environment typically focus on the cognitive (logical) aspects to motivate retrofit decisions, such as health considerations, savings on energy bills and financial returns on investment. This focus, though, neglects the emotional aspects of how homeowners themselves make sense and attach meaning to the potential benefits of low-carbon dwellings.To include the emotional aspects of motivation, this paper develops a home-meanings framework around the concept of perezhivanie (emotional and cognitive experience), which is subsequently used to analyse homeowner energy retrofit motivations. The paper draws on current literature of home-meanings and empirical insights from: (i) ten cases where homeowners achieved significant carbon emission reductions through retrofit activities, and eight cases where they did not; (ii) a workshop with 36 participants, representing various actors interested to advance domestic energy retrofit activities in the UK, e.g. industry, government, academia, intermediaries.The paper illustrates the analytical use of the developed home-meanings framework to create narratives for energy retrofit promotion, which resonate with homeowner cognitive and emotional reasoning. This is achieved via a single heuristic that is aimed to shape homeowner cognitive frames — **H**ome for the **C**ommon **F**uture (HCF). The acronym can simultaneously be used to describe motivations involving emotional reasoning – **H**appiness in everyday life, **C**aring identity, **F**uture-resilience, as well as cognitive reasoning – **H**ealth and well-being, **C**limate concerns and **F**inancial considerations.*

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Moderating demand for online services as a way towards digital sustainability

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Keywords: Behaviour change, systems thinking, digitalisation, human computer interaction, service design

Abstract

The use of ICT services has risen exponentially over the past decades and so have the amount of devices and infrastructure needed for them to function. And despite immaterial metaphors such as ‘the cloud’ and ‘wireless’, these services have a significant ecological footprint. Unbeknownst to many users, kilometres of transatlantic cables and a plethora of electronic devices and servers are all connected to their home routers. At the same time, the service providers design their product in such a way that it is almost irresistible for these users, to the point where excessive usage takes the form of addiction. Without any consideration for ICT’s footprint, this interaction between users and service providers will continue to cause a surge in demand for data infrastructure. So far, we have been able to mitigate this rising demand at least to a certain extent with efficiency improvements in hardware development, but in recent studies experts start to question whether this pace of innovation itself is actually sustainable. If efficiency improvements slow down, then this would be disastrous for climate policy targets. Therefore, we shift the perspective to the demand side, where a better understanding of the user’s behaviour around digital services can inform a shift towards a new paradigm of sufficient data usage. By combining knowledge from Human-Computer Interaction studies, behaviour psychology and transition studies we see opportunities for the development of new service design frameworks and policy interventions that aid the transition towards a more sustainable digital future

A Rationale to Foster the Role of Energy Communities in Creating Inclusive Social Hubs for Citizen Science in Energy Aspects.

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Keywords: Energy Communities, behaviour, citizen science, energy transition, universities

Abstract

Addressing the detrimental impact of our energy habits on the climate presents a complex challenge, with no simple solution. Nevertheless, fostering behavioural changes towards sustainability remains a crucial component of the solution. Promoting individual and collective awareness plays a crucial role, and citizen science hubs can significantly contribute to this endeavour.
This paper introduces the Aurora project, which seeks to create citizen science hubs as community-driven centres for promoting renewable energy adoption. By establishing community crowdfunded photovoltaic plants across five diverse locations in Europe, including four university environments and one rural area, the project aims to transform existing communities into renewable energy communities. To support this endeavour, the Aurora App is introduced, offering users a means to track their energy-related carbon footprint, receive personalized impact information, and provide suggestions for minimizing their carbon footprint. Moreover, users can offset their emissions by participating in the photovoltaic installations. The project also incorporates promotional and educational activities designed to raise awareness, engage community members, and drive behavioural changes.

We focus on the efforts to establish appropriate legal entities and communities for the photovoltaic demonstrators. Furthermore, we highlight the role of public universities as catalysts in promoting and supporting such citizen science hubs. We conclude with an invitation for ambassadors to propagate the Aurora project's concept within their own social communities, further expanding project's positive impact.

The French government sufficiency roadmap

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Keywords: Sufficiency, households, life style

Abstract:

In June 2022, the French government launched a process leading to the drafting of an Energy Sufficiency Plan (ESP). It was presented by all the ministers involved on 6 October 2022, and the meeting was closed by the Prime Minister. During the three-month preparatory work, from the end of June to September, the government convened several working groups representing local authorities, various institutions and private stakeholders in most sectors and relevant topics, including: residential, office and commercial buildings, including museum, department stores, as well as: transport, arts and entertainment, tourism, digital industry, work organisation and sports activities.
The first ESP identified 15 key sufficiency measures to achieve a 10% (climate-adjusted) reduction in demand for both gas and electricity by 2024. A national communication campaign was launched on the same day, highlighting 5 energy tips to show how the general public can play its part. This primary target of minus 10% was achieved during the first winter season. An ESP Stage 2 was then designed and launched in June 2023 to disseminate the achievement, secure the benefits, build for the longer term and set up governance with monitoring tools. On this occasion, a summer communication campaign was launched to bring 5 new energy saving tips to the attention of the general public.
Sufficiency has now been better defined to achieve the long-term 2050 target. Public behaviour and understanding of reducing energy demand through sufficiency is key to success, so government communication on this issue is paramount.

Increasing information seeking behaviour of small entrepreneurs for Zero Emission transport: the role of temporal framing

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Keywords: Energy efficiency, electric vehicles, SME-owners, behavioural barriers, transport behaviour, temporal framing

Abstract

To reduce transport emissions in city centers, governments worldwide are implementing Zero Emission (ZE) zones. Among the affected groups, small and medium-sized enterprise (SME) owners driving diesel vans account for 33% of emissions in The Netherlands. Surveys show that owners are largely unaware of the upcoming measures and reluctant to take action. Major behavioural barriers to information seeking are lack of perceived urgency, resistance among SME owners, and low perceived credibility of the implementation of the ZE zone. To explore the impact of urgency and credibility on information seeking behaviour, we ran a pilot study among 160 SME owners and drivers in which we manipulated the temporal framing on a poster. Framing the regulatory change as 'starting in 20 months from now' significantly increased the perceived proximity to the regulatory change. At the same time, it reduced the perceived credibility of the regulatory change. None of the participants was willing to look up further information. To further explore this interplay between urgency and credibility on information seeking, we conducted an experiment involving 13,945 entrepreneurs in a mid-sized Dutch city. The results show that increased urgency together with a 'I would like to take control' frame significantly increases information seeking (4,28%) relative to a neutral letter (1,35%). Additionally, addressing resistance by a 'What's in it for me' frame increases information-seeking (2,86%). Addressing these behavioural barriers contributes towards designing effective strategies to promote entrepreneurs' engagement with zero-emission logistics.

The experiences of heat pump early adopters: Influencing adoption amongst homeowners in Scotland.

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Keywords: Early Adopters, Heat Pumps, Pen Portraits, Energy efficiency, Scotland

Abstract

This presentation will summarize the results of a report for the Scottish Government by Changeworks and ClimateXChange that investigated the experiences of Early Adopters of ZDEH systems (primarily heat pumps) amongst private homeowners in Scotland. These twenty interviews were conducted to inform the Scottish Governments forthcoming Heat in Buildings Strategy (HiBS) engagement campaign. The interviews were used to develop pen portraits which endeavour to represent Scottish households and their experiences with ZDEH learning, acquisition and installation. These pen portraits will be utilised to influence further Scottish households to adopt ZDEH systems and help contribute to the Governments 2045 net zero goals.

The interviews not only supplied foundational information for the development of the pen portraits they also provided wider learnings for heat pump adoption in Scotland. These themes included the motivations (environmental concerns, running costs) and barriers (install cost, disruption) to heat pump adoption as well as what advice households would give to others. Participants also commented on their main influences with researching and deciding to install a heat pump as well as the lack of information provided post-install. A review of relevant literature of early adopter of ZDEH systems was also conducted which provided corroborating evidence that aligned with the households' experiences. The literature review, pen portraits thematic findings, and recommendations will be discussed with regards to the potential engagement and influence on private homeowners in Scotland.

Monitoring sufficiency : a new annual barometer to track aspirations and practices of the French households.

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Keywords: Sufficiency, households, monitoring, barometer, life style,
Abstract*:*

Sufficiency in our lifestyles will increasingly be a lever to be mobilized in response to the challenges of ecological transition. French institutions, including ADEME, are implementing more and more concrete actions on this matter, including monitoring, for example via indicators (ODYSSEE-MURE) or opinion polls.
These barometers show that the French are aware of the need to change their lifestyles to deal with the climate emergency and the scarcity of resources. However, there is a strong paradox between, on the one hand, growing aspirations for a different model of society calling into question the economic system and current lifestyles, and on the other, practices and representations that remain largely anchored in a consumerist model.

In 2023, ADEME therefore launched a new exploratory annual barometer on "lifestyles and sufficiency" with a representative sample of the French population, in order to measure and observe changes in sufficiency aspirations and practices. of the French and their opinion on sufficiency policies.
Beyond the methodology, we will present and analyze the first results of this barometer which will focus on:
- Declared practices in 6 areas: mobility, tourism, digital, consumption, food, housing
- The representations of a "good life" and the needs
- Representations and personal commitment on sufficiency
- Aspirations vis-à-vis social models and opinion on sufficiency measures

Reflecting on organisational change concerning public engagement in energy transitions

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Keywords: Public engagement, organisational change, energy grids, energy transitions, just transitions.

Abstract

There has been a recent development within Irish policy towards citizen engagement on energy transitions and climate action more broadly. The Climate Action Plan (2023) explicitly referenced the importance of citizen engagement, and through the National Dialogue on Climate Action sought to give space for different aspects of Irish society to have their voices heard in Ireland's decarbonisation and sustainability transition. The need for systematic and active engagement with different actors within Irish society, at both local and national levels, was recognised within the Climate Action Plan as crucial, with the National Dialogue on Climate Action referenced as the central mechanism through which this would be achieved. EirGrid- Ireland's national electricity transmission operator- through their own historical context, have undergone a journey into developing new strategies for citizen and community engagement with relation to energy grid developments. Here, we reflect upon this journey, situating it within the national context. This process of reflective practice seeks to provide findings for other organisations both nationally and internationally undertaking a journey towards establishing new engagement practices through implementing internal organisational behaviour change. A reflective practice approach has been applied to the organisational structure of EirGrid with cross-organisational participation, from the board and executive team to public engagement specialists and community liaison officers. As a process of reflection-for-action this approach to outlining the creation of new methods for citizen and community engagement can inform the organisation moving forward.

Matching “deep renovation” and “integrated district approaches” in social housing towards existing neighbourhoods' decarbonization

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Keywords: Energy efficiency, Decarbonization; Adaptation; Healthy Life; Communities

Abstract

The 14th of March 2023 “Energy performance of buildings (recast)” European Parliament proposal integrates the European initiatives aggregated under the “Fit for 55” legislative package with the holistic strategies of “New European Bauhaus”, were the findings of BEHAVE conferences may eventually find a space. In line with the 2018 recast, buildings are still portrayed as thermodynamic equations of heat losses/gains, and behaviours used as mere statistical representations of average occupant patterns. European citizens are included only to individually “deep renovate” their buildings by 2030/50, with “Minimum Energy Performance Standards” excluding “worst performers” from a market whose prices already cause social and economic problems. Communities, neighbourhoods and behaviours keep arising in these Directives mostly from technical reasonings: Renewable Energy production as a reason to include communities, “area-specific potentials for energy efficiency measures” as the reason to address neighbourhoods, and behaviour change as a path towards demand flexibility and virtual power plants. Yet strong (BEHAVE) opportunities are created with the mandate to tackle the “worst-performing buildings, including through integrated district renovation programmes”. This paper transposes the “state-of-the-art” of deep renovation and Energy Poverty mitigation strategies, developed within the LIFE21-CET-ENERPOV-REVERTER project, to illustrate that the 2023 recast proposal/potentially approved Directive can change the landscape of social housing, help to identify barriers/benefits and upscale deep renovation in a new way.

Acknowledging that the Directives jargon limits the contributions of BEHAVE researchers and the public they serve, this paper aims towards bridging areas and facilitating extended social sciences participation in the deep renovation processes that will shape our future. Buildings are not thermodynamic systems nor sculptures: they are places where individuals gather as households/communities and, from there, shape the society we live in.

“Healthy Neighbourhoods”, “Families in action”: reframing “deep renovation” beyond energy efficiency

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Keywords: Energy efficiency, Energy Poverty; Inclusion; Adaptation; Healthy Life

Abstract

The most socially vulnerable families struggle with increasing costs (energy, rent, inflation, ...) while continuously dealing with intrinsic, and often cyclic, difficulties in raising their children. This paper describes one perspective—the “energy efficiency” side—of a holistic approach designed to “integrate 30 families of children from (...) Coimbra Norte in the search for reasons and conditions for a healthy life through Reflection, Experimentation and Transformation workshops promoted by 15 community partners” and to “improve family health, socioeconomic well-being, healthiness and comfort in housing, without forgetting health literacy”, as declared in the manifest awarded with a 50k€ grant from an innovative national funding opportunity. Through a brief description of the context, goals and identified sources of inspiration, project results, visions and shortcomings, the authors emphasize local schools as triggers of community-scale change and action, while assuming families, and then neighbourhoods, as keystones of a cross-sectional change. It is proposed, and illustrated with visual outcomes, that investing in holistic “energy efficiency” approaches can help break cycles of (energy) poverty, and attract younger generations to the green jobs we need to deliver the New European Bauhaus motto: “Beautiful, Sustainable, Together”.

Preparatory research for certification system in circular economy for companies

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Keywords: business; circular economy; decarbonisation; energy efficiency; decision-making and behaviour.

Abstract

The challenges of sustainability and the energy transition imply a new attitude of the Intensive Energy Consumers (IEC) so that, in addition to energy efficiency, they act in sustainability and efficiency in the use of resources. Among others, training and capacity building activities on energy audits and energy efficiency measures can be encouraged, with the integration of the efficiency of other resources.

Based on the previous assumptions, ADENE started a project to create a certification system in circular economy for companies having done preparatory work in two aspects:

- *Conducting a survey on the introduction of other topics in the energy analysis of a IEC, aiming to listen to the adherence of the main stakeholders to these themes addressed to two groups that constitute the most representative stakeholders - Operators and Auditors under the Management System of Intensive Energy Consumption – SGCIE (Mandatory Energy Audits Regulation).*
- *Pilot actions with companies from various sectors of activity to adapt the scope of the future certification system in circular economy in companies, to be launched by ADENE in July 2023. Surveys were carried out with the pilot companies to assess their receptivity to the model being built.*

It is intended to present the results of these activities to highlight the behavior of companies in the introduction of resource efficiency in addition to energy efficiency.

Developments in energy equity in New Zealand:

The tension between energy hardship policy and behaviour change

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Keywords: Energy poverty; Energy equity; Energy efficiency, Behaviour change; policies and programmes

Abstract

New Zealand, having recently formalised its definition of "energy wellbeing" and associated indicators, is seeing a flurry of activity across the energy sector to alleviate energy hardship (or "energy poverty"). In the past four years, attention has turned to a significant problem of energy hardship which has arisen due to a legacy of poor housing stock, relatively low incomes and rising electricity prices. Government has completed policy development and consultation programmes, is funding innovative pilots in energy education and community energy, while community organisations and industry players explore a range of tailored local solutions, in particular providing energy efficiency education in communities. Energy knowledge and navigation skills and behaviour change messaging play a key role, but these approaches have met with resistance from the community sector. Many feel that behaviour change passes blame and places an inappropriate burden on those experiencing energy hardship, while diverting attention from wider systemic solutions that must be addressed in energy policy settings and energy market structures. This presentation will provide first hand insights from years spent working in policy, programmes and industry engagement in New Zealand. It will provide an overview of the definition, measurement and alleviation of energy hardship, and discuss the successes as well as the tensions that have arisen as various approaches are being tested and scaled.

Climate-Ready Certificates, a tool for improving water-energy nexus and climate adaptation performance in households, buildings, and neighborhoods.

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Keywords: Water-Energy Nexus, Climate Adaptation, Efficient Buildings, Behaviour Change, Water Efficiency

Abstract

The Climate-Ready Certification (CRC) scheme assesses in one certificate three dimensions: water efficiency, water-energy nexus, and climate adaptation providing a transversal performance analysis that allows for the consideration and adoption of water efficiency and climate adaption measures in different stages of the building: design phase, new construction, and operation. It can be applied to residential, small service or commercial buildings, as well as to "neighbourhoods", considering buildings and outdoor areas. The classification identified in each CRC varies from F (less efficient) to A+ (most efficient). It encompasses one global classification and three sub-classifications, related to each evaluated dimension.

CRC builds on and expands from the existing efficiency rating scheme, AQUA+®, developed by ADENE, which focuses on water efficiency and energy-related consumption, deepening the water-energy nexus analysis and adding climate adaptation evaluation criteria. The methodology has 96 evaluation criteria: 53 for assessing water efficiency, 23 for the water-energy nexus, and 20 for the climate adaptation dimension. The applicability of the criteria is adaptable to different scales of the project. Presently the methodology is under testing having been applied to one neighbourhood, three buildings, four detached houses and thirteen households.

Through CRC the different stakeholders, from policymakers to urban planners, building developers and property owners are aware of the building's performance, benefiting from a robust decision support tool in the different phases of the project. In resume, CRC guides adopting improvement measures that leverage the development of water-resilient and climate-adapted buildings.

The CRC are an initiative within the B-WaterSmart project, financed by the Horizon 2020 programme (number 869171).

Social norms and information-based behavioural interventions to promote sustainable energy choices: results of two Italian case studies of the EU-funded H2020 "*ENCHANT*" project

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Keywords: Energy efficiency, Behaviour change, Social norms, Climate information

Abstract

We present the main features of the EU-funded HORIZON 2020 research project titled "Energy Efficiency through behaviour change transition strategies - ENCHANT". The main aim of ENCHANT is to review and assess previously available knowledge about behavioural interventions targeting energy consumption, and to design, conduct and test new intervention strategies through a series of RCT-like field experiments in six countries (Norway, Austria, Italy, Germany, Romania, and Turkey). Specifically, we present and discuss here some preliminary results of two case studies testing different behavioural interventions in Italy. The interventions were conducted through the active support of an Italian energy cooperative and renewable energy provider, and of a non-profit foundation devoted to the preservation of the natural, cultural and archaeological heritage in central Italy. Results of the energy cooperative case study (N = 184) showed that the performance of sustainable behaviours by cooperative members is driven by environmental and health factors, rather than economic ones, that sustainable energy choices and behaviours are predicted by organizational identity and social norms, and that norm-based interventions may help in reducing actual energy consumption. Results of the non-profit foundation case study (N = 1114) showed that feelings of connectedness to nature predict beliefs in global warming through the mediation of discrete emotions such as guilt and happiness, and that interventions based on the provision of climate-related information, presented during a visit to an aesthetically pleasant natural and historical setting, increases individual willingness to donate money for renewable energy projects.

Enabling Affordable Cooling through India's Standard and Labelling (S&L) Program and consumer acceptance in India

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Keywords: Energy efficiency, affordable cooling, consumer behaviour, energy policy

Abstract

Equitable access to sustainable cooling is crucial for climate sustainability and economic productivity. Initiatives like India Cooling Action Plan (ICAP), aim to reduce cooling energy requirements by 25% to 40% by 2037-38 with additional benefits of thermal comfort in domestic housing.

With 88% of Indian households owning an electric fan[1], Indian fan industry produces over 60 million units annually (2018–19)[1]. The associated cooling demand has prompted India to develop labeling program for ceiling fans. India also recently launched labeling program for table, pedestal and wall-mounted (TPW) fans thereby covering 90% of Indian residential fan market. These policy interventions for aforesaid fans are expected to save 11.3 Terawatt-hours of electricity and 9.05 million tons of carbon emissions by 2030. Energy-efficiency programs are further augmented by the Lifestyle for Environment (LiFE)[2], which promotes consumer behavioral changes for advancement of energy transition.

The paper will discuss the consumer acceptance of affordable cooling solutions influenced by other drivers of consumption viz. price, quality, energy saving, durability, promotion and environmental awareness. Furthermore, market penetration of affordable cooling solutions and possibility of future policy improvements along with public engagement for future interventions will be assessed by the authors.

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[1] http://rchiips.org/nfhs/NFHS-5Reports/NFHS-5_INDIA_REPORT.pdf
[2] http://missionlife-moefcc.nic.in/

Growing consumer acceptance for affordable and energy-efficient lighting solutions through efficiency policy intervention in India

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Keywords: Energy efficiency, market transformation, consumer behaviour, efficient lighting, energy policy

Abstract

India has witnessed a massive expansion in electricity consumption in the last decade, clocking a 15% consumption alone from domestic lighting out of overall electricity consumption of India[i]. The market is gradually shifting towards efficient lighting in the past few years driven by various factors - price, quality, energy saving, durability, brand, promotion, Corporate Social Responsibility, & environmental consciousness.

Further, public policy interventions like the India's Standards and Labelling (S&L) program for Light Emitting Diode (LED) bulbs, which has provided star labels for more than 1 billion LED lights since inception. Also, Unnat Jyoti by Affordable LEDs for All (UJALA) Program, an initiative by Energy Efficiency Services Limited (EESL), Government of India and Lifestyle for Environment (LiFE) mission, which promote consumer behavioural changes for advancement of energy transition. From 2016 to 2022, India's S&L program for LED lighting itself has resulted in 6.95 Terawatt-hours of electricity savings and 5.5 million tons of carbon emissions reduction.

This paper will analyse the interplay of the said factors to enable the purchase and adoption of energy-efficient lighting by the consumers. Simultaneously, the market penetration of energy-efficient lighting, and possibility of future policy improvements along with public engagement for future interventions will also be assessed by the authors.

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[i] As per ELCOMA Vision 2024 Report

The effects of technological choices on individual energy consumption behaviours: insights from the building sector in France

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Keywords: Energy consumption behaviour change, Construction sector, Heating, Technology

Abstract *This article contributes to the general debate on the impacts of the energy transition on individual energy consumption behaviours. It puts under scrutiny the energy transition in the building sector in France which consists of inscribing new values into the professionals' practices, i.e., the energy-efficiency of buildings, the renewable energy consumption, and the renewable energy production. Individual energy consumption behaviours are embedded in multi-scalar structural environments. In the context of urban development projects, we test a hypothesis: the change in professional practices predefines individual behavioural models of energy consumption linked to household heating through the choice of technologies, their governance, and their control. The adoption and materialization of new values through technological choices for heating supply are conditioned by multiple factors, e.g., the business models, the actors' interdependencies, and the complexity of governance model' establishment, but also the territorial context and previous experiences. Three technological choice models have been identified and are analysed, the district heating network, the local collective heating with biomass boiler and the individual heating pump. First, the study reveals how energy consumption behaviours related to these heating technologies vary - what are the possibilities for individual action-specific or material-specific actions. Second, we draw attention to the limits of real estate developers in promoting behavioural change due to the short-term profitability perspective of their investment compared to lessors who invest in a long-term perspective as they keep the building in their possession and must ensure that tenants can pay their energy bills.*

ENERGY EFFICIENCY

The effects of technological choices on individual energy consumption behaviours: insights from the building sector in France

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Enhancing water and energy renovations by households: contribution of integrated one-stop-shops and certification schemes

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Keywords: Energy and water efficiency, Building Renovations, One-Stop-Shop, Water-Energy Nexus, Labelling, Performance Certification

Abstract

EU has set ambitious goals to tackle building stock challenges, aiming to achieve a highly energy-efficient and decarbonized building sector by 2050. Building renovations plays a crucial role in achieving these goals, resulting in improved energy and water performance, sustainability and reduced CO_2 emissions. This study highlights the importance of integrated tools and overarching approaches to foster building renovations through enhanced user experience and combined savings associated to home retrofit, based on casA+ hub analysis. Households using the casA+ hub[i], are encouraged to turn renovation measures into practice, including those prescribed in Energy Performance Certificates (EPC), through interoperability with the Portuguese EPC database, connecting homeowners with experts and skilled professionals for proper execution. CasA+ Hub also interoperates with voluntary labelling scheme CLASSE+® and building certification scheme AQUA+®, expanding the scale and benefits of home renovations to increased energy performance of building envelope (CLASSE+) and households water use performance (AQUA+), enhancing energy efficiency and decarbonization under the water-energy nexus. CasA+ and CLASSE+ also help to attest compliance with financial incentives granted under the Portuguese Recovery and Resilience Plan, accelerating renovation investments and procurement.

Through case studies analysis and user feedback, this study explores the contribution of the casA+ Hub as a support tool to facilitate behavioural change and adoption of energy and water efficient solutions for more sustainable buildings, including the benefits of one-stop-shop (OSS) integration with EPC and complementary labelling and certification schemes, streamlining renovation processes, improving decision-making and promoting energy and resource efficiency in buildings.

[i] Portuguese one stop shop (OSS) referred to by the Commission Recommendation (EU) 2019/786 on building renovation (https://portalcasamais.pt/)

ENERGY POVERTY ALLEVIATION BY SOCIAL HOUSING PROVIDERS

Investigating Targeted Approaches in France, England, and the Netherlands

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Keywords: Energy Poverty, Fuel Poverty, Social Housing, Renovation, Rent Setting, Housing Allocation

Abstract

Since energy prices across Europe started to rise in 2021, there has been growing concern of social housing tenants at risk of energy poverty. So far, studies have largely focused on the role of governments and on what tenants themselves could do. However, research has rarely considered specific targeting approaches by social housing providers (SHPs). This study explores the role of these stakeholders and investigates what policies French, English, and Dutch social housing providers could adopt to enhance the effectiveness of their energy poverty alleviation efforts. Focus groups with practitioners demonstrated their perspectives on the most effective interventions, their benefits and challenges, and their variation across policy contexts. We found that social housing professionals perceive a significant responsibility in addressing energy poverty among their tenants, but that there remains uncertainty regarding their role within the welfare state. While views and practices among SHPs vary, most deem prioritisation of retrofits and targeting behavioural interventions more effective and feasible approaches than setting rents progressively and targeting allocations. Particularly the presence of institutional barriers and a lack of data hinder SHPs from implementing a more targeted approach in addressing energy poverty.

Climate change and energy poverty : what are the prospects ?

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Keywords: Energy observatory, Energy poverty, Energy crisis, Measures and statistics.

Tittle : Climate change and energy poverty : what are the prospects ?

Abstract

The French national observatory on energy poverty is a tool for observing and analyzing public policies to combat fuel poverty, at the service of national and local partners and organizations since march 2011. Chaired and led by ADEME (French agency for ecological transition), the main goals of the observatory are to have a reliable and shared knowledge on energy poverty in France with the tasks of (1) pooling, processing and producing data, (2) facilitating public debate and (3) disseminating information on the subject. The publication of a twice-yearly dashboard enables the observatory to reflect on the new issues surrounding fuel poverty. Two topics have become key issues for dealing with the subject.

- **Decline in household purchasing power.** What is fuel poverty in the context of the energy crisis and rising prices? How does the government's emergency financial aid (short-term measures) fit in with an overall building renovation policy (long-term measures) ?
- **Climate change and energy poverty.** Historically, the ONPE has observed energy poverty in the cold. Climate change is forcing us to question the very definition of fuel poverty in a context of hot weather. How to describe statistically these changes ?

“Keep it Simple, Stupid!”? When Less is not More: Communicating Climate Change More Effectively

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Keywords: Climate change, Behaviour, Communication, Climate projections,

Abstract

The phrases "Keep it simple, stupid!" or "Less is More" suggest that simplicity is often more effective. Although these sayings are commonly endorsed by behavioral scientists, they do not always hold true. Let's consider a hypothetical scenario where climate scientists predict a 2.0°C temperature increase by the end of this century. If this projection appears remarkably accurate, it is essential to acknowledge the inherent uncertainty associated with climate projections, like flight time arrivals. Temperatures could potentially rise anywhere between 1 and 3°C (more or less, depending on the climate model). However, if we strictly adhere to the concept of "less is more," we might overlook the uncertainty surrounding this projection.In my presentation, I will share a study that examined the impact of climate projections on user trust, concern, and attitudes (Joslyn & Demnitz, 2019). Specifically, among a representative sample of Americans we manipulated the projections to include either probabilistic intervals (90% predictive interval) or just the mean value. The results revealed that probabilistic intervals increased trust in climate predictions, concern about climate change, and more positive opinions about climate scientists. Significantly, this effect was observed among individuals who identified themselves as Republicans, a demographic group that tends to be skeptical about climate change.This study serves as a reminder to exercise caution when accepting popular concepts such as "Less is More" without evidence. Furthermore, while beliefs about climate change may be influenced by partisan identity, they can be influenced and changed through targeted communication strategies.

The role of perceived contribution to the energy transition in acceptance of renewable energy sources: The case of biomass

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Keywords: public acceptance, perceived effectiveness, renewable energy sources, biomass

Abstract

The energy transition requires introducing renewable energy sources (RES) to replace fossil fuels in electricity, heating and cooling, and transport. Despite being a substantial player in the renewable energy sector and a needed technology for the energy transition, the social acceptance of biomass receives less attention in academia than solar and wind, and environmental activists groups do not position themselves as proponents of biomass usage in public debates. The current study investigates what drives social acceptance of biomass as RES and explores appropriate communication to inform the public about biomass. Study 1 shows that acceptance of biomass is dependent upon the materials that are listed as fuel for biomass. Biomass from wood and energy crops has significantly lower acceptance ratings than biomass from manure and organic waste. The latter types scores similar to solar and wind energy. Mediation analysis shows that acceptance towards biomass is driven by the perceived contribution to the energy transition. Biomass from wood and energy crops is considered less effective in contributing to the energy transition and as a result suffers from lower acceptance scores. Study 2 extends these findings and shows that positioning biomass as a means to handle waste streams increases perceptions of effectiveness for all types of biomass and increases acceptance. Together, the results of our study demonstrate the relevance of communicating the effectiveness and contribution of an RES, in this case biomass, to the energy transition to garner social acceptance.

A RAPID REVIEW OF QUALITATIVE RESEARCH ON BARRIERS TO PROENVIRONMENTAL BEHAVOR CHANGE

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Keywords: Energy community. Renewable energy, Energy efficiency, Behaviour

Keywords: pro environmental behaviour change, barriers, qualitative research

Abstract

In recent decades, the environmental impact of human activities has become increasingly evident, emphasizing the need for key lifestyle changes to reduce this impact. Pro-environmental behaviour (PEB) change involves adopting protective actions and avoiding behaviours that harm the environment. While considerable quantitative research has explored the aspects of PEB, a comprehensive investigation into the barriers hindering pro-environmental action is lacking. Qualitative methods offer a nuanced understanding of the contextual and meaningful aspects associated with these barriers. Although qualitative research on barriers to PEB has gained momentum in the past decade, it remains relatively underexplored. In this study, we aimed to (1) explore and overcome barriers to PEB through a Rapid Evidence Review and (2) assess the utility of integrating the Weber model as an analytical framework.

We present the findings of a rapid review that included 38 qualitative studies on barriers to PEB conducted between 2012 and 2022. Our analysis identified four primary themes: (1) barriers at the individual, community, and industrial levels; (2) a dearth of qualitative research on the industrial level, particularly regarding energy-saving behaviours, despite its prominence in individual perspectives; (3) a general emphasis on the individual level in qualitative studies, suggesting a need for policy makers to shift focus towards industry-level structural changes; and (4) a call to researchers for a broader perspective on barriers to PEB to inform policy recommendations.

Identifying Key Barriers for Joining an Energy Community in the EU Context Using AHP

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Keywords: Energy community, Energy transitions, Behaviour, Barriers

Abstract

Energy communities (ECs) offer a promising solution for achieving sustainable and decentralized energy systems. H owever, the successful establishment and operation of ECs require overcoming various barriers that can hinder stakeholder participation. Existing research has primarily focused on incentives and motivations to join ECs, thus neglecting a comprehensive understanding of the key barriers affecting all EC stakeholders in European Union (EU) countries. This paper aims to fill this research gap by identifying and ranking the barriers to joining ECs in the EU context.

To accomplish this, a framework of barriers was developed based on 20 in-depth interviews with diverse stakeholders, including energy association representatives, citizens, energy suppliers, policymakers, and community organizers. The identified barriers were categorized into four types: financial, regulatory and bureaucratic, technical and practical, and social and cultural. The Analytical Hierarchical Process (AHP) methodology was employed to estimate and rank these barriers. The findings highlight that the most significant barrier categories are Regulatory and Bureaucratic and Financial. Specifically, regulatory complexity and legal limitations emerge as the top-ranked barriers among the identified obstacles to joining ECs.

Making SMEs more sustainable: results and lessons from four behavioural studies

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Keywords: SME, Energy efficiency, Behaviour, Subsidies, Sustainability

Abstract

The climate transition requires a change in behaviour from both citizens and companies. Small and medium-sized enterprises (SME) comprise 99.8% of the Dutch business community and are a very heterogeneous group. While many studies from the behavioural sciences focus on the individual as a target group, there is still a knowledge gap when it comes to behavioural studies that focus on companies. The Behavioural Insights Team of the Ministry of Economic Affairs and Climate Policy has conducted four behavioural studies among SMEs. Using a mix of research methods, we investigated what motives and barriers for SME entrepreneurs are to invest in sustainability. Input was collected both directly from SME entrepreneurs and among various stakeholders.
A short description of the studies:

- *Survey with online experiment (n=176) and interviews among SMEs with staff ≤10 with a focus on subsidies for sustainability (2021)*
- *Focus groups with energy advisors (2022)*
- *Interviews among SMEs with medium sized roofs focused on solar panels (2023)*
- *Survey (n=425) and interviews among SMEs with staff 10< and stakeholders focused on the sustainability of the business premises (2023)*

This presentation will include the most important results from these four behavioural studies. Furthermore, we will share how these results have been applied to policy, reflect on the lessons learned and discuss with the attendees what opportunities are for scaling up. In order to give the attendees practical tools for researching this target group of businesses, we will share the [Tool Behavioural Change in Companies| BIN NL](#).

The Smart Energy Research Lab: Maximising the benefits of longitudinal data for empirical socio-technical research

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Keywords: Energy efficiency, energy behaviour, data, observatory, longitudinal

Abstract

The Smart Energy Research Lab (SERL) delivers a unique data resource to the domestic energy demand research community. SERL has developed into a critical facility that enables a broad range of multi-disciplinary, socio-technical research relating to energy consumption in domestic buildings.

The primary value in SERL is derived from the core "Observatory" panel of 13,000 representative GB homes, and ongoing data collection of the associated dataset, which is comprised of: half-hourly gas and electricity smart meter data and linked contextual data - survey data (including building characteristics, household socio-demographics and energy behaviours etc.); Energy Performance Certificate data covering the energy efficiency of the building; and hourly weather data. SERL Observatory datasets are updated every 3-6 months and provisioned to researchers via the UK Data Service with aggregated statistical data published annually.

SERL has enabled over 25 separate secure-access Observatory research projects across more than 20 institutions. These include projects investigating major disruptive events such as the impact of the coronavirus pandemic on domestic energy demand, and the impact of rising energy costs in 2022/23. Other projects, for example, aim to understand the habitualness of energy consumption; the social diversity of load profiles and the potential for demand shifting (to off-peak hours).

This presentation will discuss how researchers can best utilise SERL's energy data resources, consider opportunities to link with other data and research resources across Europe, and introduce EDOL – a project that incorporates additional in-home data streams to existing SERL datasets.

Developing an empirically based agent-based model to support local transitions

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Keywords: Sustainable technology, technology adoption behaviour, agent-based model, local transitions

Abstract

Sustainable technologies (e.g., hydrogen) have great potential to contribute to achieving sustainability goals. Nevertheless, sustainable technologies are often not readily adopted. Many transitions are currently being explored with agent-based models, allowing stakeholders to explore different scenarios to advance local transformations. However, in most cases, agent-based models, mainly built by engineers, still assume the rational actor. Actual decision-making behaviour is, however, hardly rational, lowering model reliability. A theory-based framework describing technology adoption behaviour is needed to represent local systems and actor behaviour in agent-based models accurately. Integrating psychological factors regarding adopting sustainable technologies in agent-based models helps address the complexity of the interrelated technical and social phenomena and the heterogeneous social actors. In the presented research, we, based on the results of a quantitative literature review and an initial study, build a theoretical framework that includes influential psychological factors of technology adoption and distinguishes between individuals, households and organisations. With this distinction, we explore whether similar or different factors are relevant for the various stakeholders. Through our research, we seek to advance the application of behavioural insights in energy system modelling and provide a better understanding of agent-based model potentials, which allow the exploration of outcomes of different scenarios and thereby contribute to successful decision-making and intervention design. We discuss implications for transition research and reflect on hurdles and solutions regarding the integration of psychological insights into an agent-based model.

Designing a gender-just energy policy: mapping the mindsets of Dutch municipal policy workers on mitigating energy poverty

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Keywords: Q methodology, energy poverty, multi-level governance, policy workers, mindsets, values, gender analysis, gender-just energy transition

Abstract

Citizens' participation in the energy transition seems mostly available for households with disposable incomes to invest in energy efficiency, renewable energy sources and retrofitting. Those who cannot afford the upfront costs might not benefit from the policy interventions, like tax benefits and subsidies. The energy crisis made energy poverty visible and a national energy policy issue. In the Dutch governance system, energy poverty mitigation measures are decentralized with mandate and budget for the municipalities. With decentralised budgets, municipal policy workers are the key actors in this: with tailored, local policies, they can financially support, stimulate energy-efficient behaviour and broaden access to the energy transition.

This study provides insights and deepens the knowledge on value-driven decision-making. The research analyses Dutch policy workers at the municipal level on their mindsets regarding solutions to mitigate energy poverty. The gender-just energy policy framework provides a holistic conceptual approach that includes both distributive, recognitional and procedural perspectives to inform value-driven decision-making. Q methodology is applied to uncover the subjectivity (opinions, values, etc) of the policy workers that are designing and implementing energy poverty mitigation policies. Q methodology is an exploratory methodology that unveils cohorts of like-minded people regardless of characteristics usually used in quantitative studies (such as age and gender). The study uses Q methodology to group municipal policy workers' mindsets into 'institution-focused' and 'explorers'. These mindsets pinpoint bottlenecks in municipal energy poverty mitigation in the short term. Furthermore, the mindsets uncover subjectivity in the policy cycle and present a transparent method to overcome subjectivity.

Label 2020 – New Label driving supply and demand of energy efficient products.

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Keywords: energy label; consumer awareness;

Abstract

The energy label is a decision support tool for consumers to purchase energy efficient products. Since the 90's it has been revised to accompany products innovations and adopted by several product categories. The latest revision entered in force in March 2021, with the introduction of a new energy label for washing machines, dishwashers, refrigeration products, light sources, and TVs. The most relevant were the return to the A to G scale and the introduction of a QR code to access the information available in the European Product Registry for Energy Labelling database, EPREL.

To support the adoption of the new energy label by the market and the consumer, various tools and services were developed within the LABEL2020 project, a Horizon2020-funded initiative, in force between 2019 and 2022. The main activities were in 2021, actively supporting market agents in the understanding of their responsibilities and the steps needed to introduce the new energy label in the supply chain.

For retailers' guidelines and education tools, including e-learning and dedicated support services, were provided. For consumers numerous information measures and tools were introduced through national communication campaigns, implemented in 16 European countries. The set of tools included leaflets, videos, live events and a web application, the Energy Efficiency Check that supports product and cost comparison based on the EPREL database.

The lessons learned are essential to support a successful communication towards the market and the consumers regarding the forthcoming rescaling process of the energy label for other products, ensuring the consumer's trust in the energy label is reinforced.

Tugging at Heartstrings or Promoting Pros and Cons: Understanding the Psychology of Sacrifice for Global Sustainability

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Keywords: Climate sacrifice, Climate behavior, sustainable decision-making, environmental psychology

Abstract

Given the advancing global climate change, widespread climate-related sacrifices across all aspects of life, embraced by as many institutions and individuals as possible, are necessary. Moreover, dealing with other events, such as pandemics, energy crises, and inflation, requires sacrifices with potentially positive impacts on the climate. While social science research has already demonstrated that long-term success of climate projects depends on the perception of those affected by the decisions, the concept of sacrifice in climate (policy) decisions remains largely underexplored.

Therefore, there is an urgent need to model a) groups, reasons, and domains in which individuals are willing, able, or compelled to sacrifice, b) how sacrifice is perceived and processed, and c) which factors (individual, social, moral, and societal) form the (un)willingness and public preparedness to pursue climate-related sacrifice.

We address the multi-causality and implementation of sacrifice comprehensively by using a mixed-method bottom-up approach. First, we conducted exploratory interviews with 21 German participants of various ages, incomes, moral and environmental attitudes in a first step. Two intertwined decision strategies emerged, influenced by the context and personal characteristics of the individuals: an emotional, norm-guided, and a rational, cost-benefit-driven perspective. The next step is to validate these strategies by quantitative studies.

Ultimately, this research aims to inform effective communication strategies to achieve successful implementation of climate-related sacrifice behaviour that are supported by governance and the public.

The Impact of Reminder Text Messages on Recycling Behavior: Evidence from a Field Experiment

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Keywords: Reminder, recycling, limited attention, RCT

Abstract

We conduct a field experiment to test whether reminder text messages can improve the recycling behavior of households in a middle-class neighborhood in Lima, Peru. Over a nine-week treatment period, households are randomly assigned to one of four groups: i) an untreated control group, ii) a group that receives continuous reminders, iii) a group that receives reminders only for the first three weeks, and iv) a group that receives reminders for the first three weeks and for the last three weeks, with a three weeks pause in between. We show that reminder messages can effectively encourage recycling behavior, with suggestive evidence that the continuous reminders are most effective. Our study suggests that limited attention can be an obstacle to pro-environmental behavior, which can be mitigated through low-cost interventions such as sending sms reminders. Understanding that limited attention is an obstacle to pro-environmental behavior is critical as it can inform the design of policy interventions, potentially improving their effectiveness in promoting sustainable actions in a world increasingly burdened by environmental challenges.

Understanding the impact: Exploring the influence of simplified energy communication on energy consciousness in India

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Keywords: Energy efficiency, Effective communication, Behaviour, Energy literacy, Energy conservation

Abstract

Effective communication is essential for fostering energy efficiency in communities. Providing contextualized energy savings figures is crucial to help individuals understand their potential contributions to conservation and cumulative energy savings, especially for the general non-expert audience. Aggregating individual actions can lead to significant reductions in energy consumption and associated emissions, which aligns with national-level priorities and initiatives like India's Mission LiFE (Lifestyle for Environment). However, non-expert consumers often struggle to comprehend large scientific terms like terawatt-hours (TWh) or metric tonnes of CO_2*. To overcome this, communicating in relatable terms such as households off the grid, cars off the road, or trees planted helps consumers grasp the importance of their actions and encourages positive responses. Comparisons with energy consumption of an Indian state or all households in a city provide a sense of scale, effectively conveying the magnitude of the impact.*

This study builds upon our ongoing efforts to explore the contextualization of energy saving through energy equivalents. Through this study, we aim to assess the effectiveness of energy and emissions equivalences in communicating energy-related information in the Indian context. Through an online survey targeting residents of Indian metropolitan cities, we will examine the impact of simplified energy communication on participants' attitudes towards climate change, energy savings, and their willingness to modify behaviour to become more energy conscious. Statistical analysis will be used to evaluate correlations between income group, socio-demographics, age, existing energy literacy, understanding of simplified energy numbers, and their influence on energy-use behaviour.

Unveiling Energy Consumption Flexibilities from a Gender and Diversity Perspective

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Keywords: Demand-side management (DSM), Flexibility Profiles, Diversity, Social Licence to Automate (SLA)

Abstract

Given the volatile nature of renewable energy generation, the energy transition requires improved coordination of demand and supply (Smith et al., 2020). There is a pressing need for more comprehensive research on what motivates end-users to mitigate peak demand (Azarova et al., 2020) and to permit automatic adjustments (Gupta et al., 2021). However, demand-side management (DSM) programs for residential homes tend to consider households as homogeneous entities, overlooking the diverse motivations, needs, and range of possibilities for different consumer groups. This paper aims to address this oversimplification by identifying markers of energy consumption flexibility among user groups based on electricity load profiles, with a focus on gender and diversity aspects. Insights are drawn from the IEA UsersTCP SLA 2.0 project, which investigates the acceptance of automated DSM programmes from a gender and diversity perspective. The paper follows a twofold approach. First, it systematically analyzes existing national and international datasets to identify differences in the flexibility potential of residential consumers both at the household and energy community levels. User groups are defined based on socio-demographic variables, namely gender, age and education, among others, and their respective flexibility potential is calculated by estimating the elasticity of their demand response between different time horizons. Subsequently, recommendations for future data collection are derived to inform the design of DSM solutions targeting diverse user groups. In conclusion, this paper provides insights on energy consumption and decision-making patterns of different user groups, contributing to the development of tailored approaches aimed at increasing household participation in DSM.

***References*:**

Azarova, V., Cohen, J. J., Kollmann, A., Reichl, J. (2020). Reducing household electricity consumption during evening peak demand times: Evidence from a field experiment. Energy Policy, 144, 0301-4215.
Gupta, R., Patel, R., & Srivastava, S. K. (2021). Integration of demand-side management, renewables, and electric vehicles in the smart grid. Renewable Energy, 168, 1061-1077.
Smith, J., King, J., & Harrison, G. (2020). Demand response and flexibility in the UK's electricity system: End-user engagement and public interest. Energy Policy, 145, 111749.

Assessing the Role of Digital Technologies in Daily Life for Energy Efficiency and the Climate Crisis: A Technology Acceptance Perspective

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Keywords: Digitalisation, Energy efficiency, Technology acceptance, Daily life, perceptions, digital skills.

Abstract

Digital technologies have become integral to daily life, encompassing various services, applications, and devices used at home and on the go. While research has focused on the low-carbon attributes of technology to improve energy efficiency and combat climate change, little is known about how individuals employ these technologies in their daily lives to reduce their environmental impact. This study delves into the acceptance of digital technologies in daily life and their potential to enhance energy efficiency and climate change mitigation. The study investigates individuals' willingness to adopt digital technologies in their daily routines and examines whether this acceptance influences their intentions to use such technologies regularly. Moreover, it explores how factors like social norms, digital skills, and environmental lifestyles contribute to this acceptance. The study employed the Technology Acceptance Model

(TAM), revealing that those who perceive digital technologies as valuable for climate change mitigation and energy efficiency had stronger intentions to integrate them into their daily lives. Findings showed that varying levels of digital skills can influence people's perceptions of the usefulness of these technologies in promoting energy efficiency and mitigating climate change. Understanding the individual factors determining the adoption of digital technologies in daily life is crucial for promoting low-carbon technologies to mitigate climate change. This research provides valuable insights that can inform evidence-based strategies to promote digital services and applications, thereby increasing energy efficiency and aiding climate change mitigation. By recognising the potential of digital technologies in empowering individuals to contribute to environmental preservation, society can move towards a more sustainable future.

Scaling-up digital disconnection practices in service of sustainability

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Keywords: Digital Disconnection, Digitalisation, Sustainability, Behaviour

Abstract

As the need for lifestyle changes in order to reach sustainability goals becomes more evident, more knowledge is needed in this area in order to better understand what new behaviours should be created and which existent ones encouraged.

This paper proposes that, in addition to imagining novel manners to support sustainability, we can also consider the existent user behavior which can then be scaled up in conjunction to more efficient energy use. More specifically, the proposed case is that of digital disconnection practices where users of digital devices such as smartphones choose to disengage from them for a limited time or permanently. Although privacy and productivity increases are often given as motivations for such behaviors, recent reasons also focus on the aim of sustainable consumption. To this end, the replacement of smartphones with more simplistic newly-designed phones touches upon issues such as reduced e-waste as often such devices have a longer life span, reduced energy consumption due to their long battery life, or fair-trade construction through ethical and local manufacturing.

If previous research is correct about the increased popularity of digital disconnection practices, this is an opportunity for further understanding how this behavior can be put into the service of sustainability by, for example, designing devices, interventions, or policy supporting sustainable choices with a positive impact on the environment and which are already desired and employed by many. In other words, digital disconnection has the potential to be scaled-up to the advantage of sustainable and responsible energy consumption.

New energy labels: how changing the energy efficiency scale affects energy efficient choice behaviour

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Keywords: Energy labels, Energy efficiency, Behaviour, Interventions

Abstract

In 2021 the new energy labels for household appliances have been introduced in Europe. Energy labels are a useful tool to encourage more sustainable behaviour. On the new energy label, the energy classes run from A to G instead of A +++ to D. There is also a rescaling, as there are (temporarily) (almost) no products with energy class A on the market. Centerdata conducted research for the European Commission to support the revision of the energy labels, and investigated for Milieu Centraal whether the new energy label motivates consumers to buy more energy efficient appliances. We also investigated how consumers can best be informed about these changes. An experiment was conducted in Centerdata's LISS Panel to investigate effects of the changed scale and product rescaling (N = 881). Respondents made product choices and perceptions were assessed. They either saw energy labels with the old (A+++-D) or new (A-G) scale, or the new scale with a rescaling (class B most efficient). The new energy labels lead to more energy-efficient choices. Also, the difference between the highest and middle energy class (A vs. D or A+++ vs. A) was perceived greater for the A-D scale than for the A+++-D scale. Moreover, even if no products in class A are available, choices remain just as efficient. Last, we show that providing a brief explanation can ensure that choices become even more efficient. Results were used to design information campaigns in the Netherlands.

Inclusive involvement in energy communities? The role of gender, income, education, ethnicity, and age

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Keywords: energy communities, involvement, inclusion, diversity, socio-demographics, motivation, ability, social embeddedness

Abstract

Do socio-demographic groups differ in their involvement in an energy community, and why? Initial qualitative evidence shows that community energy initiatives tend to be set up and led by wealthy, well-educated and older white men. Yet, little is known about differences in involvement beyond this group of initiative takers. We examine this among a representative sample of the Dutch population (N=1571) including both non-members and members of energy communities. Next, we consider three possible explanations for why marginalized groups may be less involved. While it is sometimes assumed that marginalized groups might be less involved simply because they are less motivated to engage in pro-environmental behavior, we propose other processes are more important predictors of their involvement. Specifically, involvement might be explained by marginalized groups having lower perceived ability to get involved (both efficacy of joining and participative efficacy to contribute to the energy community) and being less socially embedded in the initiative (having less social contact with members). Finally, we test whether the negative effects of above mechanisms might be countered by the (perceived) diversity of the members of the energy community. This way we contribute to informing initiative-takers of energy communities and policy makers on designing effective strategies for engagement in energy communities in order to achieve their full democratic potential.

Re-imagining Demand-Side Flexibility: A policy framework for targeting and coordinating user behaviour

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Keywords: Demand-side flexibility, demand response, price signals, energy policy, behavioural change

Abstract

Demand-side flexibility (DSF) plays is anticipated to play a critical role in decarbonizing the energy sector and advancing the energy transition. The prevailing market-oriented framework however, relies on incentivizing users to modify their consumption patterns based on price signals, placing the responsibility of coordination on individual users. The success of this approach has been limited, with inherent limitations placed on the effectiveness of DSF measures. This paper challenges the assumption that users should bear the coordination role and instead posits that policymakers and system operators should take on this responsibility. Accordingly, the paper presents an alternative, six-step policy framework which entails: 1) partitioning the problem of demand flexibility into a set of sub-problems and outlining their distinct properties, 2) selecting a set of descriptive and statistical demand-side features which capture the properties of the identified subproblems, 3) segmenting users according to their sectors and classifications, and evaluating these segments using the pre-selected features, 4) linking each segment to the most suitable sub-problems, 5) identifying appropriate end-behaviors tailored to each link and 6) selecting the appropriate techniques and strategies for advancing the adoption of the selected end-behaviors. In addition to outlining the motivation and method for each step, the paper discusses the strengths and weaknesses of this alternative approach. It also provides recommendations for future research, outlining areas that require further exploration. Overall, this proposed policy framework seeks to redefine the coordination role in DSF and improve the effectiveness of demand-side flexibility measures in achieving the goals of the energy transition.

Energy efficiency through 30 km/h speed limits: How to reduce road user driving speed.

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Keywords: speed limits, driving behaviour, energy efficiency, behavioural interventions

Abstract

In 2020, the Netherlands was among the 140 countries signing the Stockholm declaration, thereby pledging to establish no higher than 30 km/h speed limits in areas where vulnerable road users mix with vehicles (Stockholm declaration, 2020). This is expected to not only reduce energy consumption per driven kilometre, though also stimulate road users towards more energy efficient modes of transportation. Essential for reaching these goals is the actual reduction of driven speed by road users. The municipality of Rotterdam aims to implement 30 km/h as a standard maximum speed in built-up areas and is anticipating on road users not keeping to this new maximum speed. The current study focused on discovering the main factors (psychological/environmental) explaining the speed at which people drive within the municipality of Rotterdam and on designing interventions to stimulate speed reduction. A literature review was performed, as well as a context analysis, structured interviews with 52 road users and structured interviews with 4 mobility experts. Data were analysed using Atlas.ti. Subsequently, multiple brainstorms were organized with municipality personnel and behavioural scientists to generate interventions. 84% of road users agreed with the speed adjustment and 62% intended to adhere, whereas 84% thought others would not adhere. This indicates towards social norm as an important barrier. Other common barriers were slow feeling, haste, and road design. Main motivators for adhering to the speed limit found were anticipated regret about fines, safety, and road design. Nine lines of intervention were generated.

Temporal stability of public acceptability

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Keywords: Public acceptability, attitudes, attitude change, energy transition

Abstract

Public acceptability of different elements of energy systems has been identified as crucial for successful energy transitions. However, particularly towards novel technologies, people may have not formed stable attitudes yet as people may not have thought about them in much detail. Low attitude stability is a challenge for policymaking because public acceptability might fluctuate, potentially making public attitudes an unreliable basis for policy design. Additionally, unstable attitudes may be weak predictors of policy support behavior, such as voting, signing a petition or joining a protest. In this longitudinal research (https://osf.io/dvgfz/), we compare the stability of attitudes towards established technologies (wind, nuclear energy) with attitudes towards novel energy technologies (geothermal energy, carbon capture and storage), which people may have thought about less. Moreover, we test to what extent different variables are associated with less stable attitudes, namely low knowledge about the technology, low attitude importance, high attitudinal ambivalence, and low attitude extremity. Our two studies ($N_{Study\ 1}$= 218, $N_{Study\ 2}$= 400) suggests that attitudes towards novel technologies are indeed less stable compared to attitudes towards established ones. Additionally, attitude stability was higher the more important the attitude was, the less ambivalent, and the less extreme people's attitudes were, while subjective knowledge was not related to attitude stability. In contrast to our expectation, attitude stability did not consistently influence the relationship between attitudes and policy support behavior. Our findings add to better understanding what determines the stability of attitudes and what influence attitude stability has on policy support.

Revisiting the concept of carbon capability in the context of the climate emergency

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Keywords: Behaviour, low carbon lifestyles, carbon capability, climate citizenship

Abstract

Public concern about climate change is high and individuals are increasingly seeking low carbon behaviours, but their ability to do so depends on more than just their knowledge, attitudes and motivations. A large proportion of emissions are embedded in everyday life, dependent on systems of provision, and not subject to which constrain choice.
The concept of carbon capability has been used sporadically across the social sciences to highlight how individual, social and structural factors combine to create barriers and opportunities for carbon reductions. This presentation reviews the strengths and weaknesses of different applications of carbon capability over the last 12 years, and for the first time, articulates conceptual (dis)connections between carbon capability and Sen and Nussbaum's Capability Approach. We argue that there is a need for greater attention to social practices, material cultures, and systems of provision in studies of carbon capability. Empirically, we present findings from a nationally representative survey (n=1000) of UK residents, using this to identify groups of (more and less) carbon capable citizens. Survey questions on consumption behaviours are used to estimate annual carbon emissions (footprints) for survey respondents, and cluster analysis is conducted to identify factors that predict carbon footprints, and other elements of carbon capability, including climate citizenship and community influence.

Boosting long-term-oriented thinking to promote home energy retrofit: A choice experiment

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Keywords: Energy efficiency, home energy retrofit, transaction costs, time preference, choice experiment.

Abstract

In the built environment sector, enhancing energy efficiency through energy retrofitting is a key strategy to mitigate climate change. Despite the efforts made by local municipalities to offer technical and financial support, the rate of home energy retrofit remains low. The decision to undertake home energy retrofit is complex for homeowners. It involves high upfront financial and nonfinancial costs, as well as various benefits over the long term. Substantial costs and ambiguous benefits may prevent homeowners from investing in retrofit measures. Moreover, existing research and policy interventions have rarely accounted for the nonfinancial costs of energy retrofitting. Therefore, this study aims to understand homeowners' evaluation of nonfinancial transaction costs against financial upfront investment costs. To this end, we design a discrete choice experiment, in which recruited homeowners are presented with a series of decision-making scenarios where they must choose their preferred investment option from two alternatives, alongside the option to maintain the current status quo (no investment). For each retrofit package, we provide information on five attributes: upfront investment cost, time investment, disruption during implementation, energy bill savings, and energy independence. Furthermore, we investigate whether scalable behavioural interventions can be designed to boost homeowners' long-term-oriented thinking, thereby increasing their tolerance to short-term costs. A treatment is designed to emphasise long-term financial and nonfinancial benefits of energy retrofitting. We expect that boosting long-term thinking will reduce the negative effects of upfront investment cost, time investment, and disruption on individual utilities, thus increasing homeowners' preferences for energy retrofit investments.

FODEO - *FLEXIBLE STORAGE AND TRADING OF LOCALLY GENERATED RENEWABLE ENERGY IN OOSTERWOLD*

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Keywords: Energy communities, Peer-to-peer trading, Behaviour research, Flexibility and demand-response, Collective action and investment

Abstract:

Local use, trading and storage of renewable energy can contribute to reduce the use of fossil fuels and to solve the congestion on the public electricity grid. Besides the trading of renewable energy, the flex on the grid becomes a commodity and creates a new value for consumers and energy communities.

The aim of FODEO was to get insight in the way people, organised in an energy community, will adapt the new energy contracts and stakeholder relationships. We analysed how new business models and technology can be created for the trading and storage of locally generated renewable energy. With an organisational model aimed at ownership by the residents and their active involvement in setting up and investing in energy communities. During the FODEO-project we developed a scalable ‘honeycomb’ model in which residents work together to generate, store and trade renewable energy. The solutions are applicable in the post ’saldering’ (net metering) era where storage will play a central role.

Due to several technical and regulatory challenges we encountered during the project the active involvement of residents had to be shifted toward qualitative generative research methods. From that research we learned how to involve residents in the transformation towards becoming active members in an energy community. Main findings are:

- Recognize and do justice to the diversity of residents, understand their motives and barriers.
- Be transparent about certainties and uncertainties and what they mean in practical terms.
- From push to pull, work towards resident ownership and initiative.

Optimising the involvement of tenants in the decision-making process for energy efficiency renovation: revealing behavioural barriers of tenants

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Keywords: Energy efficiency, Renovation, Tenants, Behaviour, Transaction Cost, Engagement

Abstract*:*
Energy efficiency renovation (EER) of the existing residential housing stock is crucial to achieving further decarbonization to be climate neutral by 2050. This transition is particularly challenging for affordable rental housing providers as they have to make intensive investment decisions while balancing rental affordability for their low- and middle income tenants. The affordable housing market is designed to provide affordable and accessible accommodation for individuals or families who may have difficulties finding suitable housing in the private rental market due to low income, disabilities, senior age or other vulnerable characteristics. Although the affordable rental housing providers design, invest, coordinate and perform energy-efficiency measures to improve the energy label of the existing housing stock, in many cases they need the approval of the tenants to finally execute the EER. Depending on the national governance, arrangements and regulations, as well as the event of a well-structured arrangement, tenants may exert a degree of influence on the decision-making process. We propose that it is necessary to understand the attitudes, strategies and perceptions of people occupying affordable housing, to be able to include them efficiently in the whole EER-decision-making process. This study aims to compile all behavioural factors analysed in literature and cluster them to reveal behavioural barriers and involvement preferences. We will offer a holistic profile of influencing factors unravelling tenants behavioural characteristics and lay a solid foundation for the design of potential policy and behavioural interventions to accelerate the EER in the affordable housing sector.

The good, the bad and the ugly; assessing crisis-induced behavioural change through the lens just transitions.

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Keywords: crisis response, low carbon, practicing, systemic change, wellbeing

Abstract

The recent set of global crises (pandemic; energy prices & cost of living crisis; extreme weather events), have triggered a diverse set of strong behavioural responses amongst citizens. From a utilitarian climate policy perspective, we could ask to what extent are these responses (a) low carbon and (b) persistent. A broader framing of 'just transitions' require us to also ask (c) how the costs and benefits of changed behaviour are distributed, and (d) to what extent government interventions have or could alleviate observed inequalities. This paper seeks to structure the analysis of behavioural change evidence in respect to these four questions. Drawing on existing literature we develop a conceptual framework for this analysis. We compile a list of observed examples of crisis-induced behavioural change and feed this into our framework. Whilst acknowledging the conceptual and empirical limitations of our exploratory analysis of this huge and hugely important topic, our preliminary results include potentially important and useful categorical and systemic insights. The former allows us to identify good, bad and bad/unjust low carbon behavioural change categories. The latter includes systemic and place-based synergies and conflicts and raises issues of benchmarking in relation to health and wellbeing in particular. Our discussion focuses on key policy implications, contextualised within UK and EU settings.

Examining Policy Strategies for Electrifying Transportation in ASEAN: A STEELUP Framework Evaluation

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Keywords: Transportation, Electrification, Policy, ASEAN, Electric vehicle

Abstract

Most countries have set net-zero targets, but the level of ambition and commitment varies among them. A major contributor to carbon emissions is transportation, which is an integral part of our daily lives and essential for trade and commerce. Currently, there is a strong global focus on promoting the electrification of transportation as a key strategy for reducing its environmental impact while balancing its critical societal role. With Norway, China, and the United States leading the way in the electric vehicle (EV) industry through effective e-mobility policies, the industry is gaining traction. However, the adoption of electrification in Southeast Asia, a rapidly growing economic region with a growing population, is lagging behind, primarily due to the persistent dependence on petroleum products in the transportation sector. The frontrunners have demonstrated that the EV adoption rate within a country largely depends on government policies. Therefore, this study aims to evaluate the state of policies supporting the electrification of transportation in the ten countries in the Association of Southeast Asian Nations (ASEAN). This study developed a STEELUP framework to provide a comprehensive analysis of seven pertinent aspects: 1) Sociocultural; 2) Technological; 3) Economic; 4) Environmental; 5) Legislative; 6) Urban design; and 7) Political. Consequently, the study identifies policy gaps that each country has, which also identifies how the respective governments could enhance their efforts to increase the electrification of transportation in their countries as part of a more ambitious effort to achieve net-zero goals.

Energy-use behaviour in UK homes during the Covid-19 pandemic and the cost-of-living crisis: A longitudinal survey study

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Keywords: Covid-19, cost of living, energy use, behaviour change, survey

Abstract

The last years have witnessed the Covid-19 pandemic that in the UK saw people restricted in their movements and consequently spending much more time at home, and the cost-of-living crisis in winter 2022/2023 where energy prices skyrocketed.

In this submission, we analyze how self-reported energy use behaviour have been impacted by those crises compared to a prior time point. The Smart Energy Research lab (SERL) has smart meter and contextual data from around 13,000 UK households. During initial sign-up, households filled in a survey, including information about their energy practices (N ~ 11,000). SERL conducted also a survey towards the end of the first Covid lockdown in May/June 2020 (N ~ 1000) and then a third survey in January 2023 during the cost-of-living crisis (N ~ 6000). Data from all three surveys is available for N ~ 500 homes.

Preliminary analysis of the linked data shows that whilst thermostat settings did not increase during the Covid lockdown they significantly decreased during the cost-of-living crisis. The effort to save energy increased significantly in the winter of 2023 but had not changed during the first Covid-19 lockdown. Other results confirm that the cost-of-living crisis seems to have led to a much larger change in energy use behaviours in the home compared to the Covid-19 lockdown despite the latter constituting a major disruption in our lives.

We discuss implications of these observations for behaviour change more generally and in relation to net-zero targets.

Climate-smart solutions for housing companies: workshops to bridge the gap between general advice and targeted coaching with a side order of peer support

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Keywords: Energy efficiency, renovation, housing, workshop, peer support, capacity building

Abstract

As housing energy consumption is approximately 20 % of the overall energy end-use in Finland, it is vital to build up the housing sector decisionmakers capacity and understanding in relation to energy efficiency and climate change.

Climate-smart solutions for housing companies project was conducted by the City of Lahti in 2021-2022, aiming to increase the understanding of housing companies and property managers in Päijät-Häme region of the connection between climate change, greenhouse gases and buildings and housing. In a series of five workshops targeting 32 housing companies and their board members, information and advice was offered and enabling peer support. The aim was to bridge the gap between general advice and one-on-one coaching, to build capacity and to boost implementation of energy efficiency measures and renovation.

The workshops centred around the basics of energy efficiency as well as the planning, target setting, and possible incentives for renovation, on a level that was understandable for various knowledge backgrounds. In groups, the housing companies had a chance to go into more detail, as well as hear about the experiences and results of others.

As a result, the participants expressed having received new ideas and improved capacity for developing their own renovation projects, and they saw the need and use of more tailored, one-on-one coaching. The importance of peer support was notable. In the presentation more detailed results will be given of the workshops, as well as the backgrounds and baselevel of the participants in addition to the end results.

Change from the Middle-Out: Home Owners Associations (HOAs) and the Adoption/Rejection of Environmental Behaviours and Strategies

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Keywords: Energy efficiency, Behaviour, Middle Actors, Intermediaries, Middle-Out Perspective, Group Decision-Making

Abstract

Home Owner's Associations (HOAs) in the US are characterized by their vigilant attention to uniformity and social norms. As a form of social organisation, they are similar to housing associations in Europe and social housing in the UK. Environmental behaviours can conflict with HOA covenants, such as watering lawns sparingly in summer and advocating for solar and/or light-colored roofs.

29% of the US population lives in an HOA, and 82% of all single-family homes sold in 2021 were located in one. This paper reviews current trends and considers the impacts of HOAs—as a form of group decision-making and hyper local governance--on efforts to combat climate change. It uses a 'middle-out perspective' to view HOAs as not just a collection of individual homeowners, but a separate class of home ownership that should be addressed by energy programs and local policies. Many utility energy efficiency programs are directed towards homeowners, multi-family properties, or businesses, rather than towards HOAs. Many local governments do not regulate HOAs because they are considered to be private groups.

Using data from recent research in two US states (Wisconsin and Minnesota), this paper suggests that academic research on behaviour should be expanded to consider the potential positive and negative effects of HOAs on climate change behaviours and practices. In particular, when do HOA covenants trump local laws but not regional or national ones? Findings suggest that working with HOAs to adapt their covenants can create new opportunities to aggregate and implement higher levels of pro-environmental behaviour.

Energy services for all: opportunities and challenges to taking a 'full community' approach to homelessness

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Keywords: Energy poverty, homelessness, co-housing, tiny homes, middle actors, intermediaries, Middle-Out Perspective, faith-based philanthropy

Abstract

Energy poverty policies assist the energy poor at home. However, the chronically homeless have no homes. What are the energy implications of re-homing the homeless?

We consider an evolving faith-based response to homelessness through the lens of the middle-out perspective (MOP). Homelessness is usually approached by local authorities and non-profits with a 'housing first' (HF) model, which provides affordable houses. A broader approach is a 'full community' (FC) model. FC tackles homelessness with a mixture of tiny homes and co-housing, set within an intentional faith-based community to foster social cohesion. From an energy perspective, the FC approach redistributes the 'normal' ownership of energy services. Lighting and thermal comfort are provided individually in tiny homes, but intermittent energy services, like cooking and bathing, are provided in church communal spaces. In FC, churches and faith-based organisations use their agency and capacity to aggregate, enable and mediate the tiny homes and communal spaces as well as fostering community. We analyze the crucial roles that faith-based organisations play as middle actors in two USA-based FC programs for helping the homeless: (1) 'Community First Village' in Austin, Texas (started in 2015) and (2) 'Settled' in Saint Paul, Minnesota. We find the combination of existing land assets, moral mission, and volunteerism distinguishes FC from HF in important ways. Adding housing to church property results in an increased environmental footprint. However, these cases demonstrate the importance of intensifying local energy services while fostering sufficiency and social cohesion as a broader practice for the common good.

The role of financial data in scaling behaviour change

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Keywords: Behaviour, Change, Engagement, Technology, Banking

Abstract

Transaction data comprehensively records our actions, offering profound insights into our lifestyles. It reveals earnings and savings, dining preferences, entertainment choices, shopping habits, and even travel patterns. This data serves as a valuable window into people's everyday behaviours and actions, many of which have a negative impact on the environment.

In the battle against climate change, one of the core principles is to influence public behaviours and habits, encouraging more environmentally friendly decisions that benefit the planet. However, traditionally, changing behaviours requires significant effort and time. What if there were a solution that could assist us in gradually shifting people's behaviours through personalised insights and nudges based on our transaction history?

The ongoing digitisation of payments and financial services has opened up an opportunity for retail and business banks to actively contribute to the daily efforts against climate change. Leveraging transaction data, banks can assist customers in monitoring their carbon footprint and provide them with eco-conscious content to support environmentally friendly decision-making.

In the past, tracking personal emissions was a complex and challenging task, as nearly every aspect of our lives generates some level of carbon. However, by assigning predetermined CO2 values to various transaction categories, customers can effectively monitor their emissions. Subsequently, banks can offer personalised, eco-conscious insights and recommendations, including carbon footprint budgets and carbon conscious rewards.

Moneythor provides a best-in-class system of engagement for financial services. Powered by real-time data analytics and behavioural science, the Moneythor Solution delivers un-matched, data-driven and personalised experiences to customers across all digital banking channels. Examples of these include money management nudges, budgets, savings goals, predictive forecasts, financial literacy material, relevant offers, loyalty programs and more.

Promoting the uptake of heat pumps in "heat pump ready" oil-heated Irish homes: Insights from installer interviews and a homeowner survey

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Keywords: Heat pumps, Technology adoption, Consumer decision making, Heating

Abstract *The decarbonisation of the residential heating sector through heat pump deployment is a key component of Ireland's Climate Action Plan. To meet our targets, a step change will be required in the annual number of heat pump installations in existing dwellings. To address this, we are investigating avenues to accelerate uptake specifically in homes that use a carbon-intensive fuel (oil) for space heating and that are already considered "heat pump ready" in terms of their energy efficiency, meaning they should not require too much additional work in order to be eligible for government grants. We present results from interviews with a small sample of Irish heat pump installers as well as a survey with a sample of 1,402 target homeowners, which included a willingness-to-pay experiment. The results contain insights into the main factors driving and hindering heat pump uptake among this cohort and will be used to inform further policies and interventions.*

Introducing a toolkit to apply behavioural insights to energy policy

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Keywords: energy demand reduction, behavioural insights, policy effectiveness, consumer behaviour change, toolkit

Abstract

Public and private organisations have several instruments at hand to reduce consumer demand for energy. These instruments can take the form of information campaigns, various subsidy programs, or regulations to encourage consumers to adopt greener technology, develop energy-efficient habits or travel more sustainably. However, the well-intended programs often stumble over people's unwillingness to change, lack of interest, or limited attention. As part of this workshop, we will introduce an online toolkit developed by the Users TCP Behavioural Insights Platform that helps policymakers consider psychological factors that might affect the success of their policy. In the workshop, participants will learn how use the tool to make energy programs and policies more behaviourally informed and ultimately more likely to succeed.

Applying behavioural insights to increase energy demand flexibility in high-emitting countries

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Keywords: demand flexibility, barriers and enablers, multi-stakeholder collaboration, randomized controlled trials

Abstract

The session introduces a new multi-national research collaboration of policymakers, utilities, and academics to develop and test behavioural interventions that improve household-level demand flexibility in four high-income and high-emission countries. This new collaboration—organised under the umbrella of IEA Users TCP and supported by J-PAL King's Climate Action Initiative—will deploy five randomised controlled trials across different countries over the next three years. In the session, I will present the results of a large-scale literature review of behavioural barriers and enablers linked to demand flexibility. I will also introduce the design of the experimental trials, which will be conducted in early 2024, and discuss the challenges of multi-stakeholder, multi-national collaboration in promoting household demand flexibility.

Social simulation of consumer co-adoption of low carbon energy technologies

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Keywords: Co-adoption, Social simulation, Consumer preferences, Policy mixes

Abstract

By coupling photovoltaic (PV) systems with heat pumps, electric vehicles, and home batteries, households can not only reduce greenhouse gas emissions, but manage variable renewable energy production, which is key to realize large scale implementation of decentralized renewable energy sources in the electricity grid. Whereas previous research has mainly investigated adoption patterns of single technologies, we use social simulation to study how the adoption patterns of different technologies interact and to test the effectiveness of adoption and co-adoption policies.

We investigate the adoption decisions of 1469 Swiss residents through an online discrete choice experimental study and integrate the results in an agent-based model to simulate how various interventions impact adoption and co-adoption patterns of low carbon energy technologies. We build upon previous work by giving high attention to psychological components of technology adoption. Specifically, the cognitive evaluation underlying agent decision-making is affected by social influence and emotions, following the risk as feelings framework. In our bottom-up model, we link individual decision making to the energy transition to determine the impact of behavioural interventions on individual households and on the energy system. We test financial interventions (subsidies and electricity tax), environmental standards, new adoption solutions for tenants, and social influence strategies. We find non-linear effects in the policies' impact, implying not just individual interventions but also policy mixes should be assessed in policy development. Furthermore, we find that the effectiveness of the interventions differs between households, e.g., between urban, suburban, and rural households and income groups.

Empowering Citizens as Energy Intermediaries for Inclusive Energy Transitions

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Keywords: energy citizenship, intermediaries, energy transition, participation, just transition, diversity

Abstract: *In heterogeneous societies, energy transition policies can either alleviate or exacerbate socio-economic inequality and societal divisions. However, individual households often remain passive consumers in the current energy transition landscape. This paper proposes a novel approach to involve citizens more actively in the energy transition by introducing the concept of energy intermediaries as agents of diversity in sustainability transitions. Drawing on qualitative interviews and a document analysis from the city of Darmstadt in Germany, we argue that energy intermediaries perform two crucial functions: (1) acting as translators between society, policy, and technology, and (2) serving as interpreters within communities, identifying and expressing the diverse resources and needs of society in relation to transition efforts. Through empirical evidence, we establish a theoretical framework illustrating that energy intermediaries, positioned as "middle actors" at the intersection of agency and structure, can drive meaningful change horizontally and vertically by providing information, facilitating access to energy transition policies, and representing societal and intersectional diversity.*

Circular economy approaches in the construction sector: Citizens' perceptions and behaviour

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Keywords: Circular economy, Construction sector, Behaviour, Attitudes, Perceptions

Abstract

The CO_2NSTRUCT Horizon Europe project (2022-2026) aims to develop a framework for adding Circular Economy (CE) measures relevant to the value chain of six construction materials (i.e., cement, steel, brick, glass, wood, and insulation materials) to the JRC-EU-TIMES energy systems model. In this regard, one of the key goals of CO_2NSTRUCT is to establish a technique for evaluating citizen behaviour on CE measures and update the JRC-EU-TIMES model based on the corresponding findings. On this basis, an investigation is performed on how individuals perceive and act concerning CE and climate change challenges and how this affects the development of climate change mitigation models. In identifying gaps and opportunities in citizen behaviour connected to climate change mitigation through CE, the first step has been to perform a literature assessment relevant to the project's themes. Following the results of the literature review have been utilized to construct a theoretical model and a questionnaire focusing on citizens' perceptions and behaviour on circular construction materials, including the following themes: sharing spaces; reusing building components; using recycled construction materials; performing household renovations/ repairs; refusing to use specific construction materials. The questionnaire will be distributed through a survey from September-October 2023 in nine European countries (Denmark, Germany, Greece, Italy, Poland, Portugal, Romania, Spain, and the UK), involving 500 participants each (4500 responses total). Apart from providing input for the model, the survey will improve the understanding of citizens' perceptions and behaviour and assist in developing targeted strategies and policies.

Acknowledgments

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This output reflects only the authors' view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

The MOF4AIR European project – Overview of the societal perspectives of promising CCS infrastructural solutions

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Keywords: Carbon capture and storage, MOF technology, Public engagement, Social acceptance, Societal perspectives

Abstract

Carbon capture and storage (CCS) can contribute to global efforts to mitigate the effects of climate change. However, it remains a controversial technology that often faces public resistance. Social acceptance is a prerequisite for further developing and disseminating this technology. On this basis, the MOF4AIR Horizon 2020 project explores this issue, gathering 14 partners from eight countries to develop and demonstrate the performances of MOF (Metal Organic Framework)-based CO2 capture technologies in power plants and energy-intensive industries. A quantitative social survey focusing on the general public (performed during January-February 2022 by a surveying company in the seven MOF4AIR European countries) was performed to examine societal perspectives. The study examined various CCS-related aspects, such as citizens' knowledge, general perceptions towards CCS, and social acceptance of CCS infrastructure. In addition, the study aimed to identify the factors significantly affecting the aspects mentioned above while considering distinct scenarios in each country (Belgium, France, Greece, Italy, Norway, Turkey, and the UK). The results of the general public's social survey indicated significant differences between the seven countries in most of the themes under investigation, with Norway differing mainly within the group of countries. The overall level of CCS knowledge was somewhat balanced (evenly distributed above-average and below-average knowledge), while general perceptions of CCS (regarding how useful, valuable, and acceptable CCS is) were mainly positive. Respondents' perceived attitudes towards CCS infrastructure at a national level were relatively positive but lower on the local level.

Acknowledgments

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This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Innovating with smart meter data-based tools to empower pupils, teachers and local communities to tackle the climate crisis.

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Keywords: smart meters, schools, behaviour changes

Abstract

A UK Government innovation competition supported the development of smart meter data-based tools in schools to help them achieve net zero by helping them improve energy management. Interventions led by two community energy groups developed school-specific energy analysis tools and energy education programmes aimed at management, teachers and pupils in schools and at local authority level. The tools enabled users to view theirs and other schools' energy data via a dashboard, identify ways of reducing their school's carbon emissions and energy bills, flexibility, and learn more about energy consumption and waste.

The tools had a curriculum and education focus encouraging pupils to monitor energy consumption with their schools, and use the data and educational curriculum to investigate and act upon effective energy demand solutions to reduce emissions and bills, and present positive outcomes to their school, teachers and parents, thus facilitative a wider cultural shift towards Net Zero within their local communities. The research demonstrated how school pupils can inspire their local communities to tackle the climate crisis, improving awareness and understanding of opportunities to improve energy demand using smart meter data. This small-scale project had disproportionately wide impacts, influencing energy demand reductions and wider-scale impacts such as local events, including a ministerial visit in 2022.

The Influence of Public Support Principles on Climate Policy Acceptance: Evidence from a Choice Experiment in the Netherlands

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Keywords: public support, energy policies, choice experiment

Abstract

Achieving national climate goals related to renewable energy generation and CO_2 emission reduction requires the implementation of ambitious climate and energy policies. Incorporating specific "public support principles", including the perceived fairness and estimated effectiveness of policy measures, and their influence on citizens' lives, during the design and implementation of these policies is crucial to enhance their acceptance. In pursuit of this objective, the present study utilizes a choice experiment analysis to examine the impact of applying public support principles in policy-making on the public support for three distinct policy measures. The researchers, together with policy makers, applied the principles to different policies or policy packages: energy performance standards for owner-occupied houses, a minimum price for returning online orders in the retail sector, and measures to change clothing consumption by increasing the affordability of second-hand clothes while making new clothes more expensive. A nationwide survey involving 3,300 participants is currently conducted. The findings will be presented in November 2023 at the BEHAVE conference in Maastricht. The study aims to contribute valuable insights into designing climate and energy policies that align with public values and increase policy acceptance in the pursuit of climate goals.

- PROTECTING OUR PLANET, PROTECTING OUR HEALTH: COMPARING BEHAVIOUR CHANGE IN THE CLIMATE AND THE COVID-19 CONTEXT –

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Keywords: Adoption of Energy Behaviours, Behavioural Models, Behaviour Change, Climate Mitigation, COVID-19 Pandemic

Abstract

Changing human behaviour is critical in achieving climate mitigation, as it has been in curbing the COVID-19 pandemic. In both contexts, many interventions focus on information and persuasion. This implies a model of behaviour change that centres on knowledge, attitudes, and beliefs. We present the results of a preregistered study comparing predictors of climate mitigation behaviours and COVID-19 protective behaviour in a representative German sample (climate group: n = 430, COVID-19 group: n = 437). Therein, we integrate prominent theories of behaviour change from environmental and health psychology. In the climate context, we estimate three distinct partial least squares structural equation models for changing three high-impact behaviours: Driving, heating, and eating animal products. Intentions to change behaviour were mostly predicted by beliefs about behavioural efficacy, with the explained variance indicating weak to moderate predictive power. Similarly, the correlation between intended behaviour change and actual behaviour change measured at a two-week follow-up was weak to moderate. By comparison, COVID-19 behavioural intention was much more varied in its predictors, and more strongly correlated with behaviour change at follow-up. While there are similarities with behavioural efficacy being a strong predictor across contexts, the results also point to the difference between establishing new behaviours in a new context like a global pandemic and changing more habitually ingrained patterns like energy-related household behaviours. Ultimately, this again demonstrates that models that focus on knowledge, beliefs and attitudes are insufficient to explain climate mitigation behaviour change. Consequently, interventions too must go beyond such models.

The role of the participants in the smart grid

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Keywords: Smart grid, energy democracy, energy citizenship

Abstract

During recent years, calls for a democratic and just transition to renewable energy systems have accentuated debates about participatory forms of energy decision-making. The Clean Energy for all Europeans Package emphasizes the need for energy democracy and energy citizenship to boost the transition to renewables. It includes a vision of a new role for citizens, going from a passive energy consumer to an active energy citizen. Energy infrastructure is a key enabler for the energy transition and the development of democratic and inclusive smart energy systems is a challenging issue. The motivations for inclusive and democratic smart grids are several. Seldomly have policymakers and energy companies been pushed to seek more participative grid systems. Still, the electricity grid is a key enabler for the energy transition and the smart grid is expecting active citizens. This raises questions of new forms of policies and even regulations: should citizen participation be ensured by regulating the right to representation in decision-making processes, local ownership or formal consultation at the EU level as well as national levels? We aim to analyze key governmental documents with the EU and within the national contexts of Austria, Finland and Sweden, to identify if and how energy democracy and energy citizenship are included in the development of the smart grid.

From start to finish: using the insights of drivers and barriers of home-owners in all nine steps of the costumer journey towards natural gas free living

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Keywords: Resident participation, engagement, sustainable homes, municipalities

Abstract

Gaining insight in what hinders and motivates residents to move towards a natural gas free home is crucial in accelerating the local energy transition. The Netherlands has set up 67 pilot projects Residents go through various steps towards a gas-free home. We call this the customer journey to gas-free living. At three different times, TNO conducted empirical research in different municipalities. Various municipalities that were part of the TNO study have one of the 67 dedicated pilot projects set up by the Dutch government in which municipalities learn how to help residents make their homes natural-gas-free. The main research question of this research program is what drivers and barriers homeowners experience in their journey towards natural gas free living?

TNO has analyzed the drivers and barriers that homeowners experience in the various steps towards a natural-gas-free home. Homeowners are at different stages in different steps of the customer journey. The distribution of drivers and barriers across the different steps provides insights about the type of information and support that residents need in different stages of the costumer journey.

The research shows that the first experiences with actually living in a gas-free home are very positive, but that the process leading up to it is perceived as challenging. Another conclusion is that seemingly minor issues are major issues for residents and that the degree of attention paid to them can be decisive for cooperation with sustainability programs.

Integrating behavioural factors in modelling of energy savings in households

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Keywords: Heat transition, Households, Energy saving models, Financial policy

Abstract

Higher energy prices can accelerate the energy transition by making energy efficiency and renewables more attractive. Therefore, financial instruments such as energy taxes and carbon pricing can be part of the policy package.

When forecasting the effect of energy prices on household energy use, often a techno-economic approach is used. With this approach the profitability of cost-effective sustainability measures – such as insulation and heat pumps - is modelled under certain price paths, followed by the energy savings of those measures. This approach, however, has two major limitations: 1) it is implicitly assumed that all households actually implement those measures, and 2) behavioural measures such as lower thermostat temperature (not requiring investment) are left out of the picture.

We propose an approach that combines bottom-up cost-effectiveness models, including household characteristics, with behavioural factors to improve forecasts of the effect of energy prices on CO2 emissions. Firstly, we correct cost-effectiveness calculations for sustainability measures with an adaption factor, taking into account that not all households for whom a measure is cost-effective, choose to implement it (for example due to hassle or a lack of information). Secondly, we apply a (short-term) price elasticity for demand to the remaining energy use of households. This factor is based on energy savings in 2021-2022 in The Netherlands, corrected for temperature levels using heating degree days.

Whereas a wider availability of (consumer) data could still improve the model, this approach makes it possible to better include behavioural factors in economic models for energy savings in households.

How to accelerate the local heating transition although the vision is blurry? Insights on participative neighborhood talks in Waldsee-Freiburg

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Keywords: Heating Transition, Citizen Needs, Positive Energy District, Transdisciplinarity, Neighborhood Talks, Stakeholder Engagement

Abstract

The concept of Positive Energy Districts (PED) addresses districts applying tailor-made integrated energy systems and, therefore, having a positive impact on neighboring energy systems (IEA & EBC, 2023). While stakeholder cooperation is not yet a research focus of this young concept, it is a key factor in implementing PEDs (Brozovsky et al., 2021).

This study applies an iterative and transdisciplinary approach examining citizens' needs by designing a participatory series of neighborhood talks and executing three talks in the district Waldsee-Freiburg. The concept design was informed by literature research and a quantitative survey (Gölz et al., 2023). The talks focused on enabling interchange between energy experts and citizens, providing information and space for interaction. Data from protocols and surveys was collected and analyzed. The talk series was adapted according to needs identified during the sessions. This iterative participatory approach was fruitful in enabling an accessible dialogue between the participants and creating knowledge co-production (Chambers et al., 2021; Lang et al., 2012).

Preliminary analysis shows that citizens encounter several barriers to implementing renewable heating and cooling technologies, such as the need for more trust, knowledge, contact points, and meaningful consultation. Transparency and communicative practices can alleviate some challenges. Further research could focus on better understanding and classifying these needs through quantitative surveys and testing tools to overcome barriers in further neighborhood talks.

The study contributes to scaling up behavior change for the energy transition by better understanding citizens' needs and adding to the design of stakeholder engagement.

BEHAVIOURAL MODEL FOR ENHANCING STAKEHOLDER ENGAGEMENT IN LOCAL RENEWABLE ENERGY SYSTEMS AND ENERGY COMMUNITIES

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Keywords: Citizen Engagement, Community Acceptance, Local Energy Systems, Energy Communities

Abstract

Decentralised renewable energy production and collective self-consumption contribute to meeting climate targets and allow citizens to participate actively in the energy transition. Beyond functional technology and a sustainable business model, long-lasting local renewable energy systems (LES), collective energy solutions and energy communities require engagement and participation of local stakeholders.

Key to successful stakeholders' participation is a shift from technology-push towards a needs-based approach that identifies stakeholders' needs and ensures that energy solutions create value for them. With this work, we propose a behavioural model for local stakeholders' participation in a collective energy solution, underpinned by academic literature on the social acceptance of clean energy and field experience in community engagement in energy solutions. Then, we propose an analysis tool that supports the design of energy solutions in line with local priorities and values. The tool helps identify relevant stakeholders and assess their views, values and practices, utilising a pre-defined questionnaire and interview guide. The tool is modular and can be customised for residential energy users as well as for public, commercial and industrial stakeholders. It is designed for urban planners, energy managers, and those interested in establishing LES and local energy communities. The model and tool were developed within EU Horizon 2020 project E-LAND and tested in a rural community in India, an industrial port in Norway, and a technology park in Spain, demonstrating the potential for scalability and replicability towards the future.

Unlocking India's Transition from LPG-Based Cooking to Ecooking through Behaviours Change, Innovation, and Opportunities

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Abstract

Policy serves as a key enabler but should be considered a starting point in India's transition to ecooking. While the recently introduced energy efficiency policy for e-cooking appliances, particularly induction cooktops, aims to reduce dependence on Liquefied Petroleum Gas (LPG) usage and imports, there is still a significant reliance on LPG among 85% of Indian households.

In addition to policy measures, promoting behaviour change is crucial to facilitate the transition to ecooking. Understanding existing cooking practices, cultural norms, and barriers to change is essential for designing effective interventions. Awareness campaigns, household education, and highlighting the environmental and health benefits of ecooking can motivate individuals to adopt sustainable cooking practices.

Furthermore, the adoption of ecooking solutions can be facilitated by innovations in financing models, distribution networks, and after-sales services. Collaboration among government agencies, non-governmental organizations, manufacturers, and research institutions is essential to foster innovation, knowledge sharing, and resource mobilization. Policy interventions, including subsidies, tax incentives, and regulatory frameworks, create an enabling environment for ecooking adoption.

To unlock India's transition to ecooking, a multi-faceted approach is necessary, which includes addressing behaviour change, financing issues, and policy implementation. This abstract provides insights into the strategies and actions required to drive this transformative shift, contributing to India's sustainable development goals and global efforts to combat climate change.

Circular Public Procurement: Driving Sustainable Change in Municipalities and Beyond

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Keywords: Circular Economy, Public Procurement, Behavioural Change, Resource Efficiency

Abstract

The Circular Economy has gained attention in policy agendas as a means to address unsustainable production and consumption patterns by promoting closed material loops and value retention. With contracts accounting for 15% of the EU's GDP, public procurement not only has a significant impact on purchased goods, but can also be an important tool to optimise resource utilisation, reduce energy demands and meet climate goals by incorporating Circular Economy principles.

Public authorities play a significant role within the transformation towards a Circular Economy as their purchasing power can increase demand, innovation and competition for the market of sustainable and circular products. Further, it has an impact on the consumers or citizens purchasing behaviour within the private sector. This shows how Circular Public Procurement is closely connected to behavioural changes in a larger system and raises the following questions: How can public procurement impact behavioural changes for the transformation towards circularity? What are the challenges public authorities are facing when implementing circular elements within their procurement processes?

This session aims to explore motivations and operational, technical, and regulatory challenges faced by municipalities during the implementation of circular public procurement. It seeks to initiate a dialogue on the potential influence of circular public procurement on the private sector. The session will feature presentations of best practices from the Netherlands, Germany and Sweden, followed by an interactive panel discussion that actively engages speakers and the audience, encouraging their participation and the integration of diverse perspectives.

Exploring factors affecting electricity use during peak and off-peak times of day – results from Ireland's Behavioural Energy and Travel Tracker

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Keywords: Off-peak consumption, Adoption of energy behaviours, Demand flexibility, Smart meters

Abstract *Decreasing the proportion of electricity use that occurs during peak use times of day has benefits for consumers, suppliers and society. One of the primary benefits for consumers (reduced cost) of off-peak usage is dependent on being on a time-of-use tariff. Reducing peak use should also reduce reliance on fossil fuels for electricity generation, thereby decreasing associated emissions. Research has shown however that demand responsiveness rates are generally low, as is voluntary uptake of time-of-use tariffs. Identifying drivers and barriers to off-peak use is thus important. In an ongoing monthly survey – the Behavioural Energy and Travel Tracker (BETT) – that measures energy use in a representative sample of Irish homes, we record the time of use of a range of large electrical appliances, as well as space and water heating. Using an adapted form of the day reconstruction method, BETT branches participants to highly detailed questions that probe duration, time and settings used, based on their prior responses to general use questions. It then records a series of psychological, sociodemographic and household characteristics relevant to energy consumption. The present work uses BETT data to investigate the extent to which being on a time-of-use tariff is related to off-peak electricity usage behaviour over several months. We also investigate relationships between off-peak use and motivational, psychological, sociodemographic and household variables. We discuss results commenting on potential avenues for – and sizes of – change.*

Women's collectivization in the Swedish energy sector and the role of care

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Keywords: Energy, Gender, Collectivization, Care

Abstract

We will explore women's collectivization in the Swedish energy sector, and its contribution towards greater inclusion and diversity therein. While Sweden is a country that holds the first place in the EU on the Gender Equality Index, women are a minority in the energy sector, with 76% of employees being men. In the past few years, there have been interventions to remedy this inequality, both through industry incentives, as well as by the women in the sector. We pay particular attention to an association started by women from the sector, aiming to provide others with mentorship, and shed light on the challenges in the sector. Previous research has addressed the beneficial effect of professional networking in terms of increasing women's career possibilities. Conducting an analysis through the network prism can, nevertheless, relegate the responsibility back to the individual, and we learn little about how individual social capital is converted into better opportunities for other women and groups. We thus propose to explore the types of relationships and exchanges that emerge through active collectivization. By examining the role that care can play in the process, we aim to shed clarity on how the bridge between and individuals' pursuit of career advancement to structural change and collective benefit can be strengthened.

Consumer and prosumer preferences for prosumer-integrated electricity supply models in the United Kingdom and South Korea

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Keywords: prosumers, preferences, retail electricity market, choice experiment, international comparison

Abstract

With the emergence of prosumers who both consume and produce energy, a range of new electricity supply models, including peer-to-peer electricity trading and aggregators, are emerging to engage prosumers in the electricity market. To enable the benefits of these models and facilitate low-carbon electricity market transitions, it is critical to consider how value is constructed for end-users through economic, social, and environmental dimensions of technological changes. This study aims to build a quantitative understanding of prosumer and consumer preferences for niche electricity supply models under different market structures. The United Kingdom, a liberalised retail electricity market, and the Republic of Korea, a centralised one, are selected for comparative analysis.

This study will collect primary data using discrete choice experiments. The data collected will be analysed using mixed logit. The analysis will show whether current consumer and prosumer preferences correspond to the existing market structure in each country. It will also be examined how prosumer preferences differ from consumer preferences and whether prosumer preferences change when buying and selling electricity. Understanding how end-user preferences are structured will help explore what types of niche models are likely to drive transitions and how to design energy systems that can involve end-users in energy transition processes under different regimes. The findings will serve as an empirical basis for the ongoing development of an agent-based model, aimed at exploring potential transition pathways to prosumer-integrated electricity markets.

UNLOCKING THE FLEXIBILITY POTENTIAL IN AGRICULTURE
An exploratory study of organisational and behavioural drivers and barriers

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Keywords: Energy flexibility, Demand-response, Agriculture, Energy transition

Abstract

The energy transition involves the widespread deployment of low-carbon technologies, particularly decentralized renewable energy sources, which requires enhanced grid flexibility to accommodate variable production considering demand patterns, while ensuring cost-efficiency. Traditionally, flexibility in the energy system has primarily relied on supply-side resources. However, given the variability and uncertainty associated with renewable energy sources, it is crucial to explore new sources of flexibility from the demand-side by making the most of the adaptive nature of some types of consumption. The agricultural sector has been overlooked in this regard, despite possessing valuable flexibility resources such as water pumps, heat pumps, water tank towers, on-site generation from renewable sources, and electrical storage (including static batteries and electric vehicles). Previous attempts to implement demand-side management programs in agriculture have been unsuccessful because they did not consider adequately the unique constraints of farming activities while aligning with the requirements of the grid. Moreover, various barriers hinder the unlocking of flexibility in this sector, including regulatory obstacles, inappropriate market mechanisms, insufficient incentives, unsuitable technologies, and the limited literacy and motivation of farmers. To address these challenges, this study presents the findings of an exploratory study conducted through semi-structured interviews with Portuguese farmers. The study assesses contextual, organizational, and behavioural drivers and barriers influencing farmers' participation in demand-response and flexibility programs. Additionally, a review of the policy and regulatory landscape is presented to provide a comprehensive understanding of the current context and offer policy recommendations.

How does income impact consumer willingness to apply energy efficiency measures? – Empirical insights from German households

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Keywords: Energy efficiency measures, low-income groups, adapted behaviour**,** willingness to invest (2a, 2b, 4b)

Abstract

Tackling climate change is built on two main pillars: shifting energy production from fossil fuels to renewable energy sources and lowering primary energy demand. While the former has experienced a steep increase in capacity in the past years, the latter remains largely unexploited in terms of emissions reduction potential. Energy efficiency measures typically require financial means to purchase technology that uses less energy or knowledge about energy-efficient behavioural adaption. Against this background, sufficient household income and energy literacy are essential enabling factors. Both are unevenly distributed within society, which sets vulnerable households at a considerable disadvantage.

This paper seeks to examine this circumstance empirically. Based on a sample of 1,506 German households, the authors use propensity score matching to analyze differences in the willingness to invest in energy-efficient technologies and to save energy through adapted behaviour between income groups. Our results show that low-income households are significantly more willing to invest in energy-efficient technologies than higher-income groups. Concerning, energy efficiency through adapted behaviour, the differences between income groups are less pronounced but, in some instances, statistically significant. Furthermore, we find significant interactions regarding the energy efficiency of household income with (co-)ownership in Renewable Energy, gender, age, and education. We conclude that low-income groups hold great potential to increase energy efficiency. Hence, policymakers should provide innovative financing and incentive design as well as broadly accessible energy education to disseminate energy-efficient behaviour throughout all societal layers.

OPTIMAL TIME RECOMMENDATION MODEL FOR HOME APPLIANCE: HSB LIVING LAB+ DISHWASHER STUDY

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Keywords: optimal time recommendation model, demand-response management, behaviour change, living lab

Abstract

This study investigates the effectiveness of an optimal time recommendation model in encouraging individuals to shift the usage of their home appliances to off-peak hours, focusing on dishwashers.
The research question can be framed as follows: "To what extent does the implementation of an optimal time recommendation model facilitate behaviour change towards more energy-efficient use of dishwashers among residents of the HSB Living Lab+ community? The research, conducted at the HSB Living Lab+ in Gothenburg, involved 75 participants from diverse social groups. A mixed-methods approach was employed, combining surveys, interviews, and data from a self-reporting interface. Participants received personalized recommendations generated by the model, considering factors like energy demand, grid load, electricity pricing, and CO2 levels. These recommendations aimed to assist users in identifying optimal times for operating their home appliances during off-peak hours. One of the model's standout features is its seamless integration into participants' daily routines. It employs a user-friendly, QR-code-based web interface, providing participants with real-time access to recommendations. This ensures that users can effortlessly incorporate the suggested appliance operation times into their schedules, maximizing the model's impact on behavior change. The study unveiled positive responses across all social groups, with participants reporting heightened awareness of energy consumption patterns and an increased willingness to adopt delay-shifting practices. This research contributes valuable insights into the realm of flexibility and demand-response energy conservation behaviors among citizens. Its implications extend to home appliance manufacturers, who can refine the usability of delay start functions; policymakers, who can emphasize eco-design; and researchers, who can develop strategies for widespread energy conservation.

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Title: Environmental and macroeconomic effects of sufficiency: Example of the French carbon neutrality scenarios

Keywords: Carbon neutrality, Sufficiency, Material footprint, Decoupling

Abstract

To reach the 1.5°C target set by the Paris Agreement, the French Agency for Ecological Transition (ADEME) has devised four pathways to achieve carbon neutrality in France in 2050. These foresight scenarios, published in 2022, use different mixes of sufficiency and technological change to reduce territorial greenhouse gas (GHG) emissions.

Here, we go beyond the analysis in terms of territorial emissions and discuss the effectiveness of each scenario to also reduce the French carbon and material footprints. Based on the Hybrid Input-Output model "MatMat", we assess and map the carbon and material footprint of each scenario and analyse the possibility of decoupling Gross Domestic Product (GDP) from it thanks to a linkage with the macroeconomic model "ThreeME". For each scenario, we estimate the effects on growth, employment, income, and the trade balance.

We find that all scenarios enable to decrease the carbon and materials footprints by 2050, compared to the trend scenario. The scenarios based on sufficiency and lower trade openness are more effective at reducing both carbon and material footprints. Only these scenarios allow an absolute decoupling between GDP growth and material footprint. The macroeconomic effects are quite small: slightly negative for the most sufficiency-oriented scenario, and slightly positive for the others. Finally, despite the achievement of territorial carbon neutrality, all scenarios fall short of the targets in terms of footprints. This points to the need for ecological transition outside of France and for international cooperation to facilitate it.

Scaling-up behaviour change: challenges to deploy energy citizenship in Europe

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Keywords: Energy citizenship, systemic behavioural intervention, energy efficiency, behaviour change, policy mixes, upscaling innovation

Abstract: *Energy citizenship refers to the active participation of individuals and collective entities in the energy system within a specific geographical area. This concept inspires policymakers to encourage a more active role of citizens in Europe's energy transition. Key questions for policy design include understanding how energy citizenship emerges and at what level of aggregation (e.g., what drives it at locally, nationally, or supranationally) and the influences between energy citizens in an ecosystem of change. Using a systemic behavioural approach, we conducted six case studies to identify energy citizenship features. We conducted a survey in 17 European countries, obtaining 10444 usable responses (9444 citizens, 500 policymakers, and 500 businesses). We collected socio-economic data, attitudes, norms, agency, emotion, and relational models from citizens, businesses and policymakers. Our results show: 1) the questionnaire demonstrated high reliability, and the model used had strong structural and content validity; 2) energy citizenship is currently low but is likely to emerge locally and be reinforced supranationally; 3) a positive relationship between attitudes, norms, agency and emotion towards engagement was confirmed; and 4) there is a systemic negative influence of the current dominant relational model of citizens with businesses and policymakers. This indicates a systemic failure that affects behavioural intervention programs promoting citizen engagement. Strategies for scaling up behavioural change must consider contextual influences as well as the direct or indirect influences on those who intend to promote and support change. Despite the systemic policy challenges, upscaling behavioural change requires considering more than just the target population.*

It matters to be heard: Increasing the citizen acceptance of low-carbon technologies in the Netherlands and United Kingdom

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The deployment of low-carbon technologies such as carbon capture utilization and storage (CCUS) and onshore wind is essential to mitigate climate change, but may be met with resistance from local residents. In two experimental surveys (Study 1: Dutch citizens, N = 395; Study 2: United Kingdom citizens, N = 240) we investigated the importance of the quality of the voice opportunity offered to local residents in the decision-making process for acceptance of CCUS (Study 1) and onshore wind (Study 2) projects. Participants read a scenario in which they were asked to put themselves in the position of a resident in a town near which a project developer planned to implement a CCUS or onshore wind project. Depending on the experimental condition, participants read that they, as local residents, could voice their opinion and that their input was considered (genuine voice) or was not considered (pseudo voice) by the developer, or that they could not voice their opinion (no voice). As predicted, giving local residents a genuine voice opportunity resulted in higher project acceptance compared to giving a pseudo voice or no voice opportunity, due to an increase in perceived procedural fairness and trust in the project developer. Results further showed that giving a pseudo voice opportunity can be equally detrimental as giving no voice opportunity at all. The findings underline the importance of genuine voice opportunities and show that policymakers and project developers should avoid voice opportunities where residents' input is seemingly ignored.

Key words: Voice in decision-making; Public acceptance; Procedural fairness; Trust; Carbon capture utilization and storage (CCUS); Onshore wind energy

The research we describe in the abstract has recently been published in Energy Research and Social Science: https://www.sciencedirect.com/science/article/pii/S2214629623001639. Because of this, we will not submit a paper to be incorporated in the Conference Proceedings or for publication in the Energy Efficiency Journal.

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Assessing the Impacts of Advanced Heating Controls in UK Households: A Comparative Study and Systematic Review

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Keywords: Energy efficiency, Behaviour change, Heating control technology, Domestic heating patterns

Abstract

With climate change presenting unprecedented challenges globally, the need for effective, and sustainable, energy transition measures have become increasingly paramount. The domestic sector, whilst responsible for a substantial share of energy consumption, offers multifaceted potential for reducing carbon emissions through technological and behavioural interventions. Advanced heating control technology offers a promising solution to optimize energy usage within domestic, and non-domestic, settings. This study aimed to investigate the impact of advanced heating controls in UK households, aligning the findings with a systematic review of the effectiveness of advanced heating controls over the past decade.

The research involved monitoring thermostat usage in 12 UK households based in the East Midlands, aimed at investigating the effectiveness of heating controls in promoting energy efficiency and sustainable heating practices. These households were equipped with advanced heating control systems, allowing for detailed analysis of thermostat usage patterns, energy consumption, and associated behavioural changes, triangulated with qualitative data from the households. The collected data was compared against the findings from a systematic review encompassing various studies conducted in similar contexts. This research provides valuable insights into the potential of technological and behavioural interventions in achieving sustainable heating practices in domestic environments.

Given the urgent need to address climate change and accelerate the energy transition, the findings from this study provide valuable insights for policymakers, stakeholders, and homeowners. These findings highlight the importance of integrating both technological advancements and behavioural change to mitigate adverse effects of climate change and foster a sustainable future.

Empowering Energy Transitions: Exploring Collective Energy-Efficient Investments in Energy Communities

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Keywords: Energy efficiency; Collective investments; Energy community; Decision-making

Abstract

This paper explores the significance of collective energy-efficient investments in energy communities, enabling residents to pursue economic, environmental, and social objectives during the energy transition. Recognizing the pivotal role of energy efficiency, the study categorizes these investments into two distinct groups: building innovations/retrofits, and the adoption of renewable energy technologies.

Through an extensive literature review, the paper identifies six specific types of energy communities that focus on collective energy-efficient investments. This classification provides clarity and specificity for subsequent modeling processes. The first distinction made is between online and offline energy communities. The online energy community represents the first type, where residents can participate in the energy transition through online investments without physical interconnection. For offline energy communities, also known as place-based communities, the paper further divides them into five types based on the two aforementioned investment avenues. The first category focuses on Community Retrofits, while the second category describes four types based on the technologies employed, namely Community-Shared PV Panels, Community Storage, Hybrid Multi-energy Systems, and District Heating & Cooling.

Additionally, this study highlights the importance of constructing models that effectively capture residents' decision-making processes concerning investments within different types of energy communities. Through comprehensive analysis, this paper sheds light on the potential of collective energy-efficient investment as a transformative catalyst, empowering communities to achieve sustainable energy goals while fostering equitable benefits for all stakeholders involved.

Scaling-up behaviour change in the light of the energy and climate crises

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Keywords: Behaviour, Norm Activation Model, Pride

Abstract

The Norm Activation Model (NAM) is a theoretical framework which uses psychological factors such as personal norms and responsibility to explain altruistic and pro-environmental behaviour. This research paper explores the relationship between these processes as well as feelings of pride to explain individuals' attitudes and behaviours towards a green energy transition. Behavioural research, such as this, enhances our understanding of consumer behaviour while also forming a basis for effective policies required to implement sustainable energy practices. To validate the theoretical NAM model, confirmatory factor analysis was performed on data collected from a survey conducted across Europe. The results indicate that the NAM psychological processes have a significant impact on the pro-environmental behaviour of individuals. Additionally, it was found that pride partially mediates the effect of personal norms on the support for a green energy transition. Finally, the paper concludes with important implications for individuals, firms and policymakers engaged in the sustainable initiative of energy transition.

Including justice in renovation policies considering the socio-spatial vulnerability to energy poverty; a Case Study-Mixed Methods (CS-MM) approach

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Keywords: Energy Justice, Renovation, Socio-Spatial Vulnerability, Energy Poverty, Case-Study Mixed Methods, Underprivileged Neighbourhoods

Abstract

Driven by climate change and energy crises, an increasing number of households in the European Union are becoming vulnerable to energy poverty. However, current renovation programs fall short in effectively targeting and addressing the needs of vulnerable groups, particularly in underprivileged neighborhoods where low effectiveness rates and resident resistance to renovation measures persist. This exacerbates the risk of social and spatial inequity, calling for an urgent integration of justice considerations in European renovation policies.

To address this challenge, this study proposes a novel case-study mixed methods (CS-MM) approach to include justice in renovation policies, considering the socio-spatial vulnerability to energy poverty. The case of Amsterdam Zuidoost is examined to achieve four main objectives: [1] identify systematic challenges in tackling energy poverty in underprivileged neighborhoods, [2] develop a vulnerability framework encompassing social, economic, energy, and building-related factors, [3] identify and localize energy vulnerable groups, and [4] tailor policy strategies in a multi-stakeholder environment based on the characteristics and needs of the identified vulnerable groups. The findings illustrate how the CS-MM approach can be applied to incorporate justice into renovation policies, informed by local insights on energy poverty.

From a scientific perspective, this study contributes to the existing knowledge by providing insights into the identification of vulnerable groups, the inclusion of justice in renovation policies, and the deployment of a CS-MM approach to address socio-spatial vulnerability to energy poverty. From a societal standpoint, the findings empower local decision-makers to identify vulnerable groups and tailor policies accordingly.

Fostering green buildings and a sustainable construction industry in Rwanda – analysis of employment effects

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Keywords: green buildings, energy efficiency, circular economy, green jobs

Abstract

Green buildings are key to climate change mitigation and resource efficiency. Housing and construction needs in an urbanizing Rwanda are soaring with roughly half a million units required in 2022 in Kigali alone, particularly for low-income households. The greening of the construction value chain (starting with building design and ending with owner/tenant behaviour) therefore presents an essential part of Rwanda's green economy vision. As the construction industry is the second largest job creation sector in Rwanda, the policy goals of greening, providing affordable housing and creating jobs need to be reconciled. While Rwanda has taken many valuable steps towards a green economy including green, circular buildings, some knowledge gaps and implementation challenges of the current policy mix remain. It is particularly unclear which business models work, which employment effects have been occurring already due to the greening of the construction sector and which potential for future green jobs exists. In the scientific literature, hardly any sectoral, firm-level data on green jobs and the interplay with the specific policy context exist. This research therefore looks at the following questions:

- *How can the implementation of the current policy mix for green, circular buildings and a sustainable construction industry be further improved? Which additional regulatory, financial or behavioural insights measures could be helpful?*
- *What is the effect of switching to green buildings on employment in Rwanda?*

The research questions will be answered using a mixed methods approach based on qualitative interviews and a firm-level survey to be conducted in October/November 2023.

Co-construction method for policy recommendations to support energy communities.

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Keywords: Energy communities, participatory processes, co-creation tools, policy recommendations, Knowledge co-creation tools

Abstract

In recent decades, the energy sector has seen a wave of participatory processes and tools aimed at actively involving citizens, also but not only as consumers, in order to make them more aware and active in the processes of decarbonisation and promotion of renewable energies and less polluting, and therefore less risky, behaviour. Participatory processes integrate expert knowledge in the perspective of relational and situated knowledge production, which in turn can generate practical and real results. In the field of energy systems, this general consideration is even more complex, since the technological and technical component is characterised by a very high degree of specialisation and the very action of the technologies has an impact on the knowledge and practice of the world of all those involved.

Based on these considerations, it was decided to create a virtual participation space where, through the use of a foresight tool, it was possible to build new knowledge on the subject of organising and creating energy communities in Italy. The working group decided to focus on a participatory and analytical tool that would allow participants to focus on the future of Energy Communities. With this aim in mind, it was decided to involve 18 representatives of organisations that had started to experience the organisation of renewable energy communities at national and local level and were interested in understanding how an energy community could be realised in concrete terms, with a view to proposing recommendations to political bodies at national and international level.

Methods Applied to Optimise and Personalise Interventions to Increase Energy Efficiency in the Residential Sector: Review of the Literature

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Keywords: Energy efficiency, Behavioural Interventions, Machine learning, Clustering, Sustainability

Abstract

Climate change and the urgency to promote sustainable energy usage have underscored the critical need to enhance energy efficiency in residential areas. This paper presents a comprehensive review of the literature focusing on statistical clustering models and machine learning algorithms for optimizing behavioural interventions in energy efficiency. Since household energy behaviours display significant diversity, making generic intervention strategies susceptible to information overload and rebound effects. To address this, the study explores advanced methods to classify energy behaviours into distinct groups based on shared attributes, enabling the design of personalized and targeted interventions.

The main objective is to develop impactful data-driven interventions by segmenting households into clusters with similar energy consumption patterns, allowing personalized and effective strategies to meet specific needs and preferences. A key highlight is the potential of machine learning algorithms to automate and optimize policy interventions, revolutionizing their effectiveness. Utilizing sophisticated data analysis and pattern recognition, machine learning can identify intricate relationships between variables, leading to highly efficient personalized strategies for increased energy efficiency. The insights from this study hold immense value for researchers and policymakers as the societies strive for a greener and more sustainable future. By leveraging clustering econometric methodologies and machine learning algorithms, society can expedite the adoption of energy-efficient behaviours, paving the way for a successful green energy transition.

THE ROLE OF CONSUMERS IN AUTOMATED DEMAND RESPONSE: DRIVERS, BARRIERS AND ACCEPTANCE TO PARTICIPATION

Lessons from a Swedish Case Study

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Keywords: Demand response, Demand side flexibility, Automation, Load control, Consumer acceptance

Abstract

Peak demand is a challenge of major priority for energy utilities, regulators and policy-makers around the world. Automated demand response (ADR) has the potential to address this challenge by allowing for utilities to manage specific household appliances during peak periods. Previous research has, however, mainly been focusing on the technical and economic aspects of ADR, while limited attention has been paid to the user perspective. This study aims to address this gap by exploring the drivers, barriers and acceptance among residential energy users to participate in ADR programs. The study draws on 15 in-depth interviews with households enrolled in a Swedish pilot study involving direct load control of heat pumps, where the local utility company is able to reduce the energy demand by lowering customers' indoor temperature. The results suggest cost savings as the main driver to participate in ADR programs. Many respondents reported, however, that the initial reason for enrolment was due to interest in technology and energy-related topics, but that the economic motive has gradually taken over as the main driver due to rising electricity prices. Furthermore, the study highlights the importance of consumer trust and confidence in the local utility company, identified as a key factor for acceptance of direct load control. Distrust to the utility, along with limited knowledge of potential benefits of participation, were hence identified as the main barrier for consumers to enrol and remain engaged in ADR programs. Drawing from these findings, the paper discusses policy implications and key issues for further research.

Energy crisis and behaviour change: Do price caps change energy behaviours?

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Keywords: Behaviour, Curtailment, Values, Norms, Energy Crisis

Abstract

Behaviour change in the face of current and future energy crises is complex. When talking about the technical side of grid functioning and energy transition, the end-user is rarely taken into account. However, a number of psychological factors are important for successful behaviour change within energy domain. Concepts such as values, norms, sociodemographic characteristics, comfort levels and financial situation can directly affect the functioning of the grid systems through behaviours of the end-users. Current energy crises have affected multiple households, putting strain on the ability to pay the bills for the rapidly rising energy costs, which affected people's energy behaviours at home. Households attempt saving energy to be able to pay their bills by, for example, reducing thermostat settings. Recently governments have introduced policies and measures for households to be able to battle energy costs, such as price caps or single payments. The government measures can create an effect on the household energy behaviours, as people would return to their regular energy use, which is higher. On the other hand, environmental psychology research shows that when people care about the environment more, they are likely to continue keeping their energy use low. With our research we are investigating whether behaviours change before and after the policy change in The Netherlands. The results are relevant for researchers, energy companies, and various professionals to be able to predict the individual behaviours of end users in various stages of energy crisis.

Examining the determinants influencing the implementation of circular economy practices for climate change mitigation in the construction sector

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Keywords: circular economy; construction sector; climate change mitigation; stakeholders; drivers; barriers

Abstract

Circular economy (CE) is considered a significant approach to achieve climate change mitigation and is in line with the EU's ambitious goal of becoming carbon-neutral by 2050. CE refers to the non-linear economic model, which enforces practices such as rethinking, reducing, reusing, repairing, refurbishing, and recycling existing materials and products. Implementing CE practices in the construction sector is crucial, as this sector is a significant CO_2 contributor and one of the world's most considerable energy and raw materials consumers. Identifying the factors influencing the implementation of CE practices is essential to achieving climate change mitigation, with an increasing scientific research interest in recent years. However, there is a need for further analysis and the connection of potential strategies - to overcome barriers and enhance drivers - with empirical data driven by qualitative and quantitative research methods. This research examines the determinants of implementing CE practices through a literature review. Existing classifications of the factors are identified, including - among others - knowledge, financial, regulatory, technical, and technological-related categories, and potential strategies to be addressed in each category are suggested. The result of the research will be used to structure an interview protocol involving at least 25 key stakeholders from the research, academic, industrial, and policy communities. A questionnaire will also be designed in line with the outcomes of this study and will be distributed to key stakeholders during EU and national workshops to be held on CE and climate change mitigation-related topics.

A meta review of consumer behaviour and sustainable behaviour change

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Keywords: Consumer behaviour, drivers, interventions, meat reduction, protein transition

Abstract

A few decades of research have reached to broad agreement within the scientific community that consumer behaviour changes are needed to support sustainable transitions. Transitioning away from meat-heavy diets towards more plant-based diets is beneficial to environmental and public health as well as animal welfare. The current meta review supports this ambition by providing an overview of potential drivers and observes these findings from a policy perspective, resulting in two main outcomes. First, the meta review mapped potential drivers in terms of capability, opportunity, and motivation. The latter appeared to be given more attention than the other two drivers. Motivational and opportunity drivers emerged as the most prominent. Especially awareness, motives, and beliefs, as well as redesign of menus and recipes by defaults, portion sizes and visibility of plant-based options proved relevant. Emotions, social and cultural environment, and development of skills appeared promising but remained under-researched. Second, the present meta review reviewed the findings from a policy perspective. The number of studies that translated findings to policymaking turned out to be limited. Besides, all studies only refer to non-coercive interventions. The meta review finalizes with the most prominent routes for future research and policies. For example, highlighting the need for an integrated framework, comparison research and a focus on real-life and long-term behaviour change, to support coherent research and scholarly conclusions on the one hand and evidence-based, action-oriented policymaking targeted at the acceleration of the protein transition on the other.

The effects of energy poverty in the Netherlands; a Dutch Qualitative monitor

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Keywords: Energy poverty, behaviour, policy effects

Abstract

The effects of energy poverty in the Netherlands are not limited to the living comfort of households, but can have on many elements of daily life. Households are vulnerable to physical and mental health issues, not eating hot meals and shy away from inviting people to their homes. The current research acknowledges these challenges and carries out a Dutch qualitative monitor; it aims to structurally map the challenges that energy poor households face and to investigate how their situation originated, how it changed, and how they can be supported. Therefore, a total of 29 in-depth interviews with a diverse target group living in energy poverty were held, divided over two years. The interviews focus on the following aspects; general living conditions, living comfort, energy use and strategies, challenges and the broader impact, coping mechanisms and need for help and support. The in-depth interviews exposes the stories of the households, including their living conditions, their need for support from the governmental institutions and their development over the years. In doing so, this two year study shows the effect of the rising energy prices of last year by creating detailed knowledge on the energy poor household's situations. It identifies important barriers for them in the energy transition and how to increase their resilience. Furthermore, it shows the effect of the current energy and social policy and policy solutions and unintentional side effects, and the way it can provide new insights for local and national policy makers.

Exploring the adoption of electric vehicles for the benefit of vulnerable populations: an analysis of attitudinal variables and car usage behaviors in Flanders, Belgium.

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Keywords: Electric vehicles, adoption, just transition, vulnerable populations.

Abstract

The adoption of electric vehicles EVs is a promising solution to mitigate environmental impacts and achieve long-term cost savings. However, various factors, including attitudinal variables, car usage behaviors, and socioeconomic status, limit the adoption of EVs. To address these challenges, a survey was conducted among a representative sample of the population in Flanders, Belgium in combination with indicators from the Several Material Deprivation survey, to investigate the adoption of EVs and explore ways to deploy EVs for the benefit of vulnerable populations.

To effectively capture complex interactions and nonlinear relationships among variables, we employed a Random Forest algorithm to evaluate the relationship between variables and the adoption of EVs. Our results show that attitudinal variables, such as environmental awareness and perceived benefits of EVs, significantly influence the adoption of EVs.

The findings of this study highlight the potential of EVs to address material deprivation among vulnerable populations. By exploring ways to make EVs accessible to these populations, we can contribute to more equitable and sustainable transportation solutions. Overall, our findings can inform policies and interventions to promote the adoption of EVs and achieve a more sustainable and equitable transportation system. The results could be used to develop targeted interventions to increase EV adoption, and to inform future studies on this topic.

Expanding the individual's role in the circular economy: Circular consumption and citizenship behaviours

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Keywords: Circular citizenship behaviours, circular consumption, circularity, system-level change, citizen engagement, citizen participation

Abstract

The concept of the circular economy (CE) emerged as an answer to increasing resource scarcity and global challenges such as climate change, waste, and pollution. The CE entails shifting the economic system towards decoupling resource use and value creation. Psychological studies on the CE typically focus on consumer behaviour along the so-called R strategies, such as reduce, reuse, repair. However, viewing individuals purely as consumers limits their scope of action to purchasing, using, and discarding products. Individuals can also contribute to the CE by urging other actors in the society, such as governments and businesses, that predominantly establish the economic system, to support the CE through their role. These circular citizenship behaviours include protesting, signing petitions, partaking in public assemblies, or participating in policy design and businesses' design processes of circular goods and services to voice citizens' needs, demands, and wishes to make the CE more attractive and feasible for them. Therefore, citizens can not only change their consumption behaviours towards the CE, but also aim at system change by urging decision makers to facilitate circularity as well as influencing other citizens to engage in the CE. In this presentation, I depict the extent to which individuals can engage in the CE through circular consumption and citizenship behaviours, and indicate which factors are related to both types of circular behaviours. To conclude, I illustrate practical implications for governments and businesses to support circular citizenship behaviours and amplify their impact.

Assessing the Economic Viability of Decarbonising Domestic Energy Consumption in Portugal

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Keywords: Energy Consumption; Decarbonisation; HVAC equipment; market analysis; investment costs; Portugal

Abstract

The European Union has set the target of achieving climate neutrality by 2050 [1], reinforcing its commitment to the Paris Agreement. Representing 40% of energy consumption and 36% of GHG emissions [2], buildings are a key pillar of the energy transition, and the domestic sector has a particularly significant impact, representing 28% of final energy consumption in the EU in 2021 [3]. Although building renovation should stand as the foundation of the sector's transformation, renewable energy integration and electrification through equipment replacement are considered as main routes toward this goal [4,5]. In Portugal, the decarbonization and electrification of buildings is a political objective framed and reiterated in several energy and climate policies. There is still an arduous path ahead, as fossil fuels and biomass still represented 23% and 39% of consumption in 2021 [6]. This paper explores the feasibility of decarbonizing energy consumption in Portuguese homes. It combines a quantitative economic analysis of equipment replacement scenarios and a qualitative auscultation of market players on public behaviour, and technological availability and evolution. Current challenges and barriers are identified, and potential technological solutions are evaluated, considering the population characteristics and needs, for a just and inclusive transition. A significant estimated investment is required, ranging from 26 to 28 billion euros. There is the perception that energy transition targets are too demanding considering the current equipment stock, lack of qualified workforce, need for building adaptation, and heavy investment cost for families. Key learnings are synthesized to inform decision-makers at different scales.

References

[1] European Commission. (2023). 2050 Long-term Strategy. Available at: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

[2] European Commission. (2020). In focus: Energy efficiency in buildings. Available at: https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en

[3] Eurostat. (2023a). Final energy consumption by sector. Available at: https://ec.europa.eu/eurostat/databrowser/view/ten00124/default/table?lang=en

[4] EEA. (2022). Greenhouse gas emissions from energy use in buildings in Europe. European Environmental Agency. Available at: https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-energy

[5] Zachmann, G., Holz, F., Roth, A., McWilliams, B., Sogalla, R., Meissner, F., Kemfert, C. (2021). Decarbonisation of Energy: Determining a robust mix of energy carriers for a carbon-neutral EU. Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies. Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/695469/IPOL_STU(2021)695469_EN.pdf

[6] DGEG. (2023). Energy Balance 2021 Provisory. Directorate General for Energy and Geology. Available at: https://www.dgeg.gov.pt/pt/estatistica/energia/indicadores-energeticos/

Smart Energy Apps and Sustainable Household Behaviour: A Text Mining Analysis of User Perceptions and Impacts on Energy Consumption in Norway.

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Keywords: Sustainable household energy behaviour, smart energy app, Norway, technology-based behaviour change, sentiment analysis, topic modelling

Abstract

The path to a low-carbon society requires innovative solutions and multidisciplinary research approaches to promote sustainable lifestyles. This study integrating smart digital solution and household energy consumption explores users' attitudes using a text-mining approach. The Tibber energy app is taken as a case study, drawing on publicly available user-generated reviews from Norwegian app users on Google play store and Appstore – with over 3 thousand reviews in total. The dataset is analysed using natural language processing techniques to reveal descriptive and content-based insights into users' sentiments, perceptions, and motivation towards the app. We further conducted exploratory qualitative analysis by considering the intent-impact criterion to explore users' sustainable energy practices, motivation to engage, and the signals of behaviour change. Our findings reveal an increasing number of app users actively interacting with the energy feedback and have predominantly positive sentiments towards the app. Furthermore, although the number of users who explicitly express environmental concern in their reviews is low, the actions they perform in interaction with the app are significantly impactful towards promoting sustainable energy behaviours. This study on citizens' perceptions of smartphone-based household energy app has important implications for the future prospects of policy interventions, emissions reductions, and technology-driven behaviour change.

CAPABILITIES APPROACH TO UNDERSTANDING FAIRNESS IN PARTICIPATION IN DOMESTIC DEMAND RESPONSE (2b)

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Keywords: capabilities approach, demand-side flexibility, demand response, households, fairness, wellbeing

Abstract

Domestic demand response (DR) holds potential to support energy system decarbonisation and also benefit participating households. However, DR participation could also negatively impact on households' wellbeing, with implications for energy justice.

Several conceptual lenses have been introduced (Capabilities Lens, Flexibility Capital) or adapted (Capabilities Approach) to support the analysis of such issues. This paper reviews these existing approaches and critically reflects on the application of the Capabilities Lens while developing a Smart Local Energy System as part of Project Local Energy Oxfordshire (Project LEO). Drawing on this, it develops a new conceptual framework that builds on the Capabilities Approach and uses meanings people attach to their homes to conceptualise ultimate desired outcomes (primary capabilities). It then illustrates application of the framework in the case of DR involving domestic heat pumps.

Novel contributions include conceptualising both valued outcomes and inputs that influence opportunities to achieve them in a single framework; conceptualising valued outcomes in relation to home meanings; and conceptualising inputs as relational and emerging across four levels (household, community, market and state). Differentiating between primary and secondary capabilities highlights the most relevant criteria for the evaluation of fairness and the need to go beyond a focus on inputs such as access to specific technologies. At the same time, we illustrate how our conceptualisation of inputs can be applied to identify potential supportive interventions across the community, market and state levels; and discuss its further application to analyse distributional impacts and issues of power and responsibility.

Towards resource efficiency: Context-sensitive interventions to encourage recycling in Indonesian households

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Keywords: Household behaviour, waste separation, resource efficiency, recycling

Abstract

Recycling is a key step not just towards resource efficiency, but also climate protection. According to the Circularity Gap Report, switching to a circular economy could reduce greenhouse gas emissions by 39%. However, this shift depends on the prevalence of recycling infrastructure and the behaviour change of households towards waste avoidance and separation. In countries like Indonesia, where recycling and household waste separation are still in their infancy, it is crucial to understand potential behavioural levers.

This study presents and discusses the findings from a stepped wedge randomized controlled trial, testing behavioural interventions based on a collective reward and on social signaling devices. These interventions were co-designed with local partners and were informed by a context-sensitive approach, taking into account the specific challenges and opportunities in a middle income country such as Indonesia. Our data collection was based on observation rather than on self-reporting, which avoids the over-reporting of socially desired behaviours and leads to more robust results. In the course of two months, we were able to increase household participation in separation from 25% of households to 32%.

How can Evolutionary Psychology Explain Cognitive Biases that Impede Climate Mitigation Behaviours? A Meta Theory.

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Keywords: Evolutionary Psychology, Cognitive Biases, Climate Mitigation Behaviours, Meta Theory

Abstract

Given pressing environmental challenges of climate change, it has become increasingly evident that behaviour change on a societal level is imperative to mitigate its consequences. However, this process is often hindered by cognitive biases influencing decision-making and behaviors. Despite growing research on cognitive biases as psychological barriers to climate mitigation behaviours, comparatively little research has been dedicated to study their forces in relation to climate change. However, the better one can define the nature of adaptive information processing and understand their psychological roots, the clearer it becomes which psychological mechanism are necessary to create effective solutions. While traditional behavioural sciences study behaviour through direct triggers, an alterative approach elaborating on the nature of behavioural tendencies lays in evolutionary psychology. Previous research on cognitive biases from an evolutionary psychology perspective in the context of climate mitigation behaviors has been limited to a selected set of biases. This paper thus aims this literature by studying risk aversion and loss aversion, which play significant roles in climate mitigation behaviors, through an evolutionary lens. For the purpose of this research a literature review will be conducted on the evolutionary causes and origins for risk aversion and loss aversion while relating them to barriers for pro-environmental decision-making. Results may be used to design behavioral intervention and thereby advise policymaking to initiate behavioral change for sustainable action on a societal level (e.g., energy transition). Leveraging these insights from evolutionary psychology offers innovate while mitigating ineffective and short-sighted actions.

Dynamic Anthropogenic actiVities impacting hEat emissions (DAVE) and energy demand – the role of buildings

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Keywords: Agent-based modelling; urban energy demand; time use surveys; spatiotemporal dynamics

Abstract

In this contribution, we introduce DAVE, a comprehensive model that examines the impact of human activities on various urban-level variables, such as anthropogenic heat fluxes, pollutant emissions, and energy demand.

The model incorporates transportation and building energy models to enable the simulation of dynamic travel patterns, vehicle usage, occupancy rates, heating and cooling demands, and energy release through building structures to the outdoor environment. To represent the local environmental conditions, DAVE is coupled with an urban climate model. Additionally, the model takes into account variations in building stocks using archetypes. DAVE adopts an agent-based modeling approach, where the characteristics of urban residents are captured through time use surveys (TUS). By extracting different profiles based on sociodemographic variables such as age and number of occupants, the model can capture dynamic responses to environmental conditions, travel patterns, and energy demand fluctuations.

Our presentation focuses on how TUS data is utilized to simulate travelling patterns and estimate building energy demand, including the usage of appliances, lighting, water consumption, and the specific rooms where these activities occur. This methodology relies on the definition of time windows to attribute occupancies and the related features as well as travelling events associated to the changes of locations where activities are occurring.

To evaluate the performance of DAVE, we present a case study conducted in the city of Greater London, where the model's results are benchmarked against national energy consumption statistics.

Community owned/co-owned wind farms: The extent and the determinants of citizens' willingness to participate under different types of arrangements

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Keywords: Wind energy, Citizen participation and Community ownership, Social Acceptance

Abstract

Citizen participation in local wind farms has the potential to alleviate project opposition and accelerate the deployment of wind energy. However, little is known about the willingness of citizens to participate. This paper uses data from a survey of 826 Irish citizens to examine the extent and the determinants of citizens' willingness to participate under different types of community ownership/co-ownership arrangements including wholly community-ownership, joint ventures, split ownership and shared revenue agreements. Our survey results reveal a strong interest in citizen participation in local wind farms, though only a minority are very willing to participate. Using a series of generalised ordered logit models, we identify the determinants of citizen participation under the different arrangements. Across all arrangements, younger adults and people who support a project are more likely to participate. For arrangements requiring deeper citizen involvement (i.e., wholly community-ownership, joint ventures and split ownership), citizens are more likely to participate if they are knowledgeable about wind farm development, and if a project is in construction as opposed to planning/pre-planning. For arrangements where a community would be working alone, without the assistance of a developer (i.e., wholly community-ownership and split ownership), participation is more likely in communities with a strong spirit. For all co-ownership arrangements (i.e., joint ventures, split ownership and shared revenue), trust in the wind farm developer also influences participation decisions. The findings have implications for policy development on community owned/co-owned wind farms and point to particular measures for encouraging participation in different types of arrangements.

Nudging prosumers' energy demand

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Keywords: Behaviour, Nudges, Prosumers, Energy efficiency, Heterogeneity

Abstract

Non-price interventions, "nudges", are frequently used to affect individual choices without limiting their set of choices. Significant research in the field has shown that nudges are highly effective inducing on average a 5% decrease on residential energy consumption. However, most studies focus on the impact of nudges on residential consumers while prosumers remain relatively understudied. Focusing on prosumers is of great importance for two main reasons. First, the number of households that adopt solar panels significantly increases over the years and second, several studies indicate a solar rebound effect in the electricity consumption. In this study, we estimate the effect of social-norm comparisons by implementing a RCT with an energy service company in Sweden, which offers metering, and IT systems for energy efficiency and renewable energy. We collect data from a bi-weekly Home Energy Report (HER) being disseminated to prosumers from December 2020 to present. The HER includes social-norm comparisons for the amount of electricity consumed and bought by households. The dataset includes 500 and 365 households in the treatment and control group respectively. Methodologically, we estimate difference-in-differences regressions and address potential biases from heterogeneity in average treatment effect across groups and time. Based on preliminary results, we observe a statistically significant decrease in the average amount of electricity consumed by households even after controlling for other factors such as weather conditions, electricity prices and solar production. The effect on electricity consumption has also a significant seasonal pattern, being higher during periods with higher solar production (spring and summer).

Energy transition and urban regeneration involving local communities: the DE-Sign Project and the Cosenza Urban Lab.

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Keywords: Community, Urban regeneration, Energy transition, Social Psychology, Design, Public participation.

Abstract

The transition to conscious use of energy sources is vital for building sustainable communities, particularly in urban areas marked by socio-spatial inequalities and an energy divide. In Italy, collective perceptions exhibit a contradiction (Rainisio et al., 2021), with both high concern for environmental conditions and low confidence in collective transformative action. Policy approaches often prioritize technical and engineering aspects, disregarding the systemic interplay between energy, environment, and community dynamics (Coy et al., 2021).
The DE-Sign Project, a collaboration between ENEA and three Italian universities (Università degli Studi di Milano, Politecnico di Milano, and IUAV Venice), takes an innovative, multidisciplinary approach. Focused on Cosenza in Southern Italy, the project integrates education and action to drive energy transition within marginalized areas and foster urban regeneration. At the core of the initiative is the Cosenza Urban Lab, serving as a platform for research, training, and participatory activities involving the local government, associations, and schools in the targeted neighbourhoods.
During the presentation, the midterm outcomes of the DE-Sign Project will be discussed, shedding light on its potential in facilitating sustainable community regeneration at the local scale. By experimenting with creative and transformative practices for sustainable regeneration, the project aims to overcome the challenges posed by energy poverty and socio-environmental concerns. Ultimately, it seeks to promote a systemic vision that recognizes the interdependencies between energy, environment, and socio-cultural factors in driving transformative and participatory processes within communities (Forrest & Wiek, 2014).

Understanding the Dynamics in the Relationships between Electric Vehicle Adoption, Dynamic and Descriptive Norms

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Keywords: Electric vehicle adoption, Dynamic norms, Descriptive norms

Abstract

Large-scale adoption of electric vehicles (EVs) can contribute to a transition towards sustainable (energy) systems. Such large-scale changes often start on a small-scale, with initially only a minority engaging in the particular behaviour which may spread to other people and ultimately, can lead to widespread adoption in society. Key determinants of EV adoption may be descriptive norms in society, that is, the perceived adoption of EVs in society. Yet, with only a minority adopting EVs, the descriptive norm for this behaviour is likely to be weak. We expect a weak descriptive norm to inhibit the adoption of EVs in many individuals. We explore what factors determine whether people adopt EVs despite the existing descriptive norm, and how over time this may turn into a dynamic social norm (i.e., where individuals become aware that more and more people adopt EVs), and eventually a new descriptive norm. We hypothesise that individuals can become motivated to adopt EVs when they interact with someone who already owns an EV. Further, we explore how, by means of such influences and dynamic norms, tipping points can be reached, beyond which reinforcing mechanisms between EV adoption and descriptive norms can lead to large-scale changes. We tested these propositions via an empirically informed agent-based model showing that the relationships of (factors of) EV adoption, dynamic and descriptive norms form a dynamic interplay that can explain how EV adoption of a minority can lead to large-scale changes. Limitations and implications will be discussed.

Emerging sites of energy citizenship: do they support transformative practices or merely reproduce old sites of socialisation?

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Key Words: Energy Citizenship, Sites of Citizenship, Household, Cities, Rural areas

Abstract

Energy related matters, traditionally seen as technical issues, are increasingly being reconsidered with the human dimension becoming more significant within public and political policy discourse. Energy citizenship epitomises this shift and can be described in general terms as a broadening and deepening of the roles citizens can play in decarbonising the energy system. We offer insights from a mixed-method research design relying on qualitative and quantitative insights to produce a critical review of energy citizenship; this includes a scoping review of energy citizenship literature, a European-wide survey targeting the wider public (n=500), and interviews with key energy stakeholders (n=50). The focus on sites of energy citizenship is extremely relevant in terms of public engagement as it brings into focus what people do, as opposed to what people say about citizenship. This offers a complementary opportunity to studies that tend to focus solely on how people identify and perceive their own status as citizens. It also delves into practices of lived citizenship and the places and spaces in which it occurs. By doing so we seek to explore what models of citizenship are enacted, how boundaries are practically defined and what criteria of belonging are created. From the research, we identify five key sites where energy citizenship is expressed including households, urban spaces, rural areas, municipalities, and around energy storage. We explore energy citizenship manifestations emerging within these sites and we outline various opportunities and/or limitations to influence behaviours around the decarbonisation of the energy system.

Rationales and policies of the 'just transition'

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Key-words : just transition, green and brown jobs, inclusivity, democratic procedures

Rationales and policies of the « just transition »

Abstract

The energy transition concerns all sections of the population. However, they are not all affected in the same way. Women and children are particularly affected. So the question is, why is this the case?

Firstly, the majority of the world's poor are women, who account for 70% of the 1.2 billion people in the world whose income is less than $1 a day. The French High Council for Equality has been explaining this for several years : women, because of the specific social roles assigned to them by our societies and the discrimination they face, are doubly impacted by climate disruption. The same applies to children.

When it comes to the energy transition, women, are the main carers in the home. According to INSEE (National Institut Statistics and Economic Studies), women take on 65% of domestic tasks and 71% of parental duties. It has also been shown that the day-to-day running of the household, and in particular household and child-related expenses, is more often the responsibility of women. Women manage the household accounts. So it's up to them to keep a closer eye on day-to-day expenses, especially those related to energy (heating, gasoline, etc.). Children are educated by women from an early age to help them save energy.

Finally, yet these first to be affected are absent from decision-making : only 12% of environment ministers worldwide in 2015 were women. And yet, data collected in 25 developed and developing countries show that countries with greater female parliamentary representation are better combat climate change.

Sustainable Behavior and Acceptance in the Netherlands: A Two-Year Comparative Study for Carbon Reduction Potential and Behaviour Predictors

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Keywords: Public Acceptance, Circular Economy, Behaviour, Monitoring, Sustainable living, Energy Efficiency

Abstract

This study undertakes a comparative analysis of sustainable behavior amongst Dutch inhabitants in 2021 and 2023, focusing on eight key areas (including energy saving, circular consumption, and food). Surveys were used to measure not only the prevalence of sustainable behaviors, but also the acceptance (openness) towards adopting such behavior. The primary aim was to quantify the potential for CO2 reduction in the Netherlands, assessed as the difference between the proportion of inhabitants already performing the behavior and those indicating openness to behavior change. Moreover, the study aimed to identify the most influential factors predicting each behavior: from social norms, income, age, ease of behavior etc. and potential groups in society that have a higher potential to change, which could inform campaigns aimed at that behavior.

Results demonstrated limited change in sustainable behavior from 2021 to 2023, highlighting a need for further policy intervention. The lack of significant progress suggests that additional measures are needed to tap into the identified potential for CO2 reduction. Furthermore, understanding the predictors of each behavior could inform targeted policies and interventions. This research underscores the importance of proactive policy-making in promoting sustainable behaviors and harnessing their potential for environmental impact reduction and gives insight to which groups in society could be targeted first to make a change in the Netherlands.

Sparks of Change: How do Age and Gender Impact the Actions Taken to Reduce Energy Use?

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Keywords: demand side response, energy demand, gender, age

Abstract

A global focus on the demand side of the energy equation has never been more important. Supply uncertainty, high prices and urgent climate targets all point to the value of energy efficiency and energy savings. Using data for 26,337 citizens across 27 European counties, gathered as part of the Flash Eurobarometer 514 survey examining the EU's response to the energy challenges, this paper examines the actions citizens have taken (or are willing to take) to reduce their energy consumption. After controlling for factors known to impact energy consumption decisions (occupation, household size, accommodation type, standard of living, ability to pay bills, expectations about future energy prices, country) we find that gender and age significantly impact energy saving activities. For example, females and older people are more likely to engage with energy conservation behaviours such as unplugging their electronic appliances when not in use, turning off lights when they leave a room, and reducing the room temperature. Males are more likely to be involved in activities that require decisions about energy expenditure (such as installing equipment in their home to control and reduce your energy consumption, adding better insulation to the home, buying energy efficient equipment) while younger people are more likely to alter their behaviour (e.g., by using alternative ways to commute than their car/motorbike, taking the train rather than a plane). Our results suggest useful entry points for energy efficient initiatives as policymakers appropriately mainstream age and gender aspect into energy saving policies.

Initiating the Journey: Austria's innovative response to energy poverty in the midst of crisis

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Keywords: energy poverty, behaviour change, training, innovative information transfer

Abstract

Since the beginning of the energy crises, Austria has embarked on a proactive path, introducing innovative strategies to reach and assist energy poor households. This paper presents some of these new strategies.

Among these initiatives, the ENPOR project stands out due to its unique approach in developing distinct and easily understandable informational materials. The distinguishing feature of these materials is the extensive use of visual aids and simplified language to clarify complex energy-saving concepts, making them more accessible for energy poor households. The process of creating these materials employed a co-creation approach. It involved not just field experts, but crucially, the end-users – the energy poor households themselves. This co-creation process leveraged the knowledge of experienced energy advisors while incorporating invaluable feedback directly from the target demographic. These materials underwent pilot testing in the region of Vienna. The feedback was overwhelmingly positive, demonstrating the effectiveness of this new approach and the high acceptance from the households involved.

In parallel, a new training program for Social Energy Advice was introduced. This program offers specialised training to social and health care workers, equipping them with the skills needed to provide accessible and relevant energy-saving advice to vulnerable households. This training program places an emphasis on teaching methods to reduce energy consumption that do not necessitate financial investment, thereby providing a valuable resource for households struggling with energy costs. With this interdisciplinary knowledge, combining insights from both the social and energy sectors, these advisors are perfectly placed to guide vulnerable households towards energy saving measures..

TRENDS IN BEHAVIOURAL ENERGY EFFICIENCY PROGRAMMES IN THE UNITED STATES AND CANADA

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Keywords: Energy Efficiency, Behaviour, Programme, Utility

Abstract

The energy efficiency industry has increasingly recognized the potential of social science knowledge to expand programme possibilities and tap into new energy saving opportunities. To that end, the Consortium for Energy Efficiency (CEE)[i] has developed a database of utilities' behaviour-based programmes and how these programmes are being evaluated. This vast repository of programme information holds great promise for providing insights into the evolution of behaviour-based energy efficiency programmes and new programme directions. We propose a presentation that would highlight key findings from this 2023 research (completed in July 2023) as well as the methods used and resulting limitations. This presentation would cover myriad programme details, including the specific social science techniques incorporated (e.g. feedback, modelling behaviour, social norms, prompts, and goal setting), the sector (residential, commercial, or industrial) in which the programme is taking place, and whether any customer engagement technologies are utilized, among other programme components. This database also sheds light on evaluation design, metrics used to measure success (e.g. energy savings, customer satisfaction, percent of target participants reached, or adoption level of efficient practices), energy savings achieved, and whether the utility running the programme was able to count the measured savings towards their energy efficiency targets. This presentation would help shed light on which behaviour-based programmes might offer the most effective, evaluable, and promising approaches to enhance quantifiable energy efficiency gains by leveraging behavioural science techniques.

[i] *CEE is a non-governmental organization (NGO) whose 76 energy efficiency programme administrator members direct approximately 70% of the $9.3 billion USD spent annually on energy efficiency in the United States and Canada.*

Energy Communities: Chances, requirements and the right policy support to foster energy decentralisation

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Keywords: Energy Communities, Energy Sharing, Decentralised Energy Production, Policy Targets, Policy Instruments

Decentralised energy production is a high priority in the political agenda. The new geopolitical and energy market realities require a drastic acceleration of the energy transformation to increase energy independency from energy imports and fossil fuels and to cope the rising energy prices. Thus, the creation of renewable energy communities (REC) is becoming an increasingly important target, with several additional benefits, from community engagement to fighting social inequalities. Renewable energy systems under new community ownership structures, instead of the traditional energy production systems will change the future of the energy sector. There are already good pioneer examples in Europe, with the goal to bring cheap, clean and secure energy generation closer to the people who need it. Thereby energy communities may have a wide application, in different scales, sectors (power, heat supply and mobility) and geographical scopes. However, several analyses like the EnR study on Renewable Energy Communities[1] demonstrated, there are still significant barriers that hinder a greater development of REC, and so an effort must be done to remove these obstacles for a wider development of these systems.

This session addresses the recent targets and requirements for energy community deployment and demonstrates targeted policy support facilities for the accelerated expansion of energy communities. Specific policy solutions are presented by the Austrian one-stop-shop facility for energy communities as well as examples from the SHARES project how to replicate this model in other countries.

[1] https://enr-network.org/wp-content/uploads/EnR-Study-RenewableEnergyCommunities.pdf

Govemance structures for local heat projects and their financing conditions

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Keywords: Energy Communities, Renewable Heat, Cooperatives, Public Energy Utilities, Financing, Operator Models

The future's energy system is largely based on decentral renewable energy systems. In the case of heat, the energy is local by its nature and transportation across longer distances comes with high losses. In the face of sector coupling, the generation of renewable electricity and heat is entering the local space of communities. Apart from traditional public utilities in the hand of the municipality, energy cooperatives gained ground in recent years. Between public and private enterprises, there are various mixed forms as the public utilities might be purpose-oriented, profit-oriented with different shares of public ownership and different local degrees. Against this background, governance, together with the respective financing model, plays a crucial role in the formation and maintenance of a successful energy community.

This session introduces into different operating and governance models of energy communities and presents different examples for public-private participation. The financing conditions in terms of interest rates, credit periods, creditworthiness as well as stakeholder participation and governance are compared and various mixed forms demonstrated.

An interactive session raises the following questions:

- *How can conventional public energy companies transform into or participate in energy communities? What are the missing parts and how can we avoid 'community washing'?*
- *How to create a good governance structure from a financial and participatory point of view?*
- *What are recent most promising business opportunities for energy cooperatives and what are the investment chances for the public and private sector?*
- *What are economic quality and success criteria and which (digital) tools can support effective organisation of energy communities?*

Breaking Barriers, Building Communities: Enhancing Inclusive Participation in Energy Communities

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Keywords: energy communities, citizen empowerment, motives, engagement, behaviour change

Abstract

The EUs ambitious clean energy package seeks to revolutionize the energy landscape by placing citizens at the forefront of the energy transition. Central to this vision are energy communities. However, the complex requirements for becoming a prosumer pose a potential obstacle, limiting equal engagement and benefit for all consumers. Disparities arise between those equipped with knowledge, access, and opportunities to participate, and those lacking the requisite resources, training, expertise, or time.

The EU-funded SHAREs project addresses these challenges. Recognizing barriers to entry into energy communities, SHAREs delivers innovative solutions and practical guidelines aimed at surmounting these obstacles. The project empowers local heroes to establish or expand energy communities and equips them to effectively engage consumers directly, even those without a pre-existing affinity for energy matters or familiarity with the concept of energy communities. Central to SHAREs' work was the development of 14 distinct target group profiles, illuminating the diverse mindsets and motivations driving individuals to join energy communities. These profiles delve deeply into factors such as financial considerations versus environmental consciousness, attitudes towards green energy, willingness to adopt new technologies, and embrace of communal values. Moreover, the profiles delineate tailored communication strategies to reach each distinct group, highlighting the most effective platforms and approaches for engagement. Furthermore, SHAREs also addresses potential obstacles by formulating key messages and anticipating challenges that each target group may face. By pre-emptively addressing prospective members' concerns and uncertainties, local heroes are equipped to foster a sense of belonging and motivation, while catering messages to align with the unique circumstances of each group.

TAMING THE DRAGONS OF INACTION: (RE)PRIORITISING THE IMPORTANCE OF CLIMATE ACTION

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Keywords: climate action; perceptions; future concerns; timeframes; sustainable behaviour change

Abstract

The urgent need for climate action is well recognised globally, especially due to the severe impacts and implications of climate change for future generations. Understanding individuals' perceptions of the need and urgency in addressing such climate issues is paramount for developing effective strategies and interventions that can drive sustainable behaviour change. However, a critical knowledge gap persists in comprehending how individuals perceive the importance of addressing different types of climate challenges and how they prioritize these concerns in comparison to other domains such as society, technology, economy, and politics. The present study bridges this gap by exploring how individuals assess the significance of future concerns across different intricately interconnected domains that collectively shape societal progress in climate action. The population survey with 2000 individuals aged 16 years and older residing in Singapore revealed important variations in perceptions and priorities among participants across demographic groups. While some exhibited a strong sense of urgency regarding climate issues, others prioritized different domains or perceived climate challenges as less pressing than others. Importantly, we found that the timeframe participants interpreted each climate challenge vis-a-vis other societal, technological, economic, and political challenges determine the prioritization and support for climate action. This underscores the complexity of galvanizing the public for climate action and highlights the importance of recognizing the interconnectedness of domains and considering varying time frames when developing climate action strategies. Implications of these study findings are further discussed towards informing the development of a future-ready society that is resilient, inclusive, and sustainable.

Context not motivation is the barrier to energy efficiency behaviour

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Keywords: efficiency behaviour; pro-environmental motivation; barriers

Abstract

As part of the strategy to mitigate further climate change, it is important to use less energy from fossil fuel sources and transition towards renewable sources of energy. To facilitate the transition away from fossil fuels, domestic households will likely have to consume less energy. There are two main types of action households can do to reduce the energy consumption. The first is curtailment behaviour: using less energy at home by, for example, turning down the thermostat or taking shorter showers. The second is efficiency behaviour: making homes more efficient users of energy by, for example, installing additional insulation or getting underfloor heating. Efficiency behaviour can be more beneficial than curtailment behaviour because it can facilitate greater reductions in energy use, as well as improving the living conditions of homeowners. If people choose not to engage in efficiency behaviour, we may assume that they are simply not motivated enough (e.g., they do not care enough about the environment or they care too much about their own financial resources). However, people might face substantial barriers to efficiency behaviour, unrelated to their motivation, that can prevent them from making the necessary improvements to their home. That is especially true of vulnerable groups, such as those on low incomes. In the current talk, I will first show that a lack of efficiency behaviour is often not a motivational issue. Second, I will explore the potential barriers to efficiency behaviour and suggest methods for overcoming these barriers.

Employee support for energy conservation programs: examining the intention-behavior gap from a longitudinal perspective

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Keywords: Energy conservation, Willingness for energy curtailment, Behavior change, Employees

Abstract

In response to price surges and the possibility of power shortages on the European energy markets in the winter of 2022, many public and private organizations introduced short-term energy conservation measures. In Germany, these programs typically aimed at decreasing the demand for natural gas, for example by lowering indoor temperatures in offices or other public buildings. The success of these short-term interventions often depended on the voluntary behavior change of individuals. In this study, we evaluate a short-term energy conservation program at a public research university in Germany. Through repeated email appeals, university employees were asked to support several measures, such as lowering their office temperature, turning off the heating in hallways and restrooms, and deactivating decentralized boilers for hot water. We assessed employees' general support for these measures and their actual behavior at two points in time (January and April 2023) through a university-wide online survey (total N = 3,055). We also measured potential factors underlying the level of support, such as socio-demographic and workplace characteristics, psychological motivations, and beliefs about risks and benefits of the conservation program. Our analysis compared program support and behavior across the two time points as well as examining how employees' general support related to their intentions and actual conservation behavior. Statistical models of the factors underlying conservation behavior indicated that psychological motivations are a key factor for the success of the program. We discuss the theoretical implications of our findings as well as their practical relevance for similar energy conservation programs.

Price signals, when all other things are not equal – an investigation of how price signals could affect different electricity user niches.

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Keywords: Demand-response, Price Signals, Electricity Consumption, Behaviour Change, Cluster analysis, Consumer Niches

Abstract

To enhance renewable energy integration and alleviate strain on the electricity grid during peak demand, user flexibility in electricity use is crucial. Programs promoting demand-response aim to motivate users to be flexible, that is, to change their consumption patterns. Demand-response often involves some sort of price signal. There is an unspoken assumption that users respond (reasonably) similarly to such price signals. An alternative perspective considers the electricity market as a complex system with distinct user niches, containing, for example, households with children living in detached homes, 'DINK'- (dual income no kids) households or retirees. Households in each niche may exhibit different energy behaviours. Additionally, they may differ in their reception of price signals, and in their willingness and capacity to respond flexibly.

The current study aims to identify user niches with varying ability to respond to demand response initiatives. Initially, we identify user niches by applying a clustering approach on hourly meter- and building type data from a sample of suburban electricity users from Stockholm, who were recently introduced to a new price signal – a demand charge tariff. By analysing pre-demand charge data, we examine how households in each niche could have perceived the signal, in terms of what shifts it suggests and how significant those shifts would be, given the load pattern of households. Our findings demonstrate that a 'generic' demand charge tariff may incentivise different consumption changes across niches, and that not all niches are equally affected by this type of tariff.

Adoption of residential photovoltaic and battery storage adoption in Germany: A comparison between adopters and non-adpters

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Keywords: Technology adoption, residential sector, rooftop photovoltaic, multigroup SEM

Abstract

A key factor in achieving the EU's climate and energy targets is the rapid adoption of renewable energy solutions in residential buildings. Among the multitude of available technologies, residential photovoltaic (PV) is one of the most popular and well researched options. Over the past few years, PV systems are increasingly being combined with battery storage systems to enable greater energy autonomy and self-consumption, allowing the storage of surplus self-generated electricity. These developments are further driven by increasing electricity prices, declining battery prices, and the recent energy crisis. In this context, we investigate factors influencing the adoption of PV systems with battery storage. In particular, we seek to understand the differences in the perception and acceptance of the technologies among adopters and non-adopters. In order to achieve this objective, we conducted a survey among homeowners in Germany. The final sample included 368 homeowners, which is representative regarding age, gender, and household size. For our analysis, we considered sociodemographic characteristics as well as personal beliefs and attitudes toward both technologies. Moreover, we examined external influences, such as exposure to solar marketing or the observability of both technologies. After performing a confirmatory factor analysis to assess the validity of the model, the data were analyzed using multigroup structural equation modelling with maximum likelihood estimation.

Preliminary results show that expense concerns, perceived behavioral control, and social support are important predictors for the adoption and non-adoption of both technologies. Based on the results and comparison of adopters and non-adopters, implications for energy policy are presented.

How to engage right? Guidelines for public participation in energy infrastructure

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Keywords: Public participation, energy infrastructure, guidelines, acceptability

Abstract:
Involving the public in the development of energy infrastructure is crucial for the acceptance of energy solutions and the acceleration of the energy transition. It is also a core element of the implementation of the EU Governance regulation and the Energy Efficiency First principle. The forms of participation can range from providing information to empowering citizens to take the energy transition into their own hands. Despite the increasing recognition of the importance of citizen participation, effective and comprehensive public involvement is not trivial, and there are different opportunities depending on the technology, political context and the (multi-level) governance structure. To address this challenge, we conducted an extensive literature review and conducted interviews with experts from the energy sector to gain insights into best practices and key success factors for engaging citizens and communities in energy infrastructure solutions. In this interactive session, we will present a set of key guidelines for effective public involvement in energy infrastructure decisions and learn together from participants' experiences. Our insights will provide guidance to project developers, energy agencies, local and regional authorities and other actors involved in energy system transformation. The idea is not to steer the decisions for or against energy infrastructure projects, but rather enable the national, regional and local actors to increase the inclusiveness in the decision-making processes and hence the social acceptance of these decisions.

Modelling just transition pathways to climate neutrality

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Keywords: Energy system modelling; Fairness, equity, and inclusivity; Energy policy; Future energy choices; Co-creation

Abstract: *A notable inclusion in the most recent mitigation assessment from the IPCC was the need for a broader societal transformation to achieve the Paris Agreement temperature goals in a fair and equitable manner. Energy system models are becoming increasingly important in politics when it comes to informing the energy transition towards climate neutrality. Even though these tools have become very powerful, their ability to map real-world behavioural, social and political developments is limited. This can lead to neglecting important aspects of fairness and inclusion as well as behavioural change measures in politics and policies, making it (almost) impossible to keep up with the goal of leaving no one and no region behind in the transition. In this talk, we argue that it is time to rethink energy system models through the lenses of a just transition. An integrated and complementary energy modelling and social science and humanities research approach is crucial to enable fair and equitable climate neutrality pathways. Political decisions would benefit from insights not only based on modelled techno-economic pathways and scenarios of the energy transition, but also on the findings of discussions and debates with the many stakeholders involved or impacted. This is particularly important as cost optimisation ignores existing injustices, there will be geographically dispersed winners and losers in the energy transition, and the transition process can offer different socio-economic benefits for broader regional transitions. In this talk, we will discuss limitation of current modelling approaches and provide policy recommendations to broaden the evidence base to include inter- and transdisciplinary research as well as the learnings from implementation projects. The policy recommendations are based on findings and experiences from stakeholder engagement in modelling from different European research projects, including SENTINEL, SONNET, SEEDS and JustWind4All.*

Factors affecting citizens' engagement in community energy initiatives

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Keywords: Community energy, Participation, Investment, Motives, Barriers

Abstract

Community Energy Initiatives (CEIs) can help effectively produce and distribute energy and attain climate goals by giving new roles to citizens and local communities. In light of this, the current work intends to give a synopsis of the present state of knowledge regarding the factors that influence people's involvement in CEIs, whether talking about volunteering, taking on administrative roles, or making investments. On this basis, a literature study was conducted, with the findings classified as attitudinal, contextual, and personal capabilities based on the categories of causal variables identified by the Attitude-Behavior-Context (ABC) theory. A wide range of variables has been found to influence the levels of citizens' involvement, including (i) attitudinal factors such as environmental concerns, energy-related motives, and perceived innovation adoption, (ii) contextual factors such as return on investment, social recognition, interpersonal trust, spatial variables, institutional framework, policies, benefits, and barriers, and (iii) personal capabilities such as demographic and socioeconomic characteristics. According to the findings of the current analysis, it is evident that the idea of citizen involvement and investment in CEIs has not been fully explored in earlier studies. Only a few relevant studies concentrate on specific northern and central European countries. Therefore, additional research might offer a way to compare existing research, considering variations from the countries mentioned above regarding institutional structures, demographic and socioeconomic attributes, climate conditions (i.e., applied technologies), and perspectives on the cooperative institution.

Significant electricity savings with information nudging during the crisis winter in Finland

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Keywords: Energy efficiency, Energy saving, Behaviour, Information nudge, Campaign

Abstract

The extensive impacts of the Russian offensive war on the energy markets quickly became apparent in the spring 2022. There was uncertainty about energy availability, and prices rose. Finland had previously relied on electricity imports from Russia, especially during the coldest winter frosts when the demand for heating energy is at its highest. The discontinuation of electricity imports raised concerns about whether there would be enough energy for the following heating season.A joint energy-saving campaign by the government administration was planned in April. The objectives were to encourage Finns to take energy-saving measures so that energy, especially electricity, would be available in all circumstances. On average, 87% of Finns reported saving energy during the winter, with the target being 95%. Another goal was to reduce consumption by 5% during peak demand hours, which is the same as the emergency measure regulation related to high energy prices in the EU. Compared to 2021, peak consumption decreased by 8%, and when considering the long-term average and temperature, even by 12-13%. The "Down a Degree " campaign brought together Finns to take action both at home and in workplaces to save energy. The winter was passed without power outages, and the savings measures could fully compensate for the previously imported electricity from Russia in previous years. Finnish electricity consumption continues to be lower, with consumption in May 2023 being 8.5% lower than the previous year.

Unveiling sustainability-related lifestyles: A framework for lifestyle-based segmentation in sustainability research

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Keywords: Lifestyles, Sustainability, Segmentation, Interventions, Behaviour Change

Abstract

There is a rapidly growing literature on construction and application of lifestyle-based segmentations in the sustainability research. This trend is motivated by the increasing awareness that interventions tailored to a specific target group are more effective than one-size-fits all interventions and lifestyle-based segmentation approaches could be a useful concept for defining those target groups. While generalist approaches offer important advantages in terms of high replicability and applicability in a wide range of research fields, the domain-specific approaches (e.g. energy consumption, mobility) have usually larger explanatory potential regarding specific behaviours and typically result in more meaningful target groups for interventions. In this contribution, we propose a middle way. On the one hand, we avoid to develop a completely generalist lifestyle-based segmentation in order to provide more scope for applicability in the field of sustainability research. On the other hand, we focus our approach on sustainable living and working, which gives the framework a slight generalist character, since it includes a large range of behaviours and psycho-social determinants. The framework is empirically applied on a sample of 196 test persons from the German-speaking part of Switzerland recruited by an online access panel provider. In addition to standard socio-demographics, the survey contains numerous items describing reported behaviour from the sustainability-related domains, such as mobility, energy and food as well as a range of psychosocial behavioural determinants. Based on the survey content, we first reduce dimensions of the data using a factor analysis and subsequently conduct a cluster analysis to construct our sustainability-related lifestyles.

Financial incentive for retrofit in owner occupied houses: Developing new narratives for key stakeholders

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Keywords: building retrofit, energy efficiency policy, financial incentives, policy narratives, cognitive framing, home working, owner occupied housing

Abstract

Meeting decarbonisation targets through retrofitting owner-occupied housing in the UK and across Europe remains a significant challenge. Success in energy retrofits hinges on the alignment of interests among diverse actors such as homeowners, builders, national and local authorities and lenders. However, energy policies often fail to explicitly detail the alignment of these actor interests, which may partially explain the lack of effectiveness of recent financial retrofit schemes. This necessitates a radical rethink of the implementation of such schemes.

Previous work on retrofit incentives by Topouzi & Fawcett (2022) and Topouzi & Mallaburn (2021) developed the 'Retrofit Salary Sacrifice' (RSS) policy scheme, a novel approach that uses the increasing trend for hybrid working as a trigger to encourage retrofit home improvements in able-to-pay households. In this paper, we use a concept of a cognitive frame to make explicit the diverse considerations of different actors involved in the RSS scheme, facilitating their alignment and thereby increasing the chances of policy success.

The empirical insights come from stakeholder engagement activities such as surveys (n=70), workshop (n=18), and one-on-one conversations with representative actors from sectors that need to be involved in the RSS scheme for it to succeed. We use this data to create narratives that effectively promote the RSS scheme by resonating with diverse cognitive frames of different actors. This approach aims to foster shared understanding, contribute to successful policy design and implementation, and enable the adaptation of the RSS scheme to various contexts or countries.

Integrating Technology in Transformative Social Innovation for Sustainable Energy Development: A Case Study of Indonesia

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Keywords: Transformative Social Innovation, Sustainable Energy Development, Technology

Abstract

PLN is Indonesia's largest electrical service company. To provide electricity, PLN uses a significant amount of fossil fuel based, as many as 86% of the power plants owned by PLN subsidiaries in power generation are fossil-powered generators, which is bad for environment. Furthermore, the Paris Agreement countries including Indonesia must commit zero emission in 2060 to act for climate change solution. In consequence, PLN along with its subsidiaries should have some breakthrough which follows the updated issues using technology to run their business. Indonesia confronts enormous obstacles in reaching sustainable energy targets as a fast-developing country with a huge population and diversified geography. To address these challenges, integrated technology and transformative social innovation can play a crucial role. By combining technological advancements with innovative approaches to social change, Indonesia can foster sustainable energy development. Transformative social innovation involves engaging stakeholders, empowering communities, and fostering collaboration to drive change. Through community-led initiatives, capacity building programs, and supportive policies, transformative social innovation ensures the inclusivity, resilience, and long-term viability of sustainable energy solutions. The integration of technology and social innovation enables the deployment of decentralized energy systems, promotes PLN's renewable energy projects, and enhances energy access in underserved areas. It also facilitates the adoption of energy-efficient practices in various sectors and encourages behavioral changes to promote sustainable lifestyles. By leveraging integrated technology solutions and embracing transformative social innovation, Indonesia can accelerate its transition to sustainable energy development.

Social acceptance, stakeholder engagement and the local energy transition process: An empirically derived categorization of barriers, drivers and decision structures based on case studies in six European countries.

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Abstract

Municipalities play a crucial role in the transition from a 'conventional' to a low-carbon society. However, numerous challenges arise while trying to implement or adjust existing roadmaps to a sustainable energy transformation. This presentation portrays two currently running projects of municipalities in six European countries (PT, GR, FR, IT, NL, DE) and showcases the categorisation of barriers, drivers and decision structures perceived by municipal stakeholders.

The main results of the paper relate to the EU project, supported by the insights of the German project. In both projects, the perceived barriers and drivers were elicited through semi-structured interviews, conducted with relevant stakeholders of each municipality concerned. Interviewees were municipal stakeholders actively involved in reaching the projects goals through activities like participating in local municipality networks or conveying scenario modelling input into business models. The interviews were conducted by (video-)telephone, documented and then content analysed.

The analysis provided insights on how to cluster the given barriers and drivers. This classification will be presented for discussion. Multiple stages of barriers and drivers were identified, whereby social acceptance emerged as a higher-level factor. Both projects substantiate the need to view the identified aspects through the individual local lense by highlighting the perception of the relevant stakeholders. Based on concrete examples, the presentation will demonstrate if and how these barriers can be addressed and possibly be transformed into drivers, while keeping the perspective on deriving recommendations for replication. The studies thereby illustrate the importance of stakeholder engagement and social acceptance in the transition process.

Keywords: *learning municipality networks, low-carbon energy transition, social acceptance, stakeholder engagement*

The acceptance of 1.5-degree lifestyle options by citizens: individual and structural barriers and enablers

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Keywords: 1.5-Degree Lifestyles, Enablers and Barriers, Lifestyle Options

Abstract

The Paris Agreement defines the goal of not exceeding 1.5 °C global warming compared to pre-industrial levels. To make this objective more relevant to everyday lifestyles, it was expressed as per capita carbon footprints to be reached by 2030 (2.5 t CO_2e/cap/yr) and 2050 (0.7 t CO_2e/cap/yr) respectively (UNEP Emissions Gap Report, 2020), and the term "1.5-degree lifestyles" was conceptualised (IGES et al., 2019[1]). The EU 1.5° Lifestyles H2020 project aims to identify and explore everyday lifestyle options that citizens can implement in the form of behaviour-, but also technology-based changes in the main consumption domains of housing, mobility, nutrition and leisure in order to reduce their carbon footprint and reach 1.5-degree lifestyles.

This paper presents the methodology of identifying the lifestyle options and exploring barriers and enablers for adopting them with focus on Hungary, but comparing the outcomes to other countries (Germany, Latvia, Spain and Sweden). The barriers and enablers were explored through a mixed methodology of (1) interviews with citizens identified as pioneers of 1.5-degree lifestyles, (2) citizen thinking labs (CTLs), and (3) stakeholder thinking labs (STLs). As a result, most and least preferred options selected by a diverse group of citizens in the CTLs are presented, and individual as well as structural level barriers and enablers for low-carbon, 1.5-degree lifestyle are described.

The outcomes for Hungary are then compared to the other European countries, discussing similarities and differences. Finally, preliminary conclusions for policies supporting 1.5-degree lifestyles are presented, building also on the outcomes of STLs.

[1] Institute for Global Environmental Strategies (IGES), Aalto University, and D-mat ltd. 2019. 1.5-Degree Lifestyles: Targets and Options for Reducing Lifestyle Carbon Footprints. Technical Report. Institute for Global Environmental Strategies, Hayama, Japan.

Mapping energy citizenship in Europe: comparing aspects of energy citizenship in European regions

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Keywords: Energy Citizenship, Energy System Transformation, Mapping Energy Citizenship

Abstract

In order to transform the energy system into one that is just and within ecological limits, all stakeholders, among them citizens, need to be activated. The objective of the EnergyPROSPECTS H2020 project is to develop a comprehensive understanding of the conditions conducive to active energy citizenship. In order to do this, the consortium set the goal of mapping the diversity of energy citizenship (ENCI) in Europe, and created a database of 596 cases from the EU and its associated countries. To better capture diversity, the definition of ENCI adopted was intentionally broad, referring "to forms of civic involvement that pertain to the development of a more sustainable and democratic energy system. Beyond its manifest forms, ENCI also comprises various latent forms: it is an ideal that can be lived up to and realised to varying degrees, according to different framework conditions and states of empowerment." (Pel et al., 2021:64[1])

After describing the mapping methodology including the sampling strategy, standardisation processes and data validation, we present the first results of the data analysis. We provide details of ENCI relating to motivations, objectives, actors, funding sources, main types of cases as well as the level of citizen power/control apparent in the cases, the involvement of disadvantaged groups and equity/justice issues. We also examine these aspects in light of significant differences between European regions.

To conclude, we reflect on how our findings could inform policy making in order to better support ENCI in a context-sensitive way towards a more sustainable energy system.

[1] Pel, B., Debourdeau, A., Kemp, R., Dumitru, A., Schäfer, M., Vadovics, E., Fahy, F., Fransolet, A. Pellerin-Carlin, T. (2021) Conceptual framework energy citizenship. EnergyPROSPECTS Deliverable 2.1, European Commission Grant Agreement No. 101022492.

Exploring Household Acceptance of Rainwater and Recycled Greywater: Towards Sustainable Water Practices

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Keywords: water-usage, risk-perceptions, moral-obligation, self-efficacy

Abstract

Using multiple water sources, such as rainwater and recycled greywater, alongside freshwater can help protect freshwater resources. To investigate the impact of perceived water scarcity on people's willingness to reduce tap water consumption and increase the usage of rain and recycled greywater, we conducted an online survey with 2,623 participants in Belgium. The survey assessed participants' willingness to use three different water sources (tap water, rainwater, recycled greywater) for various household activities. The results showed that the acceptance of alternative water sources varied depending on the activity, with recycled greywater being more accepted for home cleaning and toilet flushing, while rainwater was preferred for cooking and showering. Sequential regression analysis was employed to examine the effects of risk appraisal, coping appraisal, moral obligation, and socio-demographic factors on the willingness to use each water source. The analysis revealed that self-efficacy, moral obligation, perceived future water scarcity, age, gender, and education significantly influenced the willingness to use recycled greywater. Perceived water scarcity, self-efficacy, and socio-demographic factors affected the willingness to use rainwater and greywater. However, the willingness to conserve tap water was primarily influenced by self-efficacy rather than risk appraisal. Overall, these findings highlight the potential of promoting alternative water sources, specifically recycled greywater, at the household level to alleviate pressure on freshwater distribution, given the importance of self-efficacy as a driving factor for intentions and behaviours.

The Energy Roadshow Portugal – promoting climate action

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Keywords: Energy, literacy, roadshow, communication, efficiency, behaviour

Abstract

The Energy Roadshow ("Rota da Energia" in Portuguese) is an initiative of ADENE the Portuguese Energy Agency aimed at improving energy literacy and promoting behaviour change and energy efficiency by acting closely with citizens.

This initiative encompasses dynamic information and training sessions tailor-made for different target audiences including students, municipalities, staff, companies, organisations and citizens. The Energy Roadshow disseminates knowledge about climate change, renewable energy, energy efficiency and more, empowering citizens as local agents who can contribute to the decarbonisation of economies by adopting sustainable behaviours.

In just over two years the Roadshow has already reached over 9000 students, 11000 citizens, 1000 company representatives and 750 staff of municipalities.

With this experience there were a lot of lessons learned, especially when it comes to the communication of energy efficiency. It is paramount to adopt a narrative that disassociates energy efficiency with sacrifice, but rather as a vehicle to a better life with more comfort and less costs.

I Will Travel by Train, if I Don't Have to

- Investigation of the Support for a Sustainable International Business Travel Policy among Academic Staff of Leiden University

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Keywords: transport mode, theory of planned behavior, international business travel, sustainable travel behavior

Abstract

Aviation is a large source of CO2 emissions and thus significantly contributing to the climate crisis (European Union Aviation Safety Agency, 2020). Moreover, a substantial amount of air travel is done for business purposes and thus reducing corporate travel can be an effective way to cut down aviation emissions (Transport & Environment, 2022). One group who travel regularly because of work are academics. Commissioned by the sustainability office of Leiden University, the present study investigates the willingness of academic staff members at Leiden University to support a change into a more sustainable travel policy. Additionally, we wanted to investigate psychological drivers behind (sustainable) travel behavior. To explore these issues, we conducted a survey study with a total of 175 participants (a sample of academic staff members at Leiden University). The preliminary results indicate that participants showed more support for a travel policy that recommends a sustainable travel option, than for a policy that makes sustainable travel mandatory. We will later analyze whether the psychological factors from the Theory of Planned Behavior (attitudes, social norms, and perceived behavioral control), as well as other factors such as academic position, concern for status, or past travel behavior influence people's travel intentions. The results provide insights into the behavioral drivers of international business travel behavior and can thus be informative for possible future intervention.

References

Airplane Pollution. Transport & Environment. (2022, June 2). https://www.transportenvironment.org/challenges/planes/airplane-pollution/#:~:text=Emissions%20from%20aviation%20are%20a,altitude%20at%20which%20aircraft%20operate.

Arrowsmith, S., S Lee, D., Owen, B., Faber, J., Boucher, O., Deransy, R., Celikel, A., Van Wijngaarden, L., Fuglestvedt, J., Laukia, J., Tronstad Lund, M., Sausen, R., Schaefer, M., Skowron, A., Stromatas, S., & Watt, A. (2020). *Report from the Commission to the European Parliament and the Council: Updated analysis of the non-CO2 climate impacts of aviation and potential policy measures pursuant to EU Emissions Trading System Directive Article 30(4)*. European Union Aviation Safety Agency, European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2020:277:FIN

Effective behavioural interventions for promoting sustainable delivery choices.

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Keywords: Field Study, Choice Behaviour, Online Stores Customers, Large-scale Interventions, Default

Abstract *The e-commerce sector aims to significantly reduce their CO_2-emissions by 2025 and is working on low-CO_2-emissions delivery solutions. One way to contribute to lowering CO_2-emissions is for online stores to encourage customers to choose sustainable delivery options more often. Accordingly, this large-scale field study investigated how to effectively promote sustainable delivery choices among online customers. By means of real-time A/B-testing, this study investigated the effect of 11 behavioural interventions at four leading online stores in The Netherlands (Blokker, Hunkemöller, Lobbes and Prénatal) among more than 35,000 customers. Interventions were composed of a selection of four behavioural techniques: associations, default option, informing, social proof. Interventions used either an individual technique (single) or a combination of two techniques (plural). All interventions were implemented on the check-out page, where customers choose from the available delivery options (home delivery, pick-up at collection point or in store). Interventions were tested on both mobile and desktop devices, accounting for a total of 88 interventions. Results showed that 35 interventions were effective in promoting sustainable delivery choices. In most of those cases it concerned a plural intervention. Most notably, a combination of two behavioural techniques led up to more than twice as many sustainable choices. In particular, pre-selecting the most sustainable delivery option (default) combined with a logo (associations) or text (informing or social proof) appeared most effective. Overall, these findings provide useful insights and tools for implementing interventions in online stores to promote sustainable delivery choices, thereby contributing to lower CO_2-emissions from the e-commerce sector.*

Effects of energy poverty support measures: Fixers/energy coaches, renovations, white good schemes

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Keywords: Inclusive energy transition, Energy poverty, Fixers/energy coaches, Renovations, White good schemes

Abstract

The number of households living in energy poverty increased with an estimated 90,000 between 2020 and 2022 in the Netherlands, to a total of about 600,000 (7.4% of the total number of households in the Netherlands). Many municipal budgets are used to deploy support measures such as fixers/energy coaches and white goods schemes. However, it is still unclear to what extent the living situation of households in the Netherlands improves due to such measures. The current research provides insight into the effects of three fixer/energy coaching trajectories, three renovation trajectories and two white goods schemes on various energy poverty-related aspects: living comfort, physical health, energy costs and consumption, financial concerns and mental health, involvement in the neighbourhood and sustainable behaviour. The study was conducted by means of a questionnaire among residents (N = 1224), comparing households that have participated in a support measure (intervention group; N = 688) with households that have not yet participated in this support measure (control group; N = 536). Results show that fixers/energy coaches, renovations and white goods schemes can have multiple positive effects on the living situation of households. However, the specific effect and the size of the effect varies by type of support measure, as well as by how a measure is implemented. With the findings, we provide government agencies with knowledge on how to support energy poor households better, organisations that implement such measures with advice to improve their support measures, and co-researchers with new knowledge and future research questions.

Flexible Energy Communities: Coupling E-mobility and Energy Communities

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Keywords: Energy Communities, E-Mobility, Collective Engagement, Group Dynamics

Abstract: *Energy communities allow citizens to collaboratively participate in a wide range of market activities related to energy. However, energy communities are generally restricted to the fixed local energy grid, restraining community activities to the street or neighbourhood level. This spatially limits energy communities' technical and social potential, partly because these groups may not be the type of groups which individuals mostly engage with.*

In the FlexECs (Flexible Energy Communities) project, we expand the scope of energy communities by integrating energy communities with electric mobility. Specifically, the project investigates whether energy communities can be formed outside the fixed local energy grid by using electric vehicles to transport electricity over longer distances. Apart from alleviating the technological restraints of current energy communities, such an approach could also enable the formation of energy communities around groups which individuals engage with relatively more.

In this presentation, we discuss which group characteristics and spatial characteristics may facilitate and promote individuals' engagement with energy communities and collective energy behaviours. From multiple studies, we have identified key variables, including group identification and interpersonal interactions, that explain one's willingness to participate in energy communities. Our findings highlight the relevant group processes that may be suitable for forming energy communities and support our reasoning that to engage individuals in energy communities it may be good to look beyond the fixed local energy grid.

Behaviour change towards nearly net-zero energy houses: a case study

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Keywords: Occupant behaviours, Energy efficiency, Decision-making tool, Residential houses, Nearly net-zero energy houses

Abstract

Energy conservation concerns have recently attracted the attention of government, industry, academia and many other agencies because of the climate challenge. Energy-efficient, -flexible, -productive buildings are seen as a promising pathway since the buildings accounted for 40% of Europe's energy demand in 2021.

This study aims to simulate and optimize energy efficiency for residents in typical Dutch residential houses with behaviour-changing suggestions including behaviour adjustments and investment behaviours so that existing houses could reach annual nearly net-zero energy houses.

Behaviour adjustments refer to those influence energy consumption directly or indirectly, such as controlling electrical appliances or changing occupancy patterns. And investment behaviours are defined as those residents actively proceeding with economic investment to improve energy efficiency or reduce residence energy consumption, such as installing solar panels and replacing appliances with energy-efficient ones. Investment behaviours are more likely to have a long-term positive effect on energy.

A case study will be conducted in a semi-detached house in the Netherlands to test the effectiveness of this tool. Using the data from the house for simulation and optimization in DsignBuilder, we will understand the relationship between occupant behaviours and energy consumption. Ultimately, residents will be provided with behaviour-changing suggestions. Exploring how to transit existing houses into nearly net-zero energy ones, and making them replicable would be very meaningful to energy or climate issues.

Climate education and behaviour change through gamification

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Keywords: behaviour change, gamified learning platform, serious gaming, community activation, engagement, social tipping points.

Abstract
Although many people are concerned about climate change, real change is not happening. If we can activate the collective with a sustainable mindset, then we are able to accelerate the transition. To do this, we need to understand the power of social networks, and use it to reach a social tipping point. When 10% of a population grabs hold of an idea, progress is slow. But when more people get on board, the social tipping point is 25%, change accelerates explosively and becomes common knowledge and habit within a few years (research by Demon Centola, 2019). With The 2B Collective we have a gamified learning platform for sustainable behavioural change and we have experienced how social networks learn and are activated for more sustainable behaviour. It would be very inspiring to showcase the behavioural change program of an energy company, where 1500 employees participated in the 6 week Sustainable Living Challenge. Or one of the neighbourhood initiatives in the Netherlands, where more than 250 households were engaged for 6 weeks on energy reduction. Our platform provides measurable results such as knowledge levels, behaviour, environmental impacts, attitude effects, opinion insights, sense of participation and appreciation.

The choice of occupation as environmentally relevant behaviour by the example of the German 'climate crafts'

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Keywords: environmentally relevant behaviour, climate crafts, pro-environmental communication, green jobs

Abstract

In its Sixth Assessment Report, the IPCC highlighted behaviour and lifestyle change as important levers in climate action. Yet, research and policymaking have long focused on behaviour and decision-making in the private sphere as consumers and – to a lesser extent – in the political sphere as citizens or activists while the professional sphere of work remains largely unrecognised. This bias becomes increasingly problematic as the shortage of skilled workers already constitutes a bottleneck for climate action. Consequently, the choice of training and occupation is becoming more environmentally relevant. Therefore, German politicians and craft organisations are increasingly calling on the pro-environmental youth to take up an occupation in a 'climate craft' and plan image campaigns to counteract the shortage of skilled workers. However, since the scientific understanding of work-related decisions in the context of climate change is limited, these campaigns risk falling short of their expectations. In this study, we explore the questions in how far the pro-environmental young people understand gainful employment as environmentally relevant behaviour, how they view training and employment in the crafts sector, what factors impede them from entering the crafts sector, and what communication strategies might be effective in increasing the inclination to take up an occupation in a 'climate craft'. Based on our findings, we seek to provide scientific insights for designing more effective governance interventions such as communication campaigns to address an essential bottleneck for climate action.

Determinants of the inclination of craft entrepreneurs in the 'climate crafts' in Berlin and Brandenburg to engage in energy transition services

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Keywords: skilled crafts and trades, small enterprises, implementation, energy transition, climate crafts

Abstract

The shortage of workers in the skilled crafts and trades increasingly becomes a bottleneck for the energy transition in several industrialised countries because energy transition services (TS) such as the installation of heat pumps, photovoltaic, or insulation require skilled workers. Due to a declining workforce and increasing orders, enterprises in the skilled trades have full order books – also for activities unrelated to the energy transition. Because the decision-making power in these enterprises is often restricted to the owner-managers, these entrepreneurs can decide how to prioritise orders rendering them powerful gatekeepers in climate action. While seminal reports have highlighted the importance of people, their actions, and agency to bring about climate action in different roles, behaviour and decision-making at work remain understudied in the context of climate change. Based on an original online survey among craft entrepreneurs in the trades of roofers, electricians, painters, and heating installers in Berlin and Brandenburg, this study takes first steps in closing this gap. It asks the main research question 'What factors determine the inclination of craft entrepreneurs to provide TS?' and the following sub-questions: What factors determine the prioritisation of orders? How do entrepreneurs perceive TS? How are their enterprises currently positioned for providing TS? How do entrepreneurs perceive climate action and their role in that?
The study seeks to provide scientific insights for designing more effective policies that account for the agency of the implementers of climate action.

When do social norm nudges go amiss? A systematized review of isolated effects in recent behavioural experiments in building energy use

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Keywords: Social norms, Meta-analysis, Energy use behaviours, Buildings

Abstract: *Social norms, a powerful tool in behaviour change, have gained much popularity as a cost-effective strategy for curtailing energy consumption in buildings. However, the individual effect size of social norms interventions has yet to be explored, as existing reviews usually incorporate effect sizes from multi-arm treatments. This systematized review of 47 experiments from 40 journal articles published since 2010 summarizes common forms of the interventions and provides a robust estimate of the overall practical significance of social norms in changing the behaviours of building occupants. It also cautions practitioners by inspecting explanations for the often-reported null or boomerang effects. Publication bias is addressed with robust Bayesian meta-analysis. The risk of bias assessment suggests some concerns in most evidence. The investigation reveals three conclusions. First, most studies employed social norms in residential energy use feedback with peer comparison, while studies using social norms as antecedent strategies mostly adopted written information to explicitly express social norms instead of contextually implied ones. Second, the independent impact of social norms has a small effect size, with very high heterogeneity across study contexts. Third, the lack of effectiveness of these social norm interventions for building energy use relates to the complexity in psychological mechanisms, the limitations in intervention design, and the insufficiency in using norms alone. Policymakers and researchers should comprehensively study the context of the targeted energy before designing interventions, especially the existing norms among occupants, and there is great potential in applying social norms in non-residential buildings.*

Would you like to show your heat pump? Choice experiment on preference for visibility of household energy efficiency purchase decisions

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Keywords: Household energy efficiency, Visibility of energy, Status signal, Conspicuous conservation

Abstract

Much of a household's decisions regarding energy use, such as appliance choice, washing, and cleaning behaviour is not publicly visible. This lack of visibility may hinder processes such as social contagion or status signalling that encourage the uptake of energy efficiency and prosumer behaviour. Although studies have found that energy efficiency devices are status signals, it is not clear whether users of these energy efficiency devices prefer to make their device more visible. Especially because there are contrasting tendencies to avoid attention or avoid association with environmentalists. To disentangle these factors, we conducted a choice experiment to identify how the visibility or conspicuousness of an energy efficiency device affects purchase decisions. In an online survey of 402 respondents, we asked respondents to choose between different options of heat pumps and solar panels that varied in six attributes, one of which was visibility. The resulting data shows that visibility negatively affects the willingness to pay for a heat pump, but has no statistically significant effect for solar panel choice. This implies that people have grown familiar with the visual presence of solar panels, while not with that of heat pumps. Further, it is found that the more environmentally effective a heat pump is, the less people want it to be visible. These results imply that visual familiarity could help in acceptance and adoption of energy efficiency devices and that further studies need to be conducted to find out in what contexts people would be willing to show their energy efficiency devices.

Effectiveness of window signalling systems in open-plan workplaces: evidence from field work

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Keywords: Window, Feedback, Behaviour, Satisfaction, Indoor climate, Energy efficiency

Abstract

Occupants are often unaware of window-opening strategies that can enhance their well-being and reduce energy consumption. Window feedback systems that indicate when to manually operate a window have become a strategy for enhancing the indoor climate, occupant's satisfaction and energy efficiency. These systems are recognized for providing the comfort benefits of manual window controls while providing the efficiency benefits of completely automated windows (Bordass et al., 2007; Day et al., 2020). However, there is a lack of evidence to what extent window feedback systems are able to guide occupants towards an effective window operation for both energy and comfort.

This research proposes a new window feedback system based on indoor air quality, thermal quality and energy performance. Results from a preliminary testing and deployment are also presented to investigate the effectiveness of the light window feedback system. The outcome of the research shows that ambient light window feedback systems can improve the indoor environment and occupant's satisfaction in open-plan workplaces. Objective measurements reveal an improved indoor temperature, relative humidity and CO_2 concentration. Furthermore, it shows a reduced ineffective window opening time by 55%. Subjective measurements reveal that a majority of the respondents understand the system, do act according to the provided feedback and were satisfied with the implementation. The outcome of this research provides also design requirements for the further development of the light window feedback system and its algorithm.

Shaping the energy and heat transition: insights from a transdisciplinary research project

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Keywords: energy transition, local heating networks, transformative research, stakeholder involvement

Abstract *The building sector faces the challenge of becoming largely climate-neutral by the middle of the century. This will require far-reaching changes and novel solutions, particularly in existing buildings, where comprehensive insulation is often impossible. Local heating networks represent one such solution. These networks allow integrating different decentralized heating sources and storage facilities. However, thus far, communities, building owners, and energy suppliers have hardly implemented this solution. This transdisciplinary project brings together relevant actors from politics, administration, industry, and civil society to identify ways of implementing decentralized heating sources in an exemplary community in Germany. As part of this project, a survey of citizens (N = 918) was conducted via a local Citizen Panel. It built on the Stage Model of Self-Regulated Behavioural Change (Bamberg, 2012), a psychological theory that can be used to explain adoption of technologies and related behaviours. Results show that many citizens would like to switch to renewable energies, but do not know how, or doubt it would be possible for them. Surveyed building owners (n = 544) also show great interest in connecting to a local heating network. Additionally performed dialog and participation formats allowed analysing incentives and constraints as well as preferences and concerns of relevant actors based on the Delta Analysis (Bizer & Führ, 2015). In a next step, the project will utilize the findings to initiate strategic communication and solution-oriented interaction between these stakeholders. The contribution illustrates how transdisciplinary research utilizing psychological theory and methods can help foster the energy and heat transition.*

Biospheric group values salience, strength and pro-environmental actions: when perceived biospheric group values become more influential

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Keywords: Salience, Strength, Biospheric group values, Pro-environmental actions

Abstract

Previous research suggested that not only biospheric personal values, perceived biospheric group values also predict individuals' pro-environmental actions. Yet, individuals seem to underestimate the extent to which others endorse biospheric values, imposing negative effects on perceived biospheric group values and pro-environmental actions. In the current study we hypothesized that by making biospheric group values salient and even strengthening them, individuals' perceived biospheric group values will grow stronger and become more influential on individuals' pro-environmental actions. Our study among 300 U.S. citizens, who depending on the condition answered questions about either their personal values, perceived group values and pro-environmental actions, found consistent support for our hypotheses. Our findings have important scientific and societal implications on reducing barriers to environmental behavioural change and promoting pro-environmental actions through groups. They suggest that by communicating the group people care about endorsing strong biospheric values, people's perceived biospheric group values can be strengthened and therefore predict pro-environmental actions more.

FULL PAPERS

WON'T YOU BE MY NEIGHBOR? LEVERAGING THE NEIGHBOR EFFECT FOR COMMUNITY ENERGY AND CLIMATE RESILIENCE

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a) Energy communities

Abstract

Relationships with peers or neighbors can influence individual or collective behavior in mitigating or responding to risks. As California faces climate-related impacts such as increasingly destructive wildfires, severe weather patterns including storms, heat events, and extended droughts, the state is encouraging pilot projects that aim to decarbonize and improve energy resilience at the local scale. Several California programs focus on lower-income or marginalized communities that face disproportionate risk and may have less access to clean, reliable power solutions. One promising approach is a community-managed clean energy system with shared power and other resources that can bolster resilience through both the physical infrastructure of a flexible, 'islandable' microgrid but also as an organized community of neighbors able to understand, plan for, and respond to collective and individual risks and needs. We refer to this neighbor-to-neighbor approach of sharing information and encouraging action as the 'neighbor effect.' The neighbor effect includes a community's collective understanding of assets and risks, and the related ability to create positive behavioral change among residents to improve resilience through improved energy and water efficiency, reduction or balancing of resource consumption, and response to potential long- and short-term threats. This research uses the example case of the Oakland EcoBlock, a clean energy pilot project in a mixed income, urban community in California, to illustrate the potential resilience value of the scalable neighbor effect. While this work focuses on the experience of California, the local scale design can be adapted to other contexts as part of a decarbonization and resilience strategy.

1. INTRODUCTION

Rising global temperatures, altered and erratic precipitation patterns, and droughts are leading to longer dry seasons and increased fire risk, with related health and environmental costs (Ellis et al., 2021; MacCarthy et al., 2023). In California, while wildfires are part of the natural ecosystem processes, fire seasons are becoming longer and more severe (Abatzoglou et al., 2020; Abatzoglou et al., 2021; Modaresi Rad et al., 2023). Wildfires are most prevalent in areas with lower household incomes and home values, and higher proportions of older residents, Native American populations, and undocumented immigrants (Masri et al., 2021; Méndez et al., 2020). For example, euring California's 2017 Thomas Fire, already vulnerable populations were disproportionately exposed to harmful impacts due to work outdoors without protective equipment, less prepared due to lack of English language skills, access to internet services, and transportation, and not adequately included in disaster preparedness and recovery planning (Méndez et al. 2020). Marginalized communities are less able to relocate permanently or temporarily, and emergency response agencies may lack transportation or shelters to support them (Wong et al., 2020a; Wong et al., 2020b).

As a preventative measure during heat or extreme weather events, or when the grid lacks service capacity, California's three largest investor-owned utilities (IOUs) initiate planned Public Safety Power Shutoffs (PSPSs) (Murillo, 2020; Wong-Parodi, 2022). Power disruptions affect interconnected infrastructure, including food and water, health and social services, and communication and transportation networks, with severe consequences for residents who rely on power for medical services, have conditions that put them at risk when heating, air conditioning, or air purifying systems fail, or have mobility issues that impede evacuation. Identifying needs and assets of a neighborhood—residents with health or other risk factors, those lacking cars or cell phones or with limited English, as well as those able to render aid—can be crucial to survival (Coughlan et al., 2019; Edgeley et al., 2020; Méndez et al., 2020).

1.1. Energy efficiency and wildfire linkages

Energy efficiency in California is intrinsically linked to wildfire vulnerability. Many of the most destructive recent wildfires have been sparked by aging electrical infrastructure as the outdated systems are susceptible to faults, sparking fires that can rapidly spread and devastate communities. PSPSs, while often necessary to prevent fires, can disproportionately impact vulnerable populations that rely on electricity for essential services and lack resources to mitigate the impacts (Abatzoglou et al., 2020; Wong-Parodi, 2022). Impacts of deadly fires and the findings from the California Fourth Climate Change Assessment underscore the potential consequences of failure to reduce greenhouse gas emissions (Goss et al., 2020; Westerling, 2018). Energy efficiency is crucial for environmental sustainability but also for mitigating the risk of fires that may trigger cascading events such as land degradation, landslides, or flooding.

1.3. Leveraging the neighbor effect

California is currently exploring decentralized community-based clean energy microgrids able to connect to the main grid and 'island' during emergencies to improve resilience during wildfires, severe storms, or PSPSs, or other events (Hwang et al., 2023; Moreno et al., 2022; Perera et al., 2023; Yang et al., 2022). There is to date limited research on the social benefit of an energy community in leveraging local-scale knowledge, common goals, and shared resources to mitigate risk. This research examines this *neighbor effect* as part of a resilience strategy with particular benefit in under-resourced or disadvantaged communities.

We define the 'neighbor effect' to include a community's collective understanding of assets and risks, and its related ability to encourage positive behavioral change to increase energy and water efficiency, reduce or balance consumption, and respond to short or long-term threats. 'Community' can refer to the group of stakeholders who are decision-makers, a defined physical location or space, and/or a group of individuals with shared interests or common vision (Kim, 2017). This paper presents an example case of an innovative *energy community*, the Oakland EcoBlock, to highlight how the neighbor effect can foster positive environmental behaviors, enhance energy conservation, manage risk, and improve resilience.

2. METHODOLOGY

The Electric Program Investment Charge (EPIC), created in 2012 under the California Energy Commission (CEC), aims to promote renewable energy, strengthen electricity infrastructure, advance electric tech, decentralize the grid, enhance community well-being, and support local businesses (CEC, n.d.). Phase I feasibility studies for 12 advanced energy community projects were funded in 2016, with emphasis on designs that could be implemented in disadvantaged to enhance energy resilience, reduce carbon emissions, and be financially sustainable.

We conducted a literature review that examined Phase I final reports and other materials and open-ended interviews with project team members and CEC staff. We chose to present an example case of the Oakland EcoBlock pilot, located in a diverse urban community of Northern California and now in the initial stages of Phase II construction, to illustrate how an energy community's design leverage the neighbor effect to enhance resilience.

3. COMMUNITY MICROGRIDS: A COLLECTIVE RESILIENCE STRATEGY

California is exploring decentralized clean energy microgrids as one solution to the aging and increasingly unreliable centralized power grid (Ajaz & Bernell, 2021b; Guliasi, 2021). A microgrid is "a group of interconnected loads and distributed energy resources" with potential for "improving power reliability and quality, increasing system energy efficiency, and providing the possibility of grid-independence to individual end-user sites" (Ton & Smith, 2012). Capacity can be augmented by feeding energy to the main grid, but the microgrid can detach allowing a community to maintain services in an emergency (Chen et al., 2020; Rickerson et al., 2022; Wang et al., 2020). As approximately 90% of power outages occur at the distribution level, with transmission lines often traversing great distances, local delivery can improve resilience and be a 'cleaner' solution than diesel generators by connecting to clean energy sources (Perera et al., 2023; Silverstein et al., 2018). A solar-plus-storage system can provide flexible back-up power with increased delivery efficiency by minimizing energy losses that occur during transmission over longer distances (Hussain et al., 2019; Hwang et al., 2023).

3.1. 'Neighbor effect' in a microgrid community: promoting peer resilience

Relationships with a community and social capital networks can encourage behaviors that mitigate risk and improve resilience (LaLone, 2012; Spialek & Houston 2019; Wolters, 2023; Wong-Parodi & Garfin, 2022). Microgrid communities with shared resources and common interests promote resilience through the technical infrastructure but also as neighbors who can assess, plan for, and respond to collective and individual risks and needs.

A study of the role of homeowners' associations in wildfire mitigation identified information sharing, raising awareness, and providing access to resources as significant, and that barriers to individual action could be reduced through an association taking on tasks for which individuals might not have capacity (Steffey et al., 2020). By disseminating crucial information, associations can raise awareness about risks, provide access to resources, and enhance understanding of a household's or neighborhood's vulnerability (Agrawal et al., 2022). Collective actions, such as neighbors collaborating across property boundaries, can be beneficial in addressing wildfire risk (Charnley et al., 2020; Meldrum et al., 2021). A study of mitigation outreach programs in six U.S. communities found that "cooperative neighbors" was one of the most frequently mentioned factors when community members were asked about pathways to success in mitigating wildfire (Stidham et al., 2014).

4. THE NEIGHBOR EFFECT: THE ECOBLOCK CASE STUDY

The example case of the Oakland EcoBlock illustrates the potential resilience value of explicitly including the neighbor effect in the design of a community clean energy project . The pilot, led by researchers at the University of California, Berkeley, aims to develop an affordable urban decarbonization prototype by retrofitting a neighborhood block, replacing natural gas with electricity and implementing a shared solar-powered microgrid (Barr et al., 2019). Objectives include reducing carbon emissions rapidly and equitably, enhancing resilience during power outages, and fostering community engagement among residents on the block leading to eventual self-management and ownership of the system.

4.1. Project scale: Finding the 'sweet spot'

EcoBlock tests the hypothesis that retrofitting at the block level is more efficient and cost-effective than in individual households to meet energy efficiency, water conservation, and wastewater treatment goals as power flows, efficiencies, and cost-benefits are spread across multiple units, systems, and finances. The project explores the optimal community size for maximizing the neighbor effect, hypothesizing that 20-40 households balances efficiency and complexity--more effective than individual decarbonization and efficiency yet more nimble than city-wide initiatives that increase technical, financial, and social complexity. Sharing energy loads at the block scale reduces the need for storage capacity (Ostfeld et al., 2018).

Resilience is enhanced through affordable retrofits, including insulation and efficient appliances; water improvements, such as installation of more efficient fixtures and reuse of water, filtration and purification of collected rainwater; transportation improvements through shared EV and access to vehicle charging stations; and a solar-generated microgrid able to connect to or operate independently from the main grid. By coupling efficiency improvements and electrification with community solar energy generation, this integrated approach aims to provide benefits such as reduced water consumption, reduced carbon emissions from vehicles and homes, and improved indoor air quality (Ostfeld et al., 2018; Barr et al., 2019).

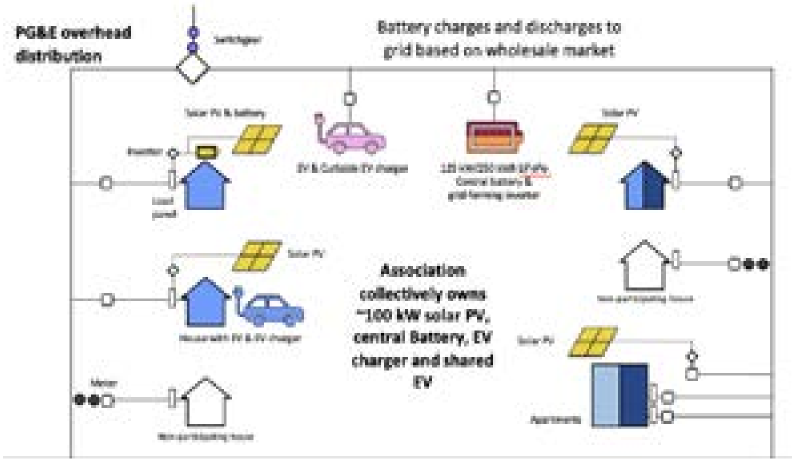

Fig. 1. EcoBlock design. Source: Therese Peffer

4.2. Phase II: Identifying a block and beginning implementation

After completing a Phase I feasibility study and securing EPIC Phase II funding, the project team identified a suitable block for construction through a competitive selection process that included criteria such as the community's vulnerability, pollution risk, and grid location. Blocks were required to demonstrate neighborhood support for participation. Other factors included the demonstrated presence of a well-connected community with shared values related to decarbonization and efficiency, willingness to take on management responsibilities, and committed community leaders (EcoBlock, 2022).

Physical factors were also considered, including the number of homes, mix of single- and multi-family dwellings, roof space for solar installation, presence of a commercial unit, and the block's geographic situation. California Public Utility (CPU) Code Section 218(b) restricts power distribution to buildings on separate electrical lines, meaning that projects serving multiple customers that cross public 'rights of way' must form energy corporations and are classified as public utilities, making them subject to complex and expensive regulations. EcoBlock—the selected block—is situated at the end of a the cul-de-sac, meaning microgrid users could be adjacent without crossing a public right-of-way (von Meier & Kammen, 2021).

4.3. Local risk factors and existing conditions in Oakland

Communities with lower incomes or predominantly minority populations are disproportionately exposed to air and water pollution, including refineries, crowded highways, and areas with hazardous waste (Banzhaf et al., 2019; Caubel et al., 2019; Fowlie et al., 2020). Risks in the City of Oakland relevant to the block include increased potential soil lead contamination, and higher air pollution levels (Caubel et. al, 2019; Fowlie et. al, 2020). Climate change risks include power failures, rising temperatures, urban heat island effect, smoke incursions, air pollution from nearby freeways, high utility expenses, altered rainfall and drought patterns, and sea level rise, with impacts expected to intensify (Gonzalez et al., 2011). Rising sea levels cause saltwater to infiltrate beneath the soil, raising the groundwater table, leading to flooding, infrastructure disruptions, and the mobilization of hazardous materials in toxic sites. A recent study showed that that over the next century, rising groundwater in the San Francisco Bay Area could threaten twice as much land area as coastal flooding alone, putting over 5,200 contaminated sites at risk, and disproportionately affecting low-income and communities of color (Hirschfeld et al., 2023).

EcoBlock is diverse in race, culture, age, and household demographics, with multiple first languages. About a third own their property while the rest rent, and more than 74% of residents in the census district live below twice the poverty level (CalEnviroScreen[1] 4.0, 2021). Homes on average date to 1934, with many built in the early 1900s, featuring poor insulation, leaks, and outdated appliances and fixtures. Respondents to a survey identified housing problems: cold or hot rooms, drafts, odors, hot water (long waits or inadequate supply), leaks, condensation, dust, and respiratory problems, and frequent outages (BondGraham, 2022).

4.4. Community engagement: leveraging the neighbor effect

A community engagement liaison, with deep ties in the community, was hired to aid in building trust between the project team and residents. The initial plan for community engagement and communication included in-person meetings, design charrettes, surveys and data collection, including profiles of energy and building use. Block preferences guided communication methods and frequency with translation provided in Spanish and Chinese. Several outdoor, in-person meetings, featuring music and refreshments, fostered connections with residents. As a pilot project involves uncertainty, developing mutual trust and transparency needed to be an integral part of the design process.

4.5. Community engagement: Neighbors as a trusted source of information

Communities, such as those with undocumented populations, may be apprehensive about providing household energy data or *in an emergency, seeking refuge in places like police stations (Kolden & Henson, 2019; Wong et al., 2020a; Wong et al., 2020b).* Households *may be apprehensive about adopting unfamiliar technologies, such as induction stove tops or heat pump space conditioning.* EcoBlock disseminated *educational materials, articles and blogs, videos, a public website with a private resident-only page, and monthly newsletter to share information on technical and other aspects of the project* but also to *foster community. The adoption of new technologies such as solar power systems—or environmental behaviors--often spreads in clusters, as individuals are influenced by neighbors (Graziano & Gillingham, 2015; Leonhardt et al., 2022; Noll et al., 2014). Leveraging this neighbor effect can encourage acceptance of a new approach to energy management and resilience.* One EcoBlock member commented: "[T]*he EcoBlock project appeals to [EcoBlock resident] as an innovative way for everyday people to take initiative to fight climate change and reduce fossil fuel dependence. [EcoBlock member] has been working hard to help form the BSA and keep lines of communication open between the EcoBlock professionals and residents. He is excited to see the solar panel installations and home upgrades take place to make [EcoBlock's] Street more comfortable and efficient."*

4.6. Community perspectives: EcoBlock surveys and behavior-based

Understanding household decision-making is crucial for improving the adoption of energy-efficient upgrades, especially where income constraints can limit access to improvements. Two surveys collected data on factors driving energy-efficient technology adoption and operational behavior among block residents (Langevin et al., 2023). The first examined factors influencing choices regarding energy-related home improvements. While residents generally favored efficient home improvements, cost and the lack of need for replacements were major implementation barriers. Efficient lighting was viewed the most positively and widely adopted

[1]California Communities Environmental Health Screening Tool. https://oehha.ca.gov/calenviroscreen

due to perceived affordability. Residents are open to heat pumps but need more information, while induction ranges and smart thermostats were viewed less favorably but can benefit from targeted education. Envelope improvements like insulation and efficient windows face barriers due to perceived costs. Survey responses highlights that cost, equipment functionality, safety, and comfort are key factors driving residents' decisions on energy upgrades. To boost adoption of energy-efficient improvements, strategies should focus on cost reduction, incentives, comfort, and safety benefits. For rental units, landlords should be engaged as decision-makers, emphasizing the attractiveness of energy-efficient upgrades to potential tenants.

The operational behavioral survey evaluated residents' energy usage and. Satisfaction with lighting was high, but temperature satisfaction was lower (Langevin et al., 2023). Block residents primarily make operational changes to enhance comfort and reduce energy costs. Smart thermostats can contribute to both comfort and energy efficiency. Energy-intensive appliances are most frequently used during the morning and evening hours, meaning an opportunity for load management, although residents may be hesitant to adjust their daily routines (Langevin et al., 2023).

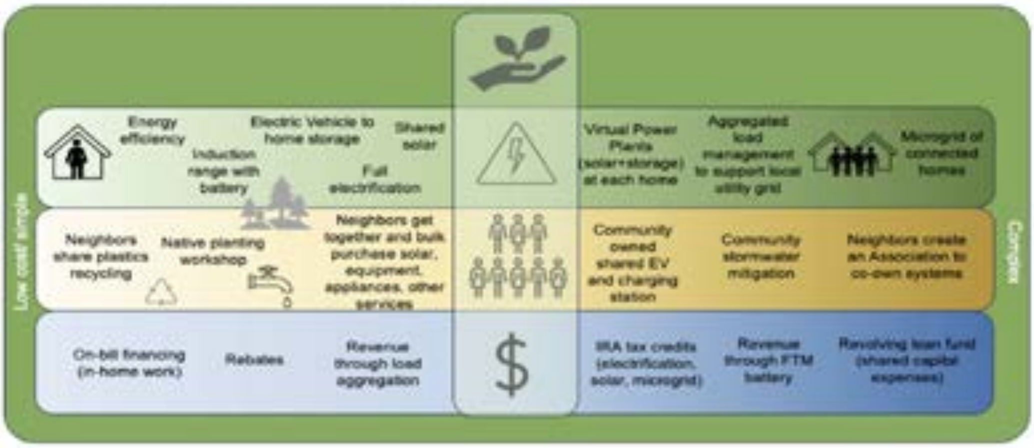

Figure 2. Design of the EcoBlock Framework. Credit: Therese Peffer

4.8. Community building: EcoBlock's laundry-to-landscape system for water efficiency

Hands-on activities can both create conservation and efficiency but build community social equity. As one replicable example, a group of block residents joined together to build a neighborhood greywater diversion system. Greywater (lightly used household water from showers, bathroom sinks and washing machines, excluding toilets, kitchen sinks, and dishwashers) can be repurposed for watering plants, conserving drinking water, reducing utility expenses, and alleviating the strain on wastewater treatment facilities. The laundry-to-landscape system, which complies with California's Plumbing Code (Ch. 15), allows the use of greywater for landscape irrigation without a permit (CBSC, 2016), and was an inexpensive, easy-to-build project for neighbors to accomplish together in a few hours.

5. DISCUSSION: FUTURE ENERGY COMMUNITIES AND ECOBLOCKS

Organizations such as the Neighborhood Empowerment Network (NEN) offer programs to assist neighborhoods in organizing themselves to improve resilience (NEN, 2021). Identifying disadvantaged populations can be accomplished by assessing income levels, pollution exposure, or through the Social Vulnerability Index mapping project, which combines data on flood risk, income, pollution, and other factors to pinpoint the most vulnerable neighborhoods (Raval et al., 2019). Sustainable neighborhoods can serve as hubs for equitable resilience as they have both social networks and physical proximity, allowing neighbors to support each other during emergencies (USDN, 2021).

Developing a self-managed energy project is challenging as there is no precedent for this type of ownership structure that diverges significantly from a centralized system. While community self-management can enhance energy, it also carries risks due to regulatory complexity and uncertain financial impacts. This highlights the importance of providing support to build capacity in the transition away from a centrally managed system (Edgeley et al., 2020). As a recent step toward community management, a non-profit common interest development association (CID) was established to enable shared asset ownership. EcoBlock emphasizes that the aim of community control is an ongoing and iterative process, as capacity is developed for the envisioned model (Aczel & Peffer, 2023).

The business model for this first EcoBlock includes the community of homeowners forming a governance vehicle to own and maintain the microgrid generation and storage assets, paying from association fees collected based on energy used. The utility will own and maintain the microgrid distribution lines. The next EcoBlock might use a variety of structures to finance the in-home improvements individually and collectively finance the operational costs of the shared microgrid assets.

6. CONCLUSIONS

As a changing climate and movement of populations increases wildfire and other risk factors, there is a need to make vulnerable communities more resilient. EcoBlock is a promising local energy model that aims to reduce carbon emissions while promoting community building and resilience. This project targets existing urban residential neighborhoods, encompassing both single-family and multi-family homes with strategies that include 1) retrofitting existing homes and small businesses for efficiency, 2) capitalizing on the economies of scale in block-level retrofits, 3) transitioning from fossil-fueled appliances, equipment, and vehicles to electric alternatives, and 4) combining energy efficiency upgrades with a renewable energy microgrid (solar power and battery storage). The EcoBlock model offers resilience through cost-effective retrofits, water efficiency improvements, access to electric mobility resources, and a microgrid that can operate independently. In the pilot business and governance model, homeowners have formed an association to own and maintain microgrid generation and storage assets, with progress toward self-governance ongoing. Future EcoBlocks could develop a different structure. Community and leveraging the neighbor effect is at the center of the EcoBlock model. The Oakland EcoBlock project is an innovative example of a community microgrid with the community as stakeholders in resource ownership, that aims to address needs of the local community, and unites the community around a shared vision of community cohesion, enhanced resilience, and affordable electrification and emissions reductions.

REFERENCES

Abatzoglou, J.T., Battisti, D.S., Williams, A.P., Hansen, W.D., Harvey, B.J., & Kolden, C.A. (2021). Projected increases in western US forest fire despite growing fuel constraints. *Commun Earth Environ*, *2*, 227. doi: 10.1038/s43247-021-00299-0

Abatzoglou, J.T., Smith, C.M., Swain, D.L., Ptak, T., & Kolden, C.A. (2020). Population exposure to pre-emptive de-energization aimed at averting wildfires in Northern California. *Environ Res Lett*, *15*(9), 094046. doi: 10.1088/1748-9326/aba135

Agrawal, S., Ambury, H., Parida, D., & Joshi, N. (2022). Understanding risk communication in practice: Insights from municipalities in Alberta, Canada. *Int J Disaster Risk Reduct 79*, 103175. doi: 10.1016/j.ijdrr.2022.103175

Ajaz, W., & Bernell, D. (2021a). Microgrids and the transition toward decentralized energy systems in the United States: A multi-level perspective. *Energy Policy*, *149*, 112094. doi: 10.1016/j.enpol.2020.112094

Ajaz, W., &Bernell, D. (2021b). California's adoption of microgrids: A tale of symbiotic regimes and energy transitions. *Renew Sustain Energy Rev*, *138*, 110568. doi: 10.1016/j.rser.2020.110568

Banzhaf, S., Ma, L., & Timmins, C. (2019). Environmental justice: The economics of race, place, and pollution. *Journal of Economic Perspectives*, *33*(1), 185-208. doi: 10.1257/jep.33.1.185

Barr, Z., Bourassa, N., Bowie, J. Brown, R., DeCuir, N., Diamond, H.J.,...Traber, A. (2019). Accelerating the deployment of advanced energy communities: The Oakland EcoBlock. CEC. CEC-500-2019-043. https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-043.pdf

BondGraham, D. (2022). Power out across Oakland following high winds. *The Oaklandside*. https://oaklandside.org/2022/01/22/power-out-across-oakland-following-high-winds/

Caubel, J.J., Cados, T.E., Prevle, C.V., & Kirchstetter, T.W. (2019). Distributed network of 100 black carbon sensors for 100 days of air quality monitoring in West Oakland, California, *Environ Sci Technol* doi: 10.1021/acs.est.9b00282.

CEC. (2020). Electric Program Investment Charge 2020 Annual Report. CEC-500-2021-029. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2021-029.pdf

Charnley, S., Kelly, E.C., & Fischer, A.P. (2020). Fostering collective action to reduce wildfire risk across property boundaries in the American West. *Environ Res Lett*, *15*(2), 025007. doi: 10.1088/1748-9326/ab639a

Chen, B., Wang, J., Lu, X., Chen, C., & Zhao, S. (2020). Networked microgrids for grid resilience, robustness, and efficiency: A review. *IEEE Transactions on Smart Grid*, *12*(1), 18-32. doi: 10.1109/TSG.2020.3010570

Coughlan, M.R., Ellison, A., & Cavanaugh, A. H. (2019). Social vulnerability and wildfire in the wildland-urban interface: Literature synthesis. https://scholarsbank.uoregon.edu/xmlui/handle/1794/25359

EcoBlock. (2022). Oakland EcoBlock residents officially join community association. Retrieved September 15, 2023, from https://ecoblock.berkeley.edu/2022/06/oakland-ecoblock-residents-officially-join-community-association/

Edgeley, C.M., Paveglio, T.B., & Williams, D.R. (2020). Support for regulatory and voluntary approaches to wildfire adaptation among unincorporated wildland-urban interface communities. *Land Use Policy*, *91*, 104394. doi: 10.1016/j.landusepol.2019.104394

Ellis, T.M., Bowman, D.M., Jain, P., Flannigan, M.D., & Williamson, G. J. (2022). Global increase in wildfire risk due to climate-driven declines in fuel moisture. *Glob Chang Biol*, *28*(4), 1544-1559. doi: 10.1111/gcb.1600

Fowlie, M., Walker, R., & Wooley, D. (2020). Climate policy, environmental justice, and local air pollution. Brookings Institute. https://www.brookings.edu/wp-content/uploads/2020/10/ES-10.14.20-Fowlie-Walker-Wooley.pdf

Gonzalez, P.A., Minkler, M., Garcia, A.P., Gordon, M., Garzón, C., Palaniappan, M.,...Beveridge, B. (2011). Community-based participatory research and policy advocacy to reduce diesel exposure in West Oakland, California. *Am J Public Health*, *101*(S1), S166-S175. doi: 10.2105/AJPH.2010.196204

Goss, M., Swain, D.L., Abatzoglou, J.T., Sarhadi, A., Kolden, C.A., Williams, A.P., & Diffenbaugh, N.S. (2020). Climate change is increasing the likelihood of extreme autumn wildfire conditions across California. *Environ Res Lett*, *15*(9), 094016. doi: 10.1088/1748-9326/ab83a7

Graziano, M., & Gillingham, K. (2015). Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment. *J.Econ Geogr*, *15*(4), 815-839. doi: 10.1093/jeg/lbu036

Guliasi, L. (2021). Toward a political economy of public safety power shutoff: Politics, ideology, and the limits of regulatory choice in California. *Energy Res Soc Sci, 71*, 101842. doi: 10.1016/j.erss.2020.101842

Guirguis, K., Gershunov, A., Hatchett, B., Shulgina, T., DeFlorio, M. J., Subramanian, A. C., ... & Ralph, F. M. (2023). Winter wet–dry weather patterns driving atmospheric rivers and Santa Ana winds provide evidence for increasing wildfire hazard in California. *Clim Dyn*, *60*(5-6), 1729-1749. doi: 10.1007/s00382-022-06361-7

Hirsch, A., Parag, Y., & Guerrero, J. (2018). Microgrids: A review of technologies, key drivers, and outstanding issues. *Renewable and Sustainable Energy Reviews*, 90, 402-411. doi: 10.1016/j.rser.2018.03.04

Hirschfeld, D., Lindquist, C.S., Cook, F., & Warner, S. (2023). Rising coastal groundwater as a result of sea-level rise will influence contaminated coastal sites and underground infrastructure. *Authorea Preprints*.

Hussain, A., Bui, V.H., & Kim, H.M. (2019). Microgrids as a resilience resource and strategies used by microgrids for enhancing resilience. *Applied Energy*, *240*, 56-72. doi: 10.1016/j.apenergy.2019.02.055

Hwang, H., Vedlitz, A., & Bixler, R.P. (2023). Growing community resilience from the grassroots: Risk awareness, confidence in institutions, and civic participation in a natural hazards context. *Nat Hazards Rev*, *24*(3), 04023020. doi: 10.1061/NHREFO.NHENG-165

Kim, H. (2017). A community energy transition model for urban areas: The Energy Self-Reliant Village Program in Seoul, South Korea. *Sustainability*, *9*, 1260. doi:10.3390/su9071260

Kolden, C.A., & Henson, C. (2019). A socio-ecological approach to mitigating wildfire vulnerability in the wildland urban interface: A case study from the 2017 Thomas fire. *Fire*, *2*(1), 9. doi: 10.3390/fire2010009

LaLone, M.B. (2012). Neighbors helping neighbors: An examination of the social capital mobilization process for community resilience to environmental disasters. *J Appl Soc Sci*, *6*(2), 209-237. doi: 10.1177/1936724412458483

Langevin, J., Putra, H.C., Zhang, J., & Peffer, T. (2023). Behavior-based energy efficiency: A case study of the Oakland EcoBlock Final Project Report. *UC Berkeley: California Institute for Energy and Environment (CIEE)*. https://escholarship.org/uc/item/63k9r489

Leonhardt, R., Noble, B., Poelzer, G., Fitzpatrick, P., Belcher, K., & Holdmann, G. (2022). Advancing local energy transitions: A global review of government instruments supporting community energy. *Energy Res Soc Sci , 83*, 102350. doi: 10.1016/j.erss.2021.102350

Masri, S., Scaduto, E., Jin, Y., & Wu, J. (2021). Disproportionate impacts of wildfires among elderly and low-income communities in California from 2000–2020. *Int J.Environ Res Public Health*, *18*(8), 3921. doi: 10.3390/ijerph18083921

McCarthy, F., Bright, S., & Fawcett, T. (2018). Building Governance and Energy Efficiency: Mapping the Interdisciplinary Challenge. In C. Foulds & R. Robison (Eds.), *Advancing Energy Policy Lessons on the Integration of Social Sciences and Humanities*. Palgrave Pivot Springer Nature.

Meldrum, J.R., Brenkert-Smith, H., Champ, P.A., Gomez, J., Byerly, H., Falk, L., & Barth, C.M. (2021). Would you like to know more? The effect of personalized wildfire risk information and social comparisons on information-seeking behavior in the wildland–urban interface. *Natural Hazards, 106*(3), 2139-2161. https://par.nsf.gov/servlets/purl/10228695

Méndez, M., Flores-Haro, G., & Zucker, L. (2020). The (in) visible victims of disaster: Understanding the vulnerability of undocumented Latino/a and indigenous immigrants. *Geoforum*, *116*, 50-62. doi: 10.1016/j.geoforum.2020.07.007

Modaresi Rad, A., Abatzoglou, J.T., Kreitler, J., Alizadeh, M.R., AghaKouchak, A., Hudyma, N.,...Sadegh, M. (2023). Human and infrastructure exposure to large wildfires in the United States. *Nature Sustainability*, 1-9. doi: 10.1038/s41893-023-01163-z

Moreno, R., Trakas, D. N., Jamieson, M., Panteli, M., Mancarella, P., Strbac, G.,...Hatziargyriou, N. (2022). Microgrids against wildfires: Distributed energy resources enhance system resilience. *IEEE Power and Energy Magazine*, *20*(1), 78-89. doi:10.1109/MPE.2021.3122772

Murillo, R.I. (2020). A (Dangerous) new normal-public safety power shutoffs (PSPS): A look into California utility de-energization authority and the potential for its abuse. *Santa Clara Law Review*, *61*(2), 653. https://digitalcommons.law.scu.edu/lawreview/vol61/iss2/6

Noll, D., Dawes, C., & Rai, V. (2014). Solar community organizations and active peer effects in the adoption of residential PV. *Energy Policy*, *67*, 330-343. doi: 10.1016/j.enpol.2013.12.050

O'Sullivan, T.L., Corneil, W., Kuziemsky, C.E., & Toal-Sullivan, D. (2015). Use of the structured interview matrix to enhance community resilience through collaboration and inclusive engagement. *Syst Res Behav Sci*, *32*(6), 616-628. doi: 10.1002/sres.2250

Perera, A.T.D., Zhao, B., Wang, Z., Soga, K., & Hong, T. (2023). Optimal design of microgrids to improve wildfire resilience for vulnerable communities at the wildland-urban interface. *Applied Energy*, *335*, 120744. doi: 10.1016/j.apenergy.2023.120744

Piltch-Loeb, R., Bernard, D., Quinones, B., Harriman, N., & Savoia, E. (2020). Engaging community leaders to identify community assets for emergency preparedness. to leverage communication and trusted assets for vulnerable populations. *Disaster Med Public Health Prep*, *16*(4), 1452-1458. doi:10.1017/dmp.2021.103

Raval, A., Chen, T., & Shah, P. (2019). *Mapping Resilience: A Blueprint for Thriving in the Face of Climate Disasters*. https://apen4ej.org/wp-content/uploads/2019/10/APEN-Mapping_Resilience-Report.pdf

Rickerson, W., Zitelman, K., & Jones, K. (2022). Valuing resilience for microgrids: Challenges, innovative approaches, and state needs. NASEO & NARUC Microgrids State Working Group. https://www.naseo.org/data/sites/1/documents/publications/NARUC_Resilience_for_Microgrids_INTERACTIVE_021122.pdf

Savelli, I., & Morstyn, T. (2021). Better together: Harnessing social relationships in smart energy communities. *Energy Research & Social Science*, *78*, 102125. doi: 10.1016/j.erss.2021.102125

Silverstein, A., Gramlich, R., & Goggin, M. (2018). A customer-focused framework for electric system resilience. https://www.preventionweb.net/quick/47078.

Spialek, M.L., & Houston, J.B. (2019). The influence of citizen disaster communication on perceptions of neighborhood belonging and community resilience. *J Appl Commun Res, 47*(1), 1-23. doi: 10.1080/00909882.2018.1544718

Steffey, E., Budruk, M., & Vogt, C. (2020). The mitigated neighborhood: Exploring homeowner associations' role in resident wildfire-mitigation actions. *Journal of Forestry*, *118*(6), 613-624. doi: 10.1093/jofore/fvaa019 https://academic.oup.com/jof/article/118/6/613/5831013

Stidham, M., McCaffrey, S., Toman, E., & Shindler, B. (2014). Policy tools to encourage community-level defensible space in the United States: A tale of six communities. *Journal of Rural Studies*, *35*, 59-69. doi: 10.1016/j.jrurstud.2014.04.006

Ton, D.T., & Smith, M.A. (2012). The U.S. Department of Energy's Microgrid Initiative. *The Electricity Journal*, *25*(8), 84-94. doi: 10.1016/j.tej.2012.09.01
USDN. (2021). Resilience Hubs. Retrieved Sept. 15, 2023, from https://www.usdn.org/resilience-hubs.html

von Meier, A., and Kammen, D.M. (2021). *White Paper: The EcoBlock Project and the "own use" exemption under Public Utilities Codes Section 218 – A way forward for privately operated microgrids [white paper]*. UC Berkeley: California Institute for Energy and Environment (CIEE). https://escholarship.org/uc/item/1s88n8c6

Wang, Y., Rousis, A. O., & Strbac, G. (2020). On microgrids and resilience: A comprehensive review on modeling and operational strategies. *Renew Sustainable Energ Rev*, *134*, 110313. doi: 10.1016/j.rser.2020.110313

Westerling, A.L. (2018). Wildfire simulations for California's Fourth Climate Change Assessment: Projecting changes in extreme wildfire events with a warming climate: a Report for California's Fourth Climate Change Assessment (p. 57). Sacramento, CA: CEC. Publication Number: CCCA4-CEC-2018- 014.

Wolters, E.A. (2023). Homeowner firewise behaviors in fire-prone central Oregon: an exploration of the attitudinal, situational, and cultural worldviews impacting pre-fire mitigation actions. *Journal of Environmental Management*, *327*, 116811. doi: 10.1016/j.jenvman.2022.116811

Wong, S.D., Broader, J.C., & Shaheen, S. A. (2020a). Review of California wildfire evacuations from 2017 to 2019. *UC Office of the President: UC Institute of Transportation Studies*. doi: 10.7922/G29G5K2R

Wong, S.D., Broader, J.C., & Shaheen, S. A. (2020b). Can sharing economy platforms increase social equity for vulnerable populations in disaster response and relief? A case study of the 2017 and 2018 California wildfires. *Transport Res Interdisciplinary Perspectives*, *5*, 100131. doi: 10.1016/j.trip.2020.100131

Wong-Parodi, G. (2022). Support for public safety power shutoffs in California: Wildfire-related perceived exposure and negative outcomes, prior and current health, risk appraisal and worry. *Energy Res Soc Sci*, *88*, 102495. doi: 10.1016/j.erss.2022.102495

Wong-Parodi, G., & Garfin, D.R. (2022). Priming close social contact protective behaviors enhances protective social norms perceptions, protection views, and self-protective behaviors during disasters. *Int J Disaster Risk Reduct, 80*, 103135. doi: 10.1016/j.ijdrr.2022.103135

Yang, W., Sparrow, S.N., Ashtine, M., Wallom, D.C., & Morstyn, T. (2022). Resilient by design: Preventing wildfires and blackouts with microgrids. *Applied Energy*, *313*, 118793. doi: 10.1016/j.apenergy.2022.118793

Developing an Uncertainty-Inclusive Decision Framework for Homeowners Energy-Efficient Investment Decisions

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Abstract

Despite the widespread consensus regarding the substantial benefits of energy efficiency, homeowners remain dubious about implementing energy retrofit measures, primarily driven by various perceived risks and uncertainties. This paper introduces an innovative framework for private homeowners to decide on energy renovation measures. It comprehensively addresses the two primary types of uncertainties encountered in each stage: aleatory uncertainties (arising from inherent variability and randomness) and epistemic uncertainties (stemming from knowledge gaps). We custom-tailored a conceptual framework based on the three first stages (Knowledge, persuasion, and decision) of the well-established diffusion of innovation model offered by Rogers for the context of energy-efficiency retrofit. Knowledge is the first stage, in which homeowners start to think about energy efficiency retrofit. Persuasion is the second stage, in which homeowners form an attitude (favorable or not) towards the energy retrofit decision. In the third stage, homeowners decide to adopt energy-efficient investments based on the information gathered, cost-benefit analysis, available financing, and personal preferences. To delve deeper into the complexity of the process, we break down the initial two stages, knowledge and persuasion, into subsections. Within the knowledge stage, we have identified two essential subsections: Awareness and Information Gathering, as well as Energy Audit and Assessment. Moving on to the persuasion stage, we further divide it into two subsections: "Cost-Benefit Analysis" and Policy intervention exploration. By elaborating on these stages and their associated uncertainties, this study presents valuable insights for policymakers and homeowners seeking energy-efficient retrofits and highlights potential avenues for future research.

1. INTRODUCTION

Despite the widespread consensus regarding the substantial benefits of energy efficiency, homeowners remain dubious about implementing energy retrofit measures, primarily driven by various perceived risks and uncertainties. According to the Neoclassical perspective on investment, the investment decision is considered "now or never". In contrast, the irreversible perspective enables investors to postpone their decisions until uncertainties are resolved (Walker et al. 2014). If uncertainties are left unresolved, they have the potential to defer investments indefinitely (Jones et al. 2002). As such, it becomes crucial to recognize and resolve these uncertainties in every investment decision-making stage.

According to the latest definition provided by Gabrielli et al. (2023), uncertainty refers to the uncertain information utilized in constructing a forecasting model. It emerges due to insufficient knowledge or imperfect information regarding a specific phenomenon, situation, condition, or data (Gabrielli et al. 2023). To put it differently, uncertainty emerges when our understanding of the source system falls short of absolute certainty, resulting in variations in different parts of the model, known as uncertainty sources (Walker et al. 2014).

This study aims to provide a holistic perspective on homeowners' energy-efficient investment decisions and the uncertainties they encounter through every single stage. By developing an innovative uncertainty-inclusive decision framework, this research aims to bridge the existing gaps in the literature and contribute to a better understanding of decision-making processes in this context.

In line with this, Section 2 will be dedicated to the taxonomy of uncertainty. Subsequently, Section 3 will propose the Uncertainty-Inclusive Decision Framework by elaborating on the different stages and the relevant extracted uncertainties in each stage. Moving forward, Section 4 will provide a concise overview of the achieved results, and finally, in Section 5, the conclusions of the current study will be presented, providing valuable insights into potential avenues for further research.

2. UNCERTAINTY TAXONOMY

The categorization of different uncertainty types is of utmost importance for making well-informed decisions, managing risks, and achieving successful outcomes in diverse domains, including energy-efficient investment decisions (Gabrielli and Ruggeri 2019) as different uncertainties need to be distinguished and treated differently based on their entity and level of ignorance about the future (Gabrielli et al. 2023).

According to the uncertainty categorization of Baustert et al. (2017), uncertainty can manifest in various forms, such as aleatory, characterized by variability and inherent randomness, or epistemic, arising from a lack of knowledge. Additionally, mixed uncertainties combine both aleatory and epistemic elements. Francis et al. (2018) further discerned between epistemic uncertainties that may be diminished through enhanced knowledge and aleatoric uncertainties that persist due to the intrinsic stochasticity of a phenomenon. Booth et al. (2013) also divided uncertainties into two categories: the second-order ("epistemic") uncertainty due to a lack of information and uncertainties associated with model accuracy (i.e. model "ignorance"). They applied an integrated approach involving probabilistic sensitivity analysis and Bayesian calibration, for quantifying the "epistemic" uncertainty. Moreover, a Monte Carlo simulation was employed to quantify the aleatory (first-order) uncertainties.

3. Uncertainty-Inclusive Decision Framework

Various researchers have proposed diverse stages within the decision-making process for the diffusion of innovation. Rogers et al. (2003), a pioneering scholar in this field, outlined five stages to conceptualize the adoption process: (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation. According to his framework, decision-makers go through these stages, starting from initial awareness of an innovation to forming attitudes, making adoption decisions, implementing the idea, and eventually confirming their choice (Rogers et al. 2003). Baginski and Weber (2017) also introduced a distinct set of stages in the decision-making process of German owner-occupiers, including: "understanding the needs," "information searching," "pre-evaluating," "finalizing the decision," "implementing," and "post-evaluating".

We have custom-tailored the first three stages of Rogers' (2003) model specifically for the context of energy-efficiency retrofit. To delve deeper into the complexity of the decision-making process, we break down the initial two stages, knowledge and persuasion, into subsections. Within the knowledge stage, we have identified two important subsections: Awareness and Information Gathering, as well as Energy Audit and Assessment. Moving on to the persuasion stage, we further divide it into two subsections: Cost-Benefit Analysis and Financing and Incentives. By conducting this breakdown, our primary aim lies in offering a more detailed understanding of each stage and its respective components, enabling a more thorough exploration of the energy-efficiency retrofit process along with the inherent uncertainties of each stage, as depicted in Figure 1**.**

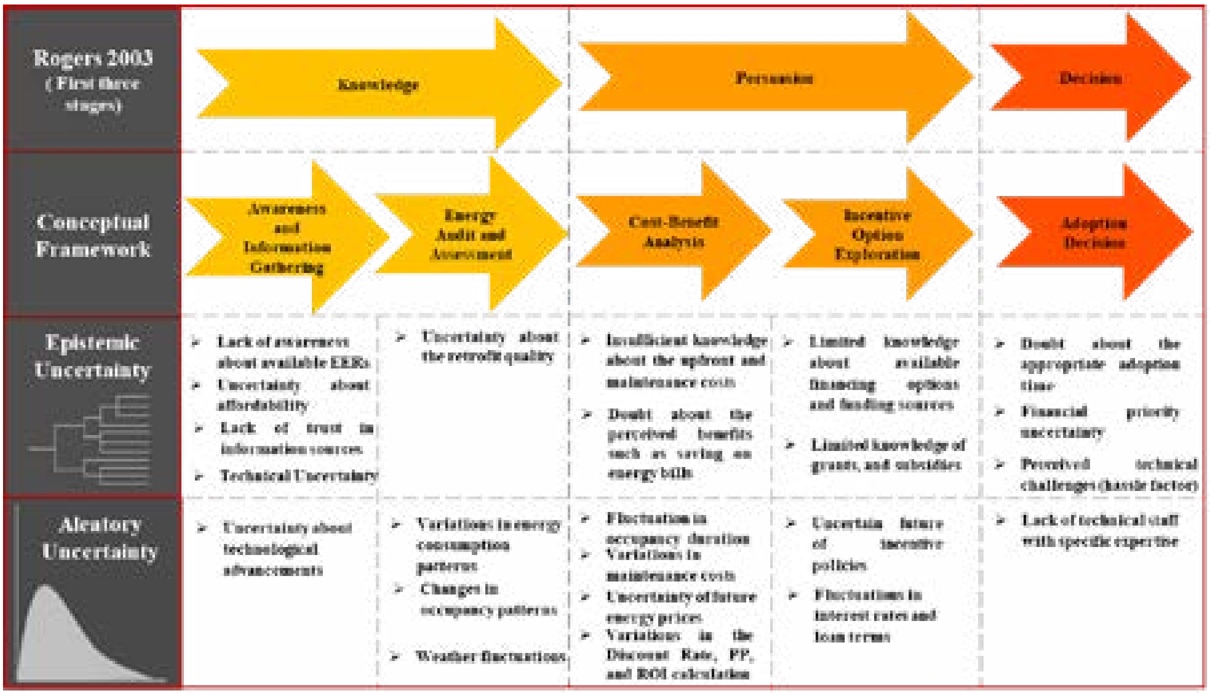

Fig.1. Decision-making stages and associated uncertainties

3.1. Knowledge Stage

Knowledge is the first stage, in which homeowners start to think about energy efficiency retrofit. Lack of knowledge is recognized as “deep uncertainty” according to Lempert (2003). We divided it into two parts as follows:

3.1.1.Awareness and Information Gathering

Initially, homeowners become aware of the potential benefits of energy efficiency and gather information about available technologies, incentives, and energy-saving measures. This step involves learning about energy-efficient measures, understanding their benefits, and exploring the potential cost savings.

The lack of awareness about different EERs and the potential benefits (e.g., energy savings, comfort) brought by such technologies (Banfi et al., 2008; Du et al. 2014; Broers et al., 2019) are primary sources of uncertainties. What is more, environmental awareness, specified as climate knowledge, is found to lead homeowners to perceive environmental and climate protection as a driving factor in undertaking energy renovation (Rocha et al., 2016; Azizi et al. 2019). Given the various benefits mentioned here, energy renovation seems to be essentially a sensible decision.

During information gathering, homeowners also evaluate the credibility and reliability of the sources. If they fail to trust the information provided or the parties involved (such as energy advisors, energy service companies, government agencies, etc.), it may lead to hesitation or reluctance in making the final investment decision (Gonzalez-Caceres et al. 2020; Ebrahimigharehbaghi et al. 2022a).

Moreover, they might be unsure about the required budget and their ability to afford the costs associated with such investments, comfortably referred to as "financial viability ambiguity" (Broers et al. 2019). Rai et al. (2015) also recognized the perception of affordability as the most significant hurdle to adoption.

Another epistemic uncertainty in this stage is technical uncertainty arising from the lack of complete knowledge or understanding of how the technology will perform in real-world conditions, its long-term durability, and maintenance requirements (Jones et al. 2002; Bakaloglou and Belaïd 2022).

The only recognized aleatory uncertainty in this stage is the unpredictability of technological development, referring to the uncertain rate at which new and groundbreaking technologies will come into the market (Rysanek and Choudhary 2013; Chen et al. 2018; Zheng et al. 2019).

3.1.2. Energy Audit and Performance Assessment

In the second energy stage, homeowners need to conduct an energy audit or performance assessment of their homes to identify inefficient areas and determine potential energy-saving opportunities (Hosseinian et al. 2017) by hiring professionals (face-to-face energy audit) or using online tools (Broers et al. 2019). This process can also be affected by different uncertainties that need to be quantified during the financial assessment of energy retrofits (Bozorgi 2015; Frei et al. 2021). The presence of unresolved uncertainties can result in a disparity between the actual performance of the building and its expected value.

In the energy audit process, monitoring all the energy-consuming devices and equipment is not practical or feasible. Selecting a smaller number of devices as a representative may not perfectly reflect the energy usage of all the devices, leading to sampling uncertainty (Bakaloglou and Belaïd 2022). Errors in the baseline models used to estimate energy savings (i.e. modeling uncertainty) during the audit, along with inaccurate measurement of uncertainty stemming from the precision of the monitoring instruments, can also contribute to discrepancies between actual and projected energy savings (Grillone et al. 2020). On the other hand, the stochastic nature of occupant behavior (Rocha et al. 2016),(Gabrielli and Ruggeri 2019),(Bakaloglou and Belaïd 2022),(Silva and Ghisi 2014), variations in occupancy patterns (Silva and Ghisi 2014; Gabrielli and Ruggeri 2019; Hu and Xiao 2020) and weather fluctuations (Jia et al. 2021),(Chen et al. 2023),(Rocha et al. 2016),(Gabrielli et al. 2023) can influence the energy performance assessment.

3.2. Persuasion Stage

Persuasion is the second stage, in which homeowners form an attitude (favorable or not) towards the energy retrofit decision. This stage comprises “cost-benefit analysis” and “Policy intervention exploration”.

3.2.1.Financial Cost-Benefit Analysis

In the third stage, homeowners conduct a financial cost-benefit analysis to assess if energy savings, environmental benefits, and comfort improvements outweigh the initial investment costs. The three commonly used investment decision criteria for this analysis are Net Present Value (NPV), Payback Period (PP), and Internal Rate of Return (IRR), with NPV being the most established technique to maximize return on investment (Jones et al. 2002).

This stage is also subject to a myriad of uncertainties that hold a greater significance than technical uncertainty, as evidenced by the research of Bakaloglou et al. (2022) and Alberini et al. (2013). Belaïd et al. (2021) identified future energy price unpredictability and discount rate ambiguity as the primary sources of uncertainty in cost-benefit analysis. Failing to precise estimation of cash flows will lead to additional uncertainty about the perceived benefits such as saving on energy bills (Ebrahimigharehbaghi et al. 2022b),(Menassa 2011),(Broers et al. 2019),(Booth and Choudhary 2013),(Jones et al. 2002; Ebrahimigharehbaghi et al. 2022b).

For the calculation of NPV under uncertainty, previous studies suggested various ways to address this issue. The most typical ways are modifying the discount rate or using the NPV at-risk method. Nevertheless, simultaneous utilization of both approaches can result in overestimating the investment's risk and potential returns (Menassa 2011).

Although uncertainty about energy prices has received the greatest attention in the literature, it is probably not the greatest source of uncertainty for potential adopters (Greene 2011). Alberini et al. (2013) explored the importance of uncertainty about future energy prices in making EER decisions using the Discrete Choice Experiment (DCE). They revealed that the respondents with the highest level of uncertainty about future prices are more inclined to stick with their current choices, placing more emphasis on immediate costs. In contrast, respondents who anticipated substantial increases in energy prices were more receptive to adopting energy-efficient retrofits. Payback is also an uncertain parameter and varies for each agent over time as it is affected by changes in prices and rebates (Robinson and Rai 2015). Uncertainty about remaining time living in the house can also be considered another aleatory uncertainty to investing in the EER (Broers et al. 2019).

3.2.2. Incentive options exploration

Following a cost-benefit analysis, homeowners investigate various incentive options in the form of grants, rebates, tax exemptions, and Feed-in Tariff (FiT) schemes to support their energy-efficient investments. Homeowners might lack complete knowledge regarding the eligibility criteria, bureaucratic procedure, or potential benefits associated with specific incentive programs. Moreover, they might not be aware of all the available incentives or the most suitable ones for their particular energy-efficient renovation project. Consequently, the "Lack of knowledge about various incentive programs" acts as a significant epistemic uncertainty, deterring homeowners from initiating the renovation process (Gonzalez-Caceres et al. 2020).

The uncertain future of incentive policies, such as the likelihood of getting grants/loans, may decrease investor enthusiasm for the development of renewable energy (Rovers 2014; Ebrahimigharehbaghi et al. 2022b). To address these uncertainties, Zhang et al. (2019a) suggested some measures such as increasing the subsidy and promoting technical progress by the government.

In spite of being eligible for various financial incentives, homeowners may be uncertain about whether the incentives will continue to be available in the future. Hence, the longevity and persistence of financial incentives would be another uncertainty source for homeowners (Bakaloglou and Belaïd 2022). As a specific example, FiT rates can vary over time due to changes in energy policies and market conditions, leading to aleatory uncertainty for investors (Alderete Peralta et al. 2022),(Wing 2015). Therefore, homeowners must undertake a meticulous evaluation of the potential risks and rewards linked to these policy changes to make an informed decision.

3.2.3. Forming an opinion

After thoroughly exploring various incentive options available for energy-efficient renovations, the information gathered is combined with the results derived from the cost-benefit analysis. The integration of these two crucial components shapes the opinion of homeowners.

3.3. Adoption decision

Finally, based on different decision criteria and the formed opinion in the previous stage, homeowners make a decision on whether to adopt energy-efficient investments or not. The investor can wait to let the passage of time clarify some matters that are uncertain at present (Walker et al. 2014). Therefore, despite a positive initial NPV and the availability of certain incentives for the retrofit project, there might be additional value in postponing the investment until some of the uncertainty is resolved.

It has been found that there is a significant gap between what people say (their opinion) and what they do, described as knowledge-action gaps, attitude-action gaps, and/or intention-action gaps (Newton and Meyer 2013; Frederiks et al. 2015; Moglia et al. 2017). To put it differently, intentions do not always lead to actual EER adoption behavior. However, studies indicate that this gap tends to decrease as the overall awareness and acceptance of energy-efficient retrofits increases.

On the other hand, homeowners may actually be willing to invest in more energy-efficient solutions rather than in the least-cost solution by considering other subjective criteria, such as the environmental impact and comfort improvements (Bragolusi and D'Alpaos 2022). Therefore, they encounter perception uncertainty arising from the difficulty of accurate prediction and quantification of these non-monetary benefits.

Moreover, homeowners may hesitate to invest in energy-efficient renovations due to the presence of other financially attractive options (e.g., installing elevators in old buildings and expanding underground parking), giving rise to "financial priority uncertainty" (Broers et al. 2019; Lai et al. 2022).

The time lag between upfront investment costs and potential returns creates a source of uncertainty at this stage. Postponing the investment allows homeowners to gather further information, gaining clarity on uncertainties during evaluation to reduce the risk associated with the investment (Gabrielli et al. 2023). As stated by Jones et al. (Jones et al. 2002), the greater the uncertainty surrounding the investment's return, the more advantageous it is to delay the investment decision.

Eventually, homeowners may have concerns about the inconvenience caused by the ongoing construction work for a relatively long period (Ma et al. 2022). In this regard, the "perceived hassle factor" introduced by de Vries et al (2020)arises from transaction costs would be a kind of epistemic uncertainty. Lack of technical staff with specific expertise (Menassa 2011) can also be recognized as only aleatory uncertainty at this stage.

4. Results and future research directions

This section expounds on research findings and outlines potential avenues for future exploration. In this paper, we have custom-tailored the first three stages of Rogers' model (Rogers et al. 2003) specifically for the context of energy-efficiency retrofit. Furthermore, we provided in-depth descriptions of various uncertainties, with the final extracted uncertainties presented in Table 1.

Once a decision is made, homeowners proceed with the implementation of the selected energy-efficient measures. Additionally, they possess the ability to exert influence on others in their social network, fostering further energy-saving initiatives based on their experiences. For instance, the energy gap between estimated and actual savings can create doubts and uncertainties in the post-adoption stages. These subsequent stages following adoption and the uncertainties involved present opportunities for further investigation in future research endeavors.

Table1. Extracted different uncertainties for each decision stagey

	Epistemic uncertainty	Aleatory uncertainty
Awareness and Information Gathering	• Lack of awareness about available energy-efficient measures (Banfi et al. 2008; Du et al. 2014; Broers et al. 2019) • Uncertainty about the required money and affordability (Ebrahimigharehbaghi et al. 2022b) • Lack of trust in information sources (Ebrahimigharehbaghi et al. 2019; Gonzalez-Caceres et al. 2020) • Technical uncertainty (Jones et al. 2002; Bakaloglou and Belaïd 2022)	• Uncertainty about technological advancements (Broers et al. 2019; Zheng et al. 2019)
Energy Audit and Assessment	• Uncertainty about the retrofit quality (Bakaloglou and Belaïd 2022)	• Variations in energy consumption patterns due to the stochastic nature of occupant behavior (Rocha et al. 2016; Gabrielli and Ruggeri 2019; Bakaloglou and Belaïd 2022) and changes in occupancy patterns (Silva and Ghisi 2014; Gabrielli and Ruggeri 2019; Hu and Xiao 2020) and weather fluctuations (Rocha et al. 2016; Jia et al. 2021; Chen et al. 2023)

Cost-Benefit Analysis	• Insufficient knowledge about the costs associated with the adoption of energy-efficient measures (Grillone et al. 2020; Jia et al. 2021; Carpino et al. 2022; Ebrahimigharehbaghi et al. 2022b) • Doubt about the perceived benefits such as saving on energy bills (Menassa 2011),(Broers et al. 2019),(Booth and Choudhary 2013),(Jones et al. 2002; Ebrahimigharehbaghi et al. 2022b)	• Fluctuations in occupancy duration (Ebrahimigharehbaghi et al. 2022b),(Rocha et al. 2016) • Uncertainty about future energy/CO2 prices (Booth and Choudhary 2013), (Zhang et al. 2019b),(Chen et al. 2023),(Chaudry et al. 2015),(Rocha et al. 2016),(Bakaloglou and Belaïd 2022),(Zhang et al. 2019a) • Variations in maintenance costs (Booth and Choudhary 2013),(Menassa 2011; Jareemit et al. 2022) • Ambiguity in the discount rate (Zheng et al. 2019),(Bakaloglou and Belaïd 2022) • Variations in payback periods (Ebrahimigharehbaghi et al. 2022b),(Gabrielli et al. 2023), and return on investment calculations (Gabrielli et al. 2023),(Jones et al. 2002),(Bakaloglou and Belaïd 2022),(Ebrahimigharehbaghi et al. 2022b)
Incentive Exploration	• Limited knowledge about available financing options and funding sources (Ebrahimigharehbaghi et al. 2022b), • Limited knowledge of grants, and subsidies(Bakaloglou and Belaïd 2022),(Jia et al. 2021)	• Uncertain future of incentive policies (Zhang et al. 2019a; Chen et al. 2023),(Ebrahimigharehbaghi et al. 2022b) • Fluctuations in interest rates and loan terms (Hill)
Adoption Decision	• Doubt about the appropriate adoption time (Gabrielli et al. 2023) • Financial priority uncertainty (Broers et al. 2019; Lai et al. 2022) • Perceived technical challenges (hassle factor) (Ma et al. 2022)	• Lack of technical staff with specific expertise (Menassa 2011)

5.Conclusion

Despite the widespread consensus regarding the substantial benefits of energy efficiency, homeowners remain dubious about implementing energy retrofit measures, primarily driven by various perceived risks and uncertainties. This paper introduced an innovative framework for private homeowners to make decisions regarding energy renovation measures.

By elaborating on different renovation decision stages and their associated uncertainties, we presented valuable insights for policymakers and homeowners seeking energy-efficient retrofits, followed by highlighting potential avenues for future research.

While efforts were made to maintain consistency, the applied methodology to extract uncertainties from different papers may introduce some level of subjectivity in the categorization process. Some uncertainties may fall into multiple categories, making it difficult to assign them to a single category. Moreover, different authors define and interpret uncertainties in slightly different ways, leading to variations in how uncertainties are identified and categorized.

The current framework's applicability can be further enriched by quantifying the diverse uncertainties associated with energy efficiency. Utilizing quantitative methods, such as Monte Carlo simulations, to model various scenarios and sensitivity analysis to comprehend the influence of each uncertainty factor on investment outcomes can offer valuable insights into the probabilistic nature of uncertainties.

Furthermore, qualitative methodologies, including case studies, expert interviews, and behavioral experiments, can enhance comprehension of the energy-efficient investment decision process. Integrating behavioral economics or psychological perspectives into the uncertainty analysis may offer a better understanding of how uncertainty perception and cognitive biases influence homeowners' choices. Exploring the interaction of multiple uncertainties and their combined effects on investment decisions can also be addressed in future studies. Additionally, in forthcoming research, we will focus on exploring the interaction between tenants and housing associations, investigating the adoption process within this specific group, and scrutinizing the uncertainties that arise throughout this process.

Additionally, it is possible to integrate pertinent empirical research related to "on-bill" financial programs for energy efficiency in future investigations, thus providing a solid empirical foundation for the proposed framework. Furthermore, future studies can delve into behavioral anomalies and their influence on decisions concerning energy usage, encompassing aspects such as bounded rationality, heuristics, procrastination and social norms.

Last but not least, while our paper primarily centers on homeowners, the framework offers a foundation that can be adapted to suit the needs of tenants and housing association groups. We formulated this framework with the underlying assumption that homeowners possess the requisite knowledge, resources, and skills to carry out a comprehensive Cost-Benefit Analysis (CBA) independently. However, in practice, homeowners may not necessarily be able to undertake a thorough CBA on their own. Subsequent research can explore alternative methodologies, such as cost-revenue analysis, and assess their feasibility and appropriateness for homeowners.

References

Alberini A, Banfi S, Ramseier C (2013) Energy Efficiency Investments in the Home: Swiss Homeowners and Expectations about Future Energy Prices

Alderete Peralta A, Balta-Ozkan N, Longhurst P (2022) Spatio-temporal modelling of solar photovoltaic adoption: An integrated neural networks and agent-based modelling approach. Appl Energy 305:. https://doi.org/10.1016/j.apenergy.2021.117949

Azizi S, Nair G, Olofsson T (2019) Analysing the house-owners' perceptions on benefits and barriers of energy renovation in Swedish single-family houses. Energy Build 198:187–196

Baginski JP, Weber C (2017) A consumer decision-making process? Unfolding energy efficiency decisions of German owner-occupiers. HEMF Working Paper

Bakaloglou S, Belaïd F (2022) The Role of Uncertainty in Shaping Individual Preferences for Residential Energy Renovation Decisions. Energy Journal 43:127–158. https://doi.org/10.5547/01956574.43.4.sbak

Banfi S, Farsi M, Filippini M, Jakob M (2008) Willingness to pay for energy-saving measures in residential buildings. Energy Econ 30:503–516. https://doi.org/10.1016/j.eneco.2006.06.001

Baustert P, Benetto E (2017) Uncertainty analysis in agent-based modelling and consequential life cycle assessment coupled models: A critical review. J Clean Prod 156:378–394

Belaïd F, Ranjbar Z, Massié C (2021) Exploring the cost-effectiveness of energy efficiency implementation measures in the residential sector. Energy Policy 150:. https://doi.org/10.1016/j.enpol.2020.112122

Booth AT, Choudhary R (2013) Decision making under uncertainty in the retrofit analysis of the UK housing stock: Implications for the Green Deal. Energy Build 64:292–308. https://doi.org/10.1016/j.enbuild.2013.05.014

Bozorgi A (2015) Integrating value and uncertainty in the energy retrofit analysis in real estate investment—next generation of energy efficiency assessment tools. Energy Effic 8:1015–1034

Bragolusi P, D'Alpaos C (2022) The valuation of buildings energy retrofitting: A multiple-criteria approach to reconcile cost-benefit trade-offs and energy savings. Appl Energy 310:118431

Broers WMH, Vasseur V, Kemp R, et al (2019) Decided or divided? An empirical analysis of the decision-making process of Dutch homeowners for energy renovation measures. Energy Res Soc Sci 58:. https://doi.org/10.1016/j.erss.2019.101284

Carpino C, Bruno R, Carpino V, Arcuri N (2022) Improve decision-making process and reduce risks in the energy retrofit of existing buildings through uncertainty and sensitivity analysis. Energy for Sustainable Development 68:289–307. https://doi.org/10.1016/j.esd.2022.04.007

Chaudry M, Abeysekera M, Hosseini SHR, et al (2015) Uncertainties in decarbonising heat in the UK. Energy Policy 87:623–640. https://doi.org/10.1016/j.enpol.2015.07.019

Chen H, Wang C, Cai W, Wang J (2018) Simulating the impact of investment preference on low-carbon transition in power sector. Appl Energy 217:440–455. https://doi.org/10.1016/j.apenergy.2018.02.152

Chen R, Fan R, Yao Q, Qian R (2023) Evolutionary dynamics of homeowners' energy-efficiency retrofit decision-making in complex network. J Environ Manage 326:. https://doi.org/10.1016/j.jenvman.2022.116849

de Vries G, Rietkerk M, Kooger R (2020) The Hassle Factor as a Psychological Barrier to a Green Home. J Consum Policy (Dordr) 43:345–352. https://doi.org/10.1007/s10603-019-09410-7

Du P, Zheng L-Q, Xie B-C, Mahalingam A (2014) Barriers to the adoption of energy-saving technologies in the building sector: A survey study of Jing-jin-tang, China. Energy Policy 75:206–216

Ebrahimigharehbaghi S, Qian QK, de Vries G, Visscher HJ (2022a) Application of cumulative prospect theory in understanding energy retrofit decision: A study of homeowners in the Netherlands. Energy Build 261:. https://doi.org/10.1016/j.enbuild.2022.111958

Ebrahimigharehbaghi S, Qian QK, de Vries G, Visscher HJ (2022b) Municipal governance and energy retrofitting of owner-occupied homes in the Netherlands. Energy Build 274:. https://doi.org/10.1016/j.enbuild.2022.112423

Ebrahimigharehbaghi S, Qian QK, Meijer FM, Visscher HJ (2019) Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making? Energy Policy 129:546–561. https://doi.org/10.1016/j.enpol.2019.02.046

Frederiks ER, Stenner K, Hobman E V (2015) Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. Renewable and Sustainable Energy Reviews 41:1385–1394

Frei M, Hischier I, Deb C, et al (2021) Impact of Measurement Uncertainty on Building Modeling and Retrofitting Decisions. Front Built Environ 7:. https://doi.org/10.3389/fbuil.2021.675913

Gabrielli L, Ruggeri AG (2019) Developing a model for energy retrofit in large building portfolios: Energy assessment, optimization and uncertainty. Energy Build 202:. https://doi.org/10.1016/j.enbuild.2019.109356

Gabrielli L, Ruggeri AG, Scarpa M (2023) Roadmap to a Sustainable Energy System: Is Uncertainty a Major Barrier to Investments for Building Energy Retrofit Projects in Wide City Compartments? Energies (Basel) 16:. https://doi.org/10.3390/en16114261

Gonzalez-Caceres A, Lassen AK, Nielsen TR (2020) Barriers and challenges of the recommendation list of measures under the EPBD scheme: A critical review. Energy Build 223

Greene DL (2011) Uncertainty, loss aversion, and markets for energy efficiency. Energy Econ 33:608–616. https://doi.org/10.1016/j.eneco.2010.08.009

Grillone B, Danov S, Sumper A, et al (2020) A review of deterministic and data-driven methods to quantify energy efficiency savings and to predict retrofitting scenarios in buildings. Renewable and Sustainable Energy Reviews 131

Hill DR Energy Efficiency Financing: A review of risks and uncertainties

Hosseinian S, Choi K, Bae J (2017) IRIER: A Decision-Support Model for Optimal Energy Retrofit Investments. J Constr Eng Manag 143:. https://doi.org/10.1061/(asce)co.1943-7862.0001362

Hu M, Xiao F (2020) Quantifying uncertainty in the aggregate energy flexibility of high-rise residential building clusters considering stochastic occupancy and occupant behavior. Energy 194:. https://doi.org/10.1016/j.energy.2019.116838

Jareemit D, Suwanchaisakul A, Limmeechokchai B (2022) Assessment of key financial supports for promoting zero energy office buildings investment in Thailand using sensitivity analysis. Energy Reports 8:1144–1153

Jia L, Qian QK, Meijer F, Visscher H (2021) Exploring key risks of energy retrofit of residential buildings in China with transaction cost considerations. J Clean Prod 293:. https://doi.org/10.1016/j.jclepro.2021.126099

Jones DW, Bjornstad DJ, Greer LA (2002) Making Energy-Efficiency and Productivity Investments in Commercial Buildings: A Choice of Investment Models

Lai Y, Papadopoulos S, Fuerst F, et al (2022) Building retrofit hurdle rates and risk aversion in energy efficiency investments. Appl Energy 306:118048

Lempert RJ (2003) Shaping the next one hundred years: new methods for quantitative, long-term policy analysis

Li FGN, Pye S (2018) Uncertainty, politics, and technology: Expert perceptions on energy transitions in the United Kingdom. Energy Res Soc Sci 37:122–132. https://doi.org/10.1016/j.erss.2017.10.003

Ma J, Qian QK, Visscher H, Song K (2022) Barriers for Homeowners in Decisions to Undertake Government-Led Energy Efficiency Renovation Projects in Northern China. Sustainability (Switzerland) 14:. https://doi.org/10.3390/su14127298

Menassa CC (2011) Evaluating sustainable retrofits in existing buildings under uncertainty. Energy Build 43:3576–3583. https://doi.org/10.1016/j.enbuild.2011.09.030

Moglia M, Cook S, McGregor J (2017) A review of Agent-Based Modelling of technology diffusion with special reference to residential energy efficiency. Sustain Cities Soc 31:173–182

Newton P, Meyer D (2013) Exploring the attitudes-action gap in household resource consumption: does "environmental lifestyle" segmentation align with consumer behaviour? Sustainability 5:1211–1233

Rai V, Robinson SA (2015) Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors. Environmental Modelling and Software 70:163–177. https://doi.org/10.1016/j.envsoft.2015.04.014

Robinson SA, Rai V (2015) Determinants of spatio-temporal patterns of energy technology adoption: An agent-based modeling approach. Appl Energy 151:273–284. https://doi.org/10.1016/j.apenergy.2015.04.071

Rocha P, Kaut M, Siddiqui AS (2016) Energy-efficient building retrofits: An assessment of regulatory proposals under uncertainty. Energy 101:278–287. https://doi.org/10.1016/j.energy.2016.01.037

Rogers DJ, Walker JTS, Moen IC, et al (2003) Understorey influence on leafroller populations in Hawkes Bay organic apple orchards. New Zealand Plant Protection 56:168–173

Rovers R (2014) New energy retrofit concept: "Renovation trains" for mass housing. Building Research and Information 42:757–767. https://doi.org/10.1080/09613218.2014.926764

Rysanek AM, Choudhary R (2013) Optimum building energy retrofits under technical and economic uncertainty. Energy Build 57:324–337. https://doi.org/10.1016/j.enbuild.2012.10.027

Silva AS, Ghisi E (2014) Uncertainty analysis of user behaviour and physical parameters in residential building performance simulation. Energy Build 76:381–391

Walker SL, Lowery D, Theobald K (2014) Low-carbon retrofits in social housing: Interaction with occupant behaviour. Energy Res Soc Sci 2:102–114. https://doi.org/10.1016/j.erss.2014.04.004

Wing LC (2015) Risk Management Methods Applied to Renewable and Sustainable Energy: A Review. Journal of Electrical and Electronic Engineering 3:1. https://doi.org/10.11648/j.jeee.s.2015030101.11

Zhang MM, Wang Q, Zhou D, Ding H (2019a) Evaluating uncertain investment decisions in low-carbon transition toward renewable energy. Appl Energy 240:1049–1060. https://doi.org/10.1016/j.apenergy.2019.01.205

Zhang MM, Wang Q, Zhou D, Ding H (2019b) Evaluating uncertain investment decisions in low-carbon transition toward renewable energy. Appl Energy 240:1049–1060. https://doi.org/10.1016/j.apenergy.2019.01.205

Zheng D, Yu L, Wang L (2019) A techno-economic-risk decision-making methodology for large-scale building energy efficiency retrofit using Monte Carlo simulation. Energy 189:. https://doi.org/10.1016/j.energy.2019.116169

Households engagement for sustainable behaviour in renovated dwellings

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Abstract

Within "Italia in Classe A", the Italian National Training and Information Program, coordinated by ENEA (Italian Energy Efficiency Agency) on behalf of the Ministry of Environment and Energy Security, OIKIA project analyses behaviours of households who recently renovated their homes with energy efficient interventions. In ancient Greek OIKIA is the house from the inhabitants' perspective, and it is meant to be a community research action on energy demand reduction.
Through a bottom up and participatory approach, OIKIA provides guidelines on post retrofitting behaviours to boost the impact of new efficient technologies increasing indoor comfort and social acceptance in line with the energy transition.
The activities draw on literacy and know-how approaches. The research methods are focused on in-depth interviews, questionnaires and informal interactions with the households. The survey was designed by experts and delivered by the network of Home Energy Advisors (HEA) built within the H2020 funded project ASSIST, to a focus group including 30 households.
Thanks to HEAs, households recognise the research group as impartial and trustworthy, interested in collecting inputs and suggestions on their experience and perspective on how to improve energy savings and domestic comfort levels through sustainable behaviours and habits.
OIKIA's final objective is to spread energy efficiency culture, increase households' energy literacy through a reflexive learning approach and avoid adverse behavioural impacts.
Key performance Indicators considered: indoor thermal comfort perception, setting temperature for heating and cooling, knowledge of energy literacy, digital skills related to energy production and consumption, use of domestic appliances and lighting systems.

INTRODUCTION

The OIKIA project is part of the campaign *Italia in Classe A*, the National Information and Training Programme for Energy Efficiency, promoted by the Ministry of the Environment and Energy Security and implemented by ENEA, the Italian National Agency for Energy Efficiency. The campaign was launched following the energy efficiency directives to encourage citizens, businesses and public administrations throughout the energy transition. Unlike other campaigns that are fragmented and limited in time, Italia in Classe A is a structural and policy-driven programme. Thus, three-year campaigns are built and delivered, addressing different targets at a national level, from institutions to citizens, from households to SMEs, with the aim of training and informing them about energy efficiency themes.

In accordance with the aims of this campaign, the OIKIA project was set up to help citizens in the orientation of behaviour and energy use in renovated homes. In ancient Greek "*oikos*" is the house seen from the outside, while "*oikia*" is the house seen from the inside, i.e. the house lived in.
Upgrading one's own dwelling from an energy point of view does not only serve to make it more efficient, to lower energy bills, but also to improve home comfort by reducing energy consumption, harmful gas emissions and mitigating climate change.
EU energy policies have mainly pushed towards thermal insulation, ventilation and heating systems, and also emerging as crucial in orienting investment towards electrification.

Studies and research on renovated dwellings have found different trends in energy consumption and energy savings in the presence of similar characteristics of the building and the estimated energy performance (Van den Brom, P, et al, 2012). These differences in consumption seem to arise mainly from occupancy characteristics, construction quality, and also to the so-called "*rebound effect*" (Khazzoom–Brookes postulate) (Gillingham, K., et al, 2014), which occurs following the introduction of efficient technologies, to specific behavioural responses that tend to reduce or cancel out the effects of the expected benefits of energy requalification. Similarly, a decrease in prices resulting from increased availability of energy as a result of energy efficiency measures may favour an increase in demand, and thus an increase in consumption that would partially or completely nullify the savings achieved.

Indeed, it is universally recognised by experts that final energy consumption is strongly determined by factors related to the habits, lifestyle and behaviour of inhabitants, but only few studies have been carried out to quantify and understand these factors.
However, the interaction between the inhabitant and the 'house', in controlling ventilation, heating, cooling, is fundamental in the process of energy consumption and can be influenced by various factors such as age, education, gender, country of origin, and personal idea of the perception of indoor comfort. There is also the novelty factor introduced by new systems or devices (photovoltaic, heat pumps, solar thermal, thermostats, mechanical ventilation, home automation, induction hobs, radiant floor heating systems) that need to be understood, managed and introduced into the daily routine with attention to consumption and proper maintenance.
It has been observed that "many smart home appliances lack usability and frustrate, rather than support, users' needs. There remains a substantial gap between the visions held by the energy sector and the reality of household users' experience of demand automation" (IEA 2022).

Living in renovated dwellings means acquiring new knowledge and gradually changing one's habits to fully enjoy a comfortable environment. The project aims to support the decision of informed citizens involved in the energy transition process, providing advice, practical tips and a support network to act consciously within their own homes and the community they belong to.

The objective of building users is to attain and sustain acceptable indoor comfort conditions, including thermal, visual, acoustic, and indoor air quality. Their comfort experiences result from a combination of objective and subjective factors. The former ones are associated with building characteristics and environmental conditions, while the latter encompass individual physiological and psychological features. In response to these various stimuli, occupants engage with building systems to adjust their surroundings and regain their preferred comfort levels. These adjustments have direct and noticeable impacts on the indoor environment and user comfort, with implications for building energy consumption that should not be underestimated (Stazi & Naspi, 2018)

METHODOLOGY

OIKIA project has adopted a bottom up and participatory approach to provide guidelines on post retrofitting behaviours to boost the impact of new efficient technologies, increasing indoor comfort and social acceptance in line with the energy transition. In order to achieve these objectives, the pilot project aims at: 1) testing a methodology which can be scaled and replicated on larger target group; 2) understanding non technological barriers (difficulties, resistance to change) 3) identifying drivers and effective key messages for information and awareness raising campaign; 4) designing new instruments and methods for capacity building.
The action implementation has required the involvement of different key actors: ENEA, as Energy Efficiency AISFOR– a knowledge and training company and Federconsumatori Lazio-, a consumers association - and RETE ASSIST- a network of Home Energy advisors-.
The initiative is based on a bottom-up process, as this approach is likely to encourage citizens to play an active role in setting priorities, identifying problems and finding solutions. Involving citizens from the beginning can ensure that decisions and policies are more legitimate and accepted by the community. When people have the opportunity to participate in decision-making, they are more likely to support and adhere to the decisions made.
The kick off took place in September 2022. The first part of the project was dedicated to building an homogeneous and significant group for the collection of insights on expectations prior to the renovation measures, their impacts in terms of energy consumption and efficiency and barriers faced with households who have carried out energy upgrading measures in their homes. The selection of the households was made following three criteria: 1) typology of energy efficiency intervention: a list of the most impactful and at the same time common energy measures was drawn; 2) geographical (and climatic) homogeneous area: to compare behaviour it was important that the group all lived in similar geographical conditions; 3) time of completion of refurbishment work: in order to analyse post-measures behaviour, and at the same time propose changes (it was important measures have been "just" implemented, ongoing works or finished at the maximum in the last 6 months).
The final group consisted of households living in 28 dwellings located in the area of the city of Rome, who had recently renovated their homes with thermal insulation of envelopes, installation of photovoltaic panels systems, or electricity charging stations .
AISFOR identified the households group with the support of Federconsumatori Lazio, a consumer association, partner of RETE ASSIST, a network of Home Energy Advisors (HEAs) , committed to protecting and informing citizens, giving advice on available public incentives for renovation. Federconsumatori Lazio is also engaged in activities aimed at alleviating energy poverty, through the network of HEAs operators, trained and skilled to communicate with people on technical topics in an understandable and effective manner.
In line with the participative approach characterising the OIKIA project, a first meeting was organised in November 2022, with the aim of presenting the project goal and to establish a sense of community, collect first hand information and insights. It was carefully considered where to organise this face-to-face meeting, in order to gain participants' trust. For this reason, the headquarters of Federconsumatori Lazio, a familiar place for the households, was selected as the venue of the meeting. During this first plenary, proposers and organisers of the project explained why households'

participation is crucial, and after this first part, the participants were involved in a practical workshop discussing the advantages and challenges met during their home renovation process.

In general, the households considered the various interventions in their homes as positive and beneficial in terms of consumption. For example, it emerged how the use of thermal insulation makes their homes warmer in the winter and cooler in the summer, and how it decreases the needed use of air conditioners and radiators. The radiant system also has advantages according to the families, offering more efficient heating.

Among the most critical issues, households reported that non-unanimity of condominiums can block the whole process of renovation of a building in an energy-efficient direction. Moreover, a critical point emerged regarding the variety of information displayed on web sites, which tends to confuse citizens more than inform them to make right decisions for renovation. A further critical issue that emerged concerned the difficulties that the households encountered in interpreting the correct use of the new devices introduced in their homes, especially for elderly people. However, lacking a trustworthy information source, some ideas emerged from the audience: an energy advisory hub or a neighbourhood energy info point could be useful to give impartial advice and empower citizens' energy skills. It also came out that in some contexts, such as condominiums, there is a need for a mediator, who can lead the interested parties to an agreement on energy renovation projects for the whole building.

Home Visits for energy assessment skills

The following step of OIKIA projects consisted in Home Energy Visits carried out by HEAs operators, to gather information both on dwellings and on households' behaviour and habits, using a questionnaire designed by researchers of ENEA Agency.

The OIKIA questionnaire items covered several sections on:

- type of dwelling;
- occupant's profile: household members, gender, age, education level, qualifications, occupation;
- energy behaviour and habits: i.e. number of hours spent indoor, heating and cooling habits, thermostat usage,
- types and number of renovation measures carried out in the dwellings;
- list of future renovation projects (e.g. thermal insulation, photovoltaic system, installation of heat pumps);
- list of domestic appliances owned and their electrical power, labelling, information on daily use;
- gas appliances and their daily use .

Furthermore, some questions investigated the motivations that drove households to undertake the energy renovation in their homes, if changes in habits and behaviour had occurred, which improvements or difficulties related to new systems installed they acknowledged. Thanks to the survey outputs both a qualitative and a quantitative analysis were carried out. On the basis of the evidence gathered, a first set of tips were produced, and a draft guidelines on the use of energy at home and sustainable behaviours. The draft guidelines were provided in a second plenary session held in the consumers association venue, sharing these findings with the households' group and asking for participants' inputs, with the objective to follow a co-design approach (Sanders et al 2008)

RESULTS AND FINDINGS

HEAs conducted semi-structured interviews by meeting households at their renovated homes. A questionnaire to analyse comparable results was filled out, obtaining qualitative and quantitative data as baseline to understand contexts and to start from users' needs analysis.

The households' sample is composed of 33 men and 39 women (distributed in 28 dwellings). Most of the respondents have high school diplomas and University degrees, while data showing the highest education level in the secondary and primary schools is probably linked to children's presence.

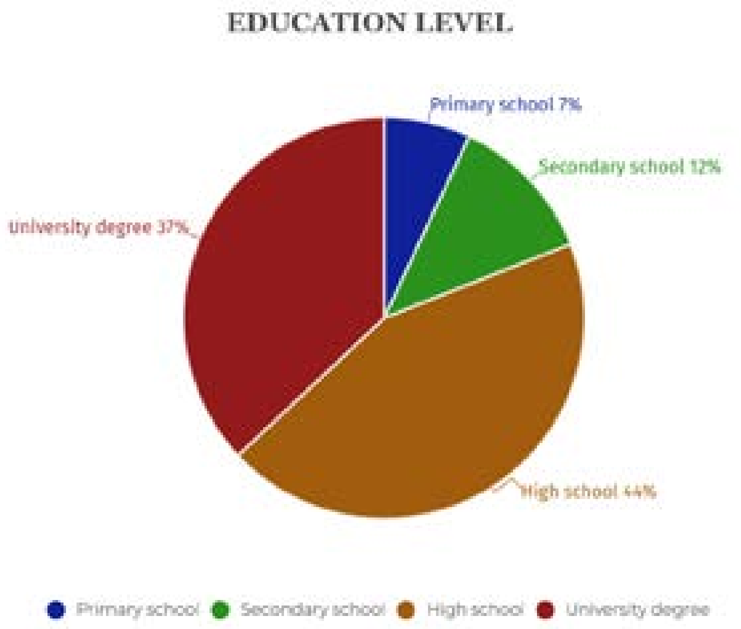

Fig. 1 Education level distribution of households

The sample includes all private homeowners, paying energy and operating costs, and questions differentiating them by the type of building where they live in (house or apartment).

The sample of households has differences in family size and composition: twelve families with children, then couples and single families. About the job position of the reference sample: 24 people declared to be employees, 10 workers, 5 freelancers, 4 lawyers, 14 students, 15 elderly people in retirement.

Participants were asked about the decision-making in their energy efficiency renovation projects: if they renovated on their own initiative, or if they decided to undertake the project when the building manager asked for their agreement.
Specifically, in the case of autonomous decisions, windows and doors replacement was the most frequent energy efficiency intervention (19), followed by solar shading (12), boiler or radiator replacement (10) and photovoltaic system installations (6). Other interventions, such as thermal insulation (3) and modern heat pump (3) are rarer. On the other hand, in the case of the renovation of the whole building, insulation (13), photovoltaic system with storage (13) and the thermal envelope (12) are the most renovation measures carried out.

Despite the high education level, the attitude towards energy efficiency, and awareness of this consumers' sample, the initial feedback confirms a general lack of knowledge on some energy-related topics: for instance, the majority of respondents do not know the energy label of their household appliances and their consumption.
In order to record consumption behaviour and habits, in fact, households were asked for each appliance in their homes about electrical and thermal power, energy class, average number of weekly use, average duration of the single use and the time slot of use (whether morning, afternoon, evening, or night). As mentioned above, a few of respondents know the consumption of their appliances, and only in the cases of the highest energy class. In general, the most used electrical devices are: laptop,

PC, television, air conditioner and the washing machine, which is always used in the evening. Obviously, the refrigerator is an exception by operating 24 hours a day. Its inclusion among the questionnaire items aimed at awareness raising, as well as several other questions. Concerning the powered gas appliances, the hob and the boiler are the most frequently used.
A set of items aimed at detecting the management of indoor comfort during summer and winter periods, and ventilation of the rooms.
During the winter period the heating system is turned on for an average of 5 hours a day, and during working days is less used than on holidays. As far as cooling systems, during the summer period the system is used almost every day for 2 or 3 hours. Concerning the frequency with which the rooms are ventilated, all the rooms are ventilated at least once a day, mainly in the morning, with a duration ranging from 6 hours to 10 minutes a day.

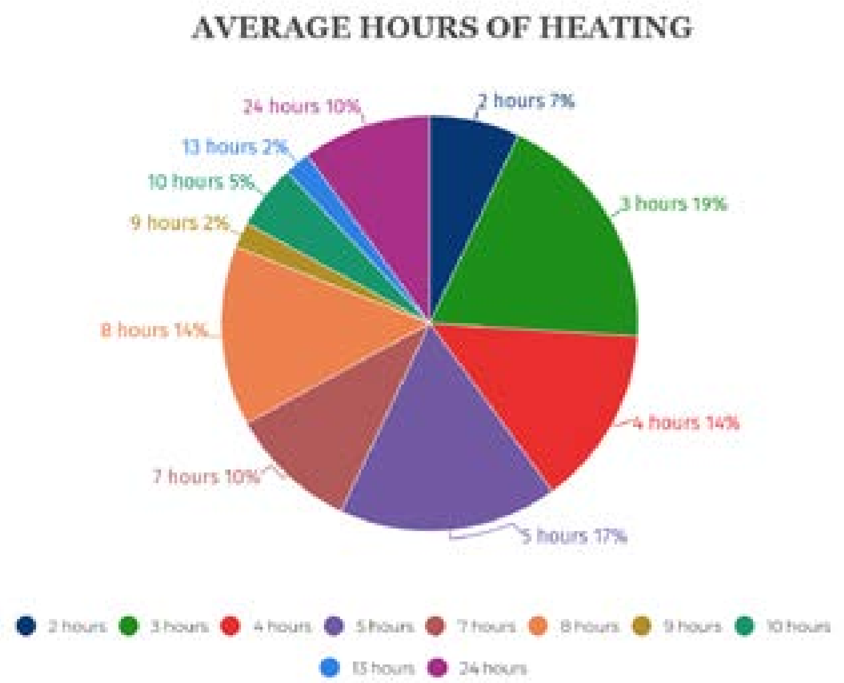

Fig. 2 Hours of heating

On the other hand, the temperature set for cooling has been resulted as too low, highlighting one of the critical issues on users behaviour.
Participants were asked if after energy efficiency renovation their habits changed. As shown in the figure 3 below, almost half of respondents have declared no changes in their daily habits, while the remainder of participants answering they have experienced a change in their habits, especially in using appliances. Households who have installed photovoltaic systems try to use electricity during the morning, but in the case of photovoltaic systems with storage, households go on to using electric appliances during the evening. Other respondents have observed the optimisation of heating, other households report a decrease in the energy bills. In fact, as shown in fig.4 the majority of answers confirm that renovation has led to an economic saving and indoor comfort level improvement.

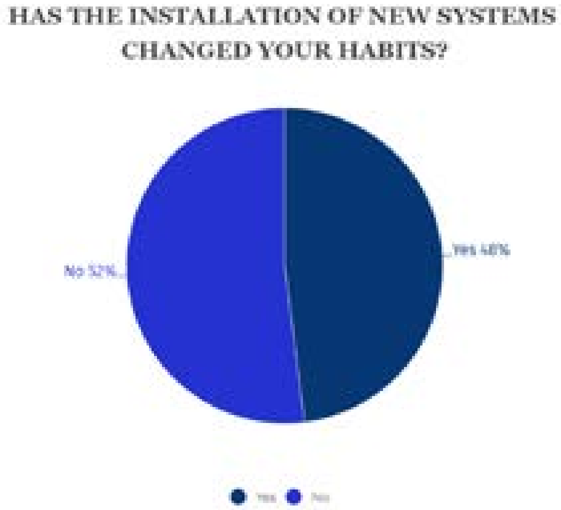

Fig. 3 Perception of impacts of new systems on daily habits

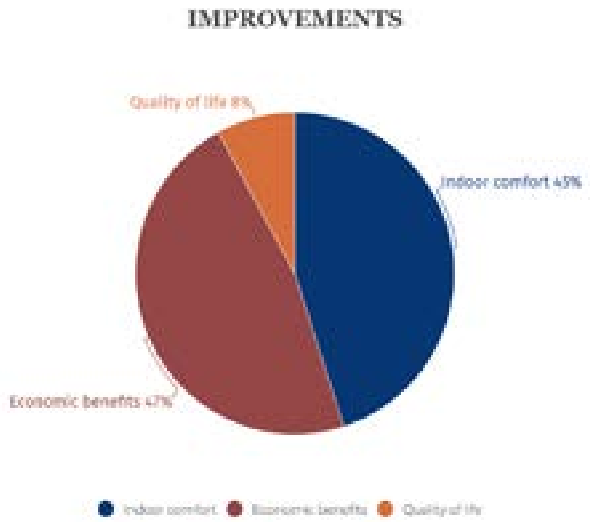

Fig. 4 Households perception on benefits of energy renovation

Investigating the perceptions on the change caused by new systems installation, different experiences and approaches with innovation are observed. Households can react to innovative technological solutions in an unexpected way, as shown by the *"automation paradox*: users don't like to feel they're not in control, yet desire technologies to be less demanding of their time" (Energy Systems Catapult 2021)

Furthermore, the majority of households (25) declared to be provided with clear instructions by the installers, while a small proportion is not satisfied (3). Furthermore, 20 households replied they know any procedure for routine maintenance of systems. Five households have complained about a lack of support by installers. In general, except for the testing phase, a good satisfaction grade is observed. Nevertheless, when families were asked about the difficulties they had encountered, many respondents complained about delays in connecting photovoltaic systems to the grid, and in general, about the change in habits due to the electrification (e.g. behaviour in kitchen: from gas hobs to electric hotplates). Households stressed the use of apps to manage problems they encountered.

The last part of the interview was focused on the projects of future interventions, barriers and triggers. Although the majority of the respondents have made the decision on the interventions thanks to financial incentives, all the respondents would like to undertake new projects, simply replacing boilers and appliances, or installing solar thermal panels or photovoltaic systems.

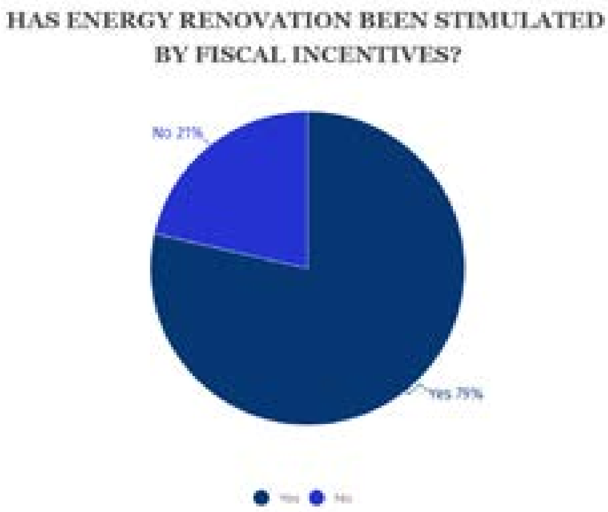

Fig. 5 Factors influencing decision-making on energy renovation

CONCLUSION

Behaviour plays a crucial role in promoting energy efficiency, and understanding the causes and patterns behind behaviour is the key to successful energy efficiency programs. Many surveys support the view that communication measures can truly have an influence on energy use and, at best, behavioural interventions can reduce energy use in a cost-effective way. (Podgornik, Sucic, Blazic, 2016)

The majority of awareness actions that support energy efficiency programmes using behavioural insights, represents the “cognition type” according to the information deficit model.(Thilakarathne, D.J., Treur, J, 2015)

These types of actions include general and tailored communication, social media, training, and information, on the assumption that increasing people’s energy literacy will change their habits and behaviours in energy use.

Actually, information is not sufficient to sustain behaviour change in the long term.

Behaviour is not only an individual process but it is also a social process with neighbourhoods and with local communities, where common values, such as environmental sensitivity, can be shared and enhanced.

This leads ideally to empowerment: how personal choices can be effective in a wider context.

Social norms, peer-to-peer learning, and an engaging communication strategy with direct messages seem to work better to boost sustainable behaviours, especially when delivered by a trusted and impartial source.

This community awareness action, carried out in the framework of *Italia in Classe A*, the National Information and Training Programme for Energy Efficiency, has been the first of its kind as it focuses on the behaviours of citizens living in recently renovated dwellings with energy efficiency

interventions and it follows a bottom up approach.
Key Performance Indicators identified in testing are: perceived indoor comfort, settled temperature for boiler and for heating, comprehension of technical instructions and knowledge of terms linked to energy, digital skills related to energy production and consumption, use of domestic appliances and lighting systems.
The Pilot is still ongoing and it will lead to draft guidelines using a bottom up approach to boost behavioural changes after renovation and the use of new efficient technologies in dwellings, and increase indoor comfort and social acceptance of energy transition and related innovation.
Oikia represents an engagement and awareness action, that follows the eighth strategic principle, based on the recommendations of the Global Commission for Urgent Actions on Energy Efficiency, that IEA included in its Policy Toolkit released in 2023: " Leverage behavioural insights for more effective policy", as people are at the centre of energy efficiency action benefitting from more comfortable and healthier environments, the insights from behavioural science can make the difference in designing more effective and inclusive energy policies.

REFERENCES

1) Gillingham, K., D. Rapson, G. Wagner, (2014), *The Rebound Effect and Energy Efficiency Policy*, Nota di Lavoro 107.2014, Milan, Italy: Fondazione Eni Enrico Mattei.
2) Van den Brom, P, Meijer, M, Visscher, H (2012) *Actual energy saving effects of thermal renovations in dwellings—longitudinal data analysis including building and occupant characteristics* Energy and Buildings, Volume 182, 2019, Pages 251-263, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.10.025.
3) Stazi, F., Naspi, F. (2018). *Impact of Occupants' Behaviour on Zero-Energy Buildings,* SpringerBriefs in Energy, https://doi.org/10.1007/978-3-319-71867-5
4) IEA (2022), *Residential behaviour changes lead to a reduction in heating and cooling energy use by 2030*, IEA, Paris https://www.iea.org/reports/residential-behaviour-changes-lead-to-a-reduction-in-heating-and-cooling-energy-use-by-2030, License: CC BY 4.0
5) Sanders, E. B.-N, Stappers, P, J (2008) *Co-creation and the new landscapes of design, CoDesign*, 4:1, 5-18, DOI: 10.1080/15710880701875068
6) Energy Systems Catapult on behalf of the Users TCP and 4E EDNA: Plug & Play (2021) *Are we getting the best out of Smart Home Technologies? The role of usability.*
7) IEA (2023), *Energy Efficiency: The Decade for Action*, IEA, Paris https://www.iea.org/reports/energy-efficiency-the-decade-for-action, License: CC BY 4.0
8) Guerra Santin, O. (2010) *Actual energy consumption in dwellings. The effect of energy performance regulations and occupant behaviour, ISSN 1879-8330; 33 IOS P*ress Delft University Press
9) Podgornik A., Sucic B., Blazic B. (2016) *Effects of customised consumption feedback on energy efficient behaviour in low-income households.* https://doi.org/10.1016/j.erss.2018.01.009
10) Thilakarathne, D.J., Treur, J. (2015) *Computational cognitive modelling of action awareness: prior and retrospective.* Brain Inf. 2, 77–106 . https://doi.org/10.1007/s40708-015-0013-3

Wind of Chance: Analysing the Impact of Crises on Sustainable Behaviour and Societal Resilience

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Abstract

Understanding sustainability behaviour is essential in tackling the global challenge of climate change. The importance of studying sustainability practices and their dynamics grows in light of recent global crises such as the COVID-19 pandemic and the energy crisis following the Ukraine war. These events both challenge and shape individual sustainable practices, offering opportunities for fostering individual sustainable practices and enhancing societal resilience. An online survey was conducted in Germany (n=571, May 2023) to investigate sustainable behaviour dynamics (mobility, energy-saving, and shopping habits) and to identify segments reflecting behavioural shifts. We found relative stability in sustainable mobility choices compared to pre-crisis times, with a tendency towards reduction, as well as an overall increase in energy-saving and sustainable shopping habits. Factor analyses revealed that sustainable mobility behaviour (SMB) and sustainable consumer practices (SCP) formed two separate domains. Cluster analyses further identified four segments within each domain, each exhibiting unique behavioural patterns compared to pre-crisis practices. Examining individual variables, the adoption of more sustainable mobility practices was associated with sociodemographic factors (income, education, and area of living), higher levels of environmental awareness, institutional trust, and increased risk perceptions. Sociodemographic variables had less influence on sustainable consumer practices. Here, higher levels of knowledge, climate change awareness, trust, and risk perceptions played a significant role. Our findings highlight the importance of separately considering behavioural domains in understanding crises-induced changes in sustainability practices. Moreover, it is important to consider specific individual factors and to develop tailored interventions and policies to promote sustainable practices during volatile times.

1 INTRODUCTION

Addressing the global challenge of climate change necessitates a comprehensive understanding of sustainability behaviour (Newell et al., 2021). At its core, sustainability behaviour refers to a set of actions and decisions of individuals or households aiming at reducing negative environmental impacts (Steg & Vlek, 2009). Such behaviours involve different aspects like food consumption, transportation, energy use, and waste management (Geiger et al., 2017).

Despite the centrality of individual and household behaviour, research on sustainability transitions often overlooks their influence and dynamics (Raven et al., 2021). Future environmental impacts, however, will not solely depend on the enforcement of policy measures but will be significantly influenced by lifestyle choices (EEA, 2019). So far, households were often approached in sustainability research using a closed-box approach, viewing them as fixed units and underestimating their internal dynamics and interactions with broader systemic changes (Raven et al., 2021). External (sometimes disrupting) factors can profoundly shape sustainable behaviours. Recent global crises like the COVID-19 pandemic and the energy crisis in the aftermath of the Ukraine war are examples, which have had direct effects on sustainability behaviours of households (Liobikienė et al., 2023). These crises can serve as catalysts for change (Ergen & Suckert, 2021), presenting both challenges and opportunities. They underscore the need for a holistic policy approach that integrates principles of energy conservation, sufficiency, and efficiency measures (Bertoldi, 2022).

In this context, the concept of resilience is also relevant. Moving beyond its technical definition related to infrastructure and supply (Hamborg et al., 2020), we refer to the concept of household energy resilience (Hasselqvist et al., 2022), i.e., the ability of households to change and fundamentally adjust their practices. Recent research has begun to investigate household behaviours in the context of crises and resilient behaviour practices. Corbos et al. (2023) found a positive impact of knowledge of energy savings on actual energy-saving behaviours during the energy crisis. This relationship was moderated by responsible behaviour, suggesting that mere awareness is not sufficient without a sense of responsibility towards sustainable practices. Liobikienė et al. (2023) investigated the factors that influence energy-saving behaviour and identified concerns stemming from the Ukraine war as the primary influencing factor. This suggests that global crises can significantly shape individual sustainability practices. Novianto et al. (2022) studied the impact of lifestyle changes on home energy consumption during recent crises. They found an increase in the use of household energy appliances, particularly among the middle-upper consumer segments. Monterde-i-Bort et al. (2022) investigated mobility patterns and mode choice preferences during the COVID-19 pandemic in 10 (mostly European) countries. During the pandemic, respondents reduced their mobility by using cars, local public transport, and walking. After the lifting of mobility restrictions, however, their habits reverted almost back to the pre-COVID-19 level.

While these studies identified factors influencing sustainable consumer behaviour (e.g., Corbos et al., 2023), partially extracted behavioural clusters (Novianto et al., 2022), and analysed crisis-induced changes in household behaviour (Monterde-i-Bort et al., 2022), a detailed investigation of the spectrum and extent of behavioural changes in sustainability practices including individual factors was not done. This study aims to fill this gap by examining changes in sustainability behaviour in the context of recent crises. Therefore, the following research aims were pursued:

1. Analysis of the pattern and extent of changes in sustainability behaviours triggered by recent crises.
2. Identification and characterization of distinct clusters of behavioural changes.
3. Derivation of policy implications aiming at fostering sustainable behaviours.

2 METHOD

To investigate changes in sustainable behaviours and underlying determinants, an empirical quantitative approach was chosen, which will be described in the following sections.

2.1 Questionnaire

The questionnaire was modular in design and included:

- Screening section (age, gender, education, federal state, and income) to target a population-representative group for Germany (individuals > 18 years)
- Demographic data (information on family status, area of residence)
- Attitude-related factors (environmental awareness: 5 items, Cronbach's alpha = .86, ESS, 2021 and institutional trust to mitigate climate change: 7 items, Cronbach's alpha = .89, Offermann-van Heek et al., 2018)
- Risk perception (regarding the future in general, individual health, and individual financial situation, 3 items, Cronbach's alpha = .76)
- Behavioural changes: Changes in sustainability behaviour compared to the time before the onset of the COVID-19-pandemic and the Ukraine war were measured by four items: "Has your behaviour changed because of recent crises such as the COVID-19-pandemic or the energy crisis resulting from the Ukraine war? Compared to the time three years ago:" a) I save energy…, b) I use public transport…, c) I buy sustainably as much as possible…, d) I use a car.... Response alternatives were "much less frequently, less frequently, rather less frequently, equally frequently, somewhat more frequently, more frequently, much more frequently".

The items related to attitude factors and risk perception had to be answered on a six-point Likert scale (1 = strongly disagree to 6 = strongly agree). Items that were formulated negatively were recoded before statistical analysis.

2.2 The Sample

Data of n = 541 respondents (M = 48.79 years, SD = 14.6, 47.5% male, 52.5% female) was analysed in the study (n = 1007 before data cleaning). Most participants completed secondary education (56.4%) according to the International Standard Classification of Education (ISCED, 2011), followed by those with tertiary education (42.5%). Only a small percentage (1.1%) reported primary education as the highest educational degree. Asked for their area of living, 28.1% of participants lived in the city centre, 43.3% in the suburbs, and 28.7% in rural areas. In terms of income distribution, the average reported income was in the category 2000-2999€.

2.3 Statistical Analysis

Information on the behaviour-change-related items was summarised into three categories: a) no changes, b) reduced behaviour referred to as “less climate-friendly behaviour” (summarising the responses “much less frequently, less frequently, and rather less frequently”), and increased behaviour referred to as “more climate-friendly behaviour” (summarising the responses “somewhat more frequently, more frequently, much more frequently"). First, descriptive and factor analyses were applied to understand the distribution of behavioural change data and their dimensional structure. Second, cluster analyses were employed to segment respondent groups based on their behavioural patterns. Third, depending on psychometric scale properties, cluster group differences and individual factors were analysed by MANOVAs and nonparametric tests.

3 RESULTS

3.1 Descriptive and factorial analysis of behavioural changes

A mixed pattern of behavioural changes compared to pre-crisis times was found (Figure 1): Regarding public transport, 54.9% indicated no changes, 23.5%, reported reduced usage, and 21.6% reported an increased usage. For the use of cars, most respondents (55.1%) reported no changes, 30.9% reported reduced car usage and 14% reported increased car usage.

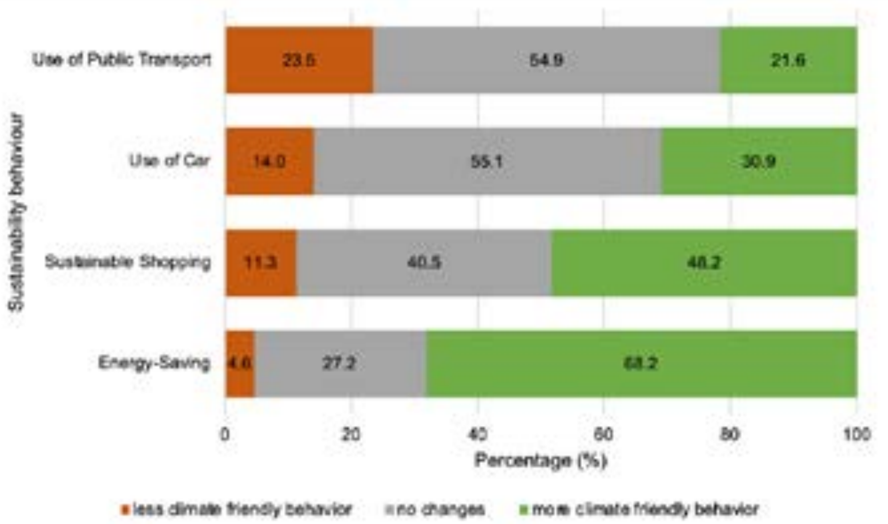

Figure 1: Sustainability behaviour changes due to recent crises (n = 541).

Sustainable shopping behaviours also increased compared to pre-crisis times, with 48.2% of participants indicating they shopped more sustainably. No changes were reported by 40.5% and 11.3% indicated reduced sustainable shopping behaviours. Regarding energy-saving behaviours, over two-thirds (68.2%) reported increased energy-saving behaviour, 27.2% reported no changes and 4.6% reported less energy-saving behaviour.

After analysing the distribution of behavioural changes, the next step focused on the analysis of their underlying dimensional structure. A factor analysis (Principal component analysis with Varimax rotation) was employed to determine whether the behavioural changes represented distinct domains or if they formed a singular construct. Bartlett's test of sphericity was significant ($\chi_{(6)} = 240$; $p < 0.01$), indicating that the data was appropriate for factor analysis. Two components with eigenvalues above Kaiser's criterion of 1 explained 71.1% of the variance (Table 1). The items "use of car" and "use of public transport" loaded on the first factor, labelled as "sustainable mobility behaviour" (SMB). The second factor, marked by loadings from "energy-saving behaviour" and "sustainable shopping behaviour", represented "sustainable consumer practices" (SCP).

Table 1: Factor loadings from the PCA on behavioural change items.

	Component	
Variables	**1**	**2**
Sustainable shopping behaviour	0.858	
Energy-saving behaviour	0.851	
Use of car		-0.839
Use of public transport		0.806

Note: the loading of the variable "use of car" is negative because lower car usage indicates higher sustainable behaviour levels.

3.2 Cluster analysis of behavioural changes

For the identified factors "sustainable mobility behaviour" (SMB) and "sustainable consumer practices" (SCP) cluster analyses were employed based on the respective factor scores. First, a two-step cluster analysis was run to determine the optimal number of clusters, followed by a K-Means clustering algorithm to partition respondents into distinct groups.

3.2.1 Sustainable mobility behaviour

The cluster analysis suggested a four-cluster solution. The identified four clusters differed significantly in car use and public transport usage ($F_{(2,539)} = 3303.1$; $p < 0.001$, Table 1). Post-hoc tests (Tukey's HSD) indicated significant pairwise differences between all clusters for both car use and public transport usage at $p < 0.05$.

Table 1: Descriptive statistics (M, SD in brackets) for Car Use and Public Transport Usage across clusters.

Variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Use of car	5.25 (1.33)	2.4 (1.03)	3.9 (0.73)	1.16 (0.37)
Use of public transport	1.54 (0.92)	4.61 (1.06)	3.87 (0.84)	6.44 (0.70)

The following cluster description is based on the original items to provide a more differentiated view of the nature of behavioural change.

- **Cluster 1** (85 cases): For *car use*, 54.1% reported an increase, 43.5% reported no change, and 2.3% reported a reduction. For *public transport*, 92.9% reported a reduction, while

7.1% reported no change. Based on increasing car usage and decreasing public transport usage, the cluster was labelled as *"car-centric converters"*.

- **Cluster 2** (90 cases): For *car use*, 86.7% reported a reduction, 12.2% reported no change, and 1.1% reported an increase. In terms of *public transport*, 46.7% reported an increase in usage, 47.8% no change, and 5.6% reported a reduction. This cluster predominantly reduced their car use while almost equally increasing or maintaining public transport usage and was labelled as *"public transport adopters"*.
- **Cluster 3** (323 cases)**:** In the biggest cluster, regarding *car use*, 77.4% reported no change, 13.6% reported a reduction, and 9.0% reported an increase. For *public transport*, 76.8% reported no change, 13.3% reported a reduction, and 9.9% reported an increase. As most of this group reported a consistent commuting pattern in their car use and public transport usage, they were labelled as *"stable multi-modalists"*.
- **Cluster 4** (43 cases): For *car use*, all respondents in this cluster, 100%, reported a reduction. Conversely, for *public transport*, 100% reported an increase. Since mobility choices indicate a strong preference for more sustainable commuting options, the cluster was labelled as *"sustainable transit converters"*.

3.2.2 Sustainable consumer practices (SCP)

A four-cluster solution was suggested, followed by K-Means clustering of the SCP-factor score. A MANOVA proved highly significant differences in energy-saving and sustainable shopping behaviour across the four clusters ($F_{(2, 536)} = 358.12$, $p < 0.001$). Post-hoc tests proved that each cluster exhibited distinct patterns in both energy-saving and sustainable shopping behaviour ($p < 0.05$, Table 2).

Table 2: Descriptive statistics (M, SD in brackets) for energy-saving- and sustainable shopping behaviour in the four SCP-clusters (N = 541).

Variables	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
Energy-saving	4.50 (0.84)	3.58 (1.84)	5.61 (0.89)	6.40 (0.65)
Sustainable shopping	3.93 (0.56)	1.92 (0.91)	4.81 (0.63)	6.07 (0.60)

Next, the clusters will be described regarding their behavioural patterns in energy-saving and sustainable shopping:

- **Cluster 1** (206 cases): For *energy-saving behaviour*, more than one half (59.2%) indicated no change, 37.4% indicated an increase, and 3.4% indicated a reduction. Regarding *sustainable shopping*, 81.1% reported no change, 7.3% an increase, and 11.7% a reduction. This cluster primarily reflected rather consistent behaviours across both domains and was labelled as *"stable shoppers and moderate energy-savers"*.
- **Cluster 2** (38 cases): For *energy-saving behaviour*, 26.3% reported no change, 28.9% an increase, and 44.7% a reduction. In *sustainable shopping*, 94.7% indicated a reduction and 5.3% reported no change. This cluster shows a diverse pattern leaning towards a less sustainable behaviour, especially in sustainable shopping. Therefore, it was labelled as *"reduced sustainable practices"*.

- **Cluster 3** (167 cases): For *energy-saving behaviour*, 91.0% indicated an increase, 8.4% indicated no change, and 0.6% indicated a reduction. For *sustainable shopping*, 70.1% indicated an increase, 29.3% no change, and 0.6% a reduction. This cluster was labelled as *"increased sustainable practices"*.
- **Cluster 4** (130 cases): In both *energy-saving* and *sustainable shopping* behaviours, 99.2% indicated an increase, and 0.8% indicated no change. The dominant pattern in this cluster was an increase in both domains, labelled as *"sustainable consumption champions"*.

To determine whether the two cluster solutions for sustainable mobility behaviour (SMB) and sustainable consumer practices (SCP) were based on a similar group structure or assignment of cases, cross-tabulations were calculated (Cohen's Kappa < 0.05), which indicated no agreement between the two clustering assignments. Nevertheless, Figure 2 provides an overview of the distribution of cases across the respective cluster groups of the two domains of sustainable behaviour, i.e., sustainable consumption, and sustainable mobility.

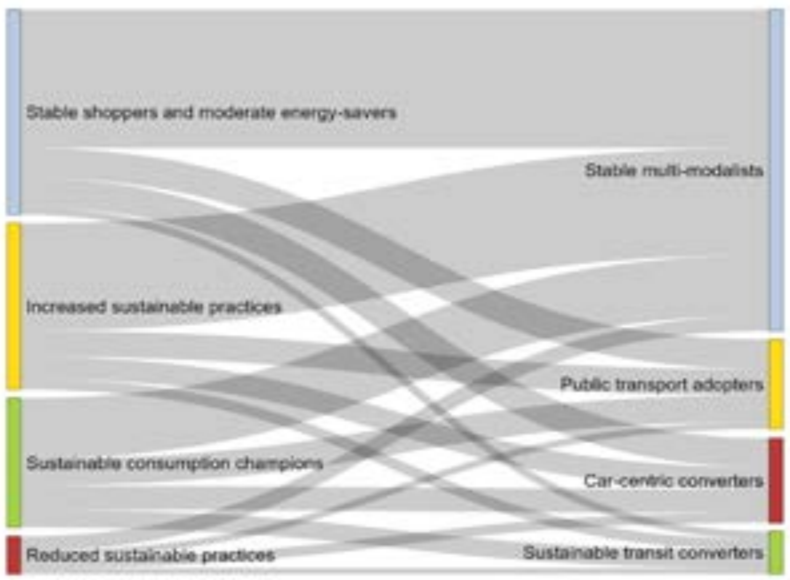

Figure 2: Sankey diagram of cluster group assignments for the SCP cluster (right) and the SMP cluster (left), (n = 541).

3.3 Detailed analysis of clusters based on individual factors

3.3.1 Sustainable mobility behaviour clusters (SMB)

Sociodemographics: Significant differences were found in the income distribution across clusters ($\chi^2_{(3)} = 46.2$, $p < .001$) as well as for education ($\chi^2_{(3)} = 36.0$, $p < .005$). Post-hoc tests revealed that Cluster 4 had a significantly higher percentage of individuals in the lowest income category (32.6%). Regarding education, Cluster 3 had a higher proportion of individuals in the tertiary education level (29.1%) compared to the other clusters. For the remaining variables (age, gender, area of living) no significant differences were found.

Knowledge: For subjective sustainability knowledge, an ANOVA revealed no significant differences across clusters (n.s.).

Attitudinal variables: For climate change awareness (CCA) and institutional trust (IT), significant differences between the cluster groups were revealed (CCA: $F_{(3, 537)} = 8.55, p < .001$; IT: $F_{(3, 537)} = 8.44, p < .001$). CCA in Cluster 1 (M = 3.2, SD = 1.4) was significantly lower than in Cluster 3 (M = 3.6, SD = 1.2) and Cluster 4 (M = 4.1, SD = 1.4), which displayed the highest CCA. For IT, Cluster 4 (M = 3.1, SD = 1.0) exhibited the highest level of trust, while Cluster 1 reported the lowest (M = 2.6, SD = 1.0).

Risk perception: Cluster 4 (M = 5.1, SD = 1.3) displayed the highest risk perception, while Clusters 2 (M = 4.7, SD = 1.2) and 3 (M = 4.7, SD = 1.0) displayed the lowest ($F_{(3,537)} = 3.5$, $p = 0.05$).

Finally, to find out which of the individual factors contributed the most to sustainable mobility behaviour changes, a stepwise regression was run with individual variables as predictors. The model was statistically significant ($F(3,537) = 10.62, p < .001$) and accounted for approximately 6% of the variance in changes in mobility behaviour ($R^2 = 0.06$). Climate change awareness ($\beta = .19$, $p < .001$), income ($\beta = -.1$, $p < 0.05$), and area of living ($\beta = -.1$, $p = < 0.05$) were significant predictors. Higher levels of climate change awareness, living in the city centre, and a lower income were associated with changes to more sustainable mobility.

Table 4: Stepwise linear regression results predicting changes in sustainable mobility behaviour from climate change awareness, income, and area of living.

Predictor	**B**	**SE**	**β**	**t**	**p**	**VIF**
(Constant)	-0.08	0.18	—	-0.43	n.s.	—
Cl. Change Awareness	0.15	0.03	.19	4.61	< .001	1.00
Income	-0.06	0.02	-.11	-2.49	< .005	1.01
Area of Living	-0.13	0.06	-.1	-2.36	< .005	1.00

Note: B = Unstandardised Coefficient; SE = Standard Error; β = Standardised Coefficient; t = t-value; p = p-value; VIF = Variance Inflation Factor. $R^2 = 0.06$

3.3.2 Sustainable consumer practices clusters (SCP)

Sociodemographics: Only income showed a statistically significant difference across the clusters ($\chi^2_{(18)} = 29.57$, p = 0.05). Cluster 2 had the lowest average income level (M = 2.9, SD = 1.5), while Clusters 3 and 4 had the highest (M = 3.8, SD = 1.7 and SD = 1.8, respectively). Age, gender, area of living, and education did not significantly differ in the cluster groups.

Knowledge: For subjective sustainability knowledge, we found significant differences across clusters ($F_{(3,537)} = 11.94$, p < 0.001). Cluster 4 had the highest average knowledge (M = 4.0, SD = 1.2), while Cluster 2 had the lowest (M = 3.0, SD = 1.6).

Attitudinal variables: The SCP-clusters significantly differed in their climate change awareness ($F_{(3,537)} = 38.4$, $_p < 0.001$) and institutional trust ($F_{(3,537)} = 9.1$, $_p < 0.001$). Cluster 4 had the highest CCA (M = 4.4, SD = 1.1), while Cluster 2 had the lowest (M = 2.7, SD = 1.3). Cluster 4 also had the highest trust (M = 3.3, SD = 1.0), and Cluster 2 the lowest (M = 2.5, SD = 1.0).

Risk perception: Cluster 4 had the significantly highest average risk perception (M = 5.1, SD = 1.2), while Cluster 2 reported the lowest (M = 4.5, SD = 1.6), ($F_{(3,537)} = 8.09$, $p < 0.001$).

Finally, a stepwise linear regression with the individual variables as predictors of changes in sustainable consumer practices was employed. The model was statistically significant ($F_{(4, 536)} = 40.22$, $p < 0.001$), and accounted for approximately 23% of variance ($R^2 = 0.23$). Higher levels of climate change awareness ($\beta = .4$, $p < .001$), increased risk perceptions ($\beta = .12$, $p < .05$), higher knowledge on climate change ($\beta = .04$, $p < .05$), and higher age ($\beta = .08$, $p < .05$) were associated with positive changes in sustainable consumer practices (SCP).

Table 5: Stepwise linear regression results predicting sustainable consumer practices from age, climate change awareness, knowledge, and risk perception.

Predictor	**B**	**SE**	**β**	**t**	**p**	**VIF**
(Constant)	-2.12	0.23	—	-9.11	< 0.001	37.92
Age	0.01	0.00	.08	2.15	< 0.05	1.00
Cl. Change Awareness	0.31	0.03	.4	9.37	< 0.001	1.27
Knowledge	0.06	0.03	.08	1.99	< .05	1.23
Risk Perception	0.10	0.04	.12	2.98	< .05	1.03

Note: B = Unstandardised Coefficient; SE = Standard Error; β = Standardised Coefficient; t = t-value; p = p-value; VIF = Variance Inflation Factor. $R^2 = 0.23$

4 DISCUSSION

Understanding sustainable behaviour, especially in the face of recent crises, is essential in tackling global challenges such as climate change. The practices of individuals are central in this context, given their impact on broader sustainable outcomes. Based on empirical data of a representative German sample, we examined self-reported changes in key sustainable behaviour domains compared to pre-crises-times: mobility, energy consumption, and shopping. In the following, we discuss the dynamics of behavioural change, followed by the impact of individual differences, combined with implications for policy measures.

4.1 Dynamics of sustainable behavioural change

Recent crises such as the COVID-19 pandemic and the energy-crisis due to the Ukraine war exerted different effects on the two domains of sustainability behaviour. Although significant potential for change toward sustainable mobility practices was anticipated due to current crises (Csutora & Zsóka, 2023), our results indicate that there was rather little change - or high stability - in mobility practices. Over half of the participants reported no change in their mobility practices. We assume that external factors like lockdowns, differing work commitments (home office), public transport availability, or societal norms shaped mobility behaviour (Renn et al., 2022). On the other hand, we found a significant shift in sustainable consumer practices: Most participants reported increased energy-saving behaviours and nearly half reported more sustainable shopping practices. This may either be a result of economic factors (increased food- and energy prices) or an increased awareness (Liobikienė et al., 2023). Comparing the extent of changes in both sustainability domains, our findings indicate a different "elasticity" of behaviours. Behaviours such as energy-saving and sustainable shopping were more adaptable to change, primarily because they are less influenced by external factors and more by individual choices. This suggests accordingly that policy interventions should create external conditions to foster more sustainable mobility habits. Further, the comparative analysis of changes within the two sustainability behaviour domains suggests high consistency and limited spillover effects (Puntiroli et al., 2022). This means that adopting sustainable practices in one area (e.g., energy-saving) doesn't necessarily lead to sustainable decisions in another area (e.g., mobility). This differentiation emphasises the need for targeted interventions across different domains of sustainability. Finally, the shift towards sustainable consumer practices suggests an emerging recognition of the importance of (energy) resilience at the household level and underscores the potential of individual behaviour in shaping a more resilient energy and consumption landscape (Hasselqvist et al., 2022). To ensure long-term environmental sustainability, policymakers should prioritise initiatives that support and promote household energy resilience.

4.2 Cluster-specific sustainable behaviours and impact of individual factors

The varied patterns of sustainable behaviour changes underscore the fact that individuals react differentially to crises. While some took it as an opportunity to adopt more sustainable behaviours ("sustainable transit converters" and "sustainable consumption champions"), others remained locked in old habits ("stable shoppers and moderate energy-savers") or even changed their behaviour to less sustainable ones ("car centric converters", "reduced sustainable practices"). Parts of society choose to shift towards sustainability - even (or especially) during times of crisis. However, the presence of clusters that either remained static or shifted towards less sustainable behaviours presents a significant challenge. A mere awareness or experience of a crisis does not guarantee positive behavioural change (e.g., Venghaus et al. 2022). In view of growing social polarisation and climate change-sceptical positions, it is even more important to focus on these groups to identify barriers and incentives to change (e.g., Moberg et al., 2021). The inclusion of individual factors revealed that the (non-)adoption of sustainable behaviours is influenced by several factors including socio-demographics, knowledge, attitudinal factors, and risk perception, which highlights the importance of multi-dimensional approaches in understanding and promoting sustainable behaviours. Regarding *sociodemographics*, the lower *income* of "sustainable transit converters" indicates economic constraints leading to more sustainable choices. Similarly, higher *income* and *education* of the SCP-cluster "sustainability champions" may provide individuals the means to make more sustainable choices. For policymakers, this suggests considering the options of increased subsidies or incentives to improve affordability across all income groups. The *area of living* was a significant predictor in the SMB domain, underscoring the role of urban infrastructure in sustainable mobility choices. Urban areas often have better public transport infrastructure and more incentives or restrictions regarding car usage, making sustainable commuting more feasible. This highlights the importance of improving public transport and promoting sustainable mobility options also in non-urban areas. Regarding attitudinal factors, those with higher *climate change awareness* were more inclined to engage in sustainable behaviours, both in mobility and consumption. The regression analysis further solidified this, showing a strong association between climate change awareness and positive changes in both mobility and consumer practices. Subjective sustainability *knowledge* was significant in predicting sustainable consumer practices. The better-informed individuals were, the more they leaned towards sustainable shopping and energy-saving behaviour. Knowledgeable consumers seem to be better equipped to make informed decisions, suggesting that awareness campaigns can play a pivotal role in promoting sustainable consumer practices. *Risk perception* was another influential factor. Those who perceived higher risks associated with climate change were more likely to adopt sustainable consumer practices (e.g., Arning et al., 2018). This implies that understanding the consequences of climate change can significantly impact behaviour. *Trust* in institutions was also important, especially in the context of sustainable mobility. Clusters with higher trust levels were more inclined towards sustainable practices, suggesting that institutional trust can potentially guide individuals towards more sustainable choices (e.g., Rayner, 2010) . However, an essential point to consider is the low proportion of explained variance in the regression analyses, especially for mobility behaviour. This suggests that the complexity of sustainable (mobility) behaviour extends beyond these individual factors. Each cluster represents a distinct response to the crises, influenced by a combination of individual characteristics and, other, unmeasured systemic or structural factors, which underscores the need for a comprehensive approach.

4.3 Methodological considerations and future research

Our findings must be contextualised within certain methodological constraints. Future studies should include additional individual, systemic, and structural factors like social norms, flexibility to work from home, policy, and regulation. Further, the study provides insights into behaviours over three years, but the temporal stability of these changes is still uncertain. It remains unclear whether these shifts represent short-term responses to specific crises or indicate longer-term behavioural adaptations. Additionally, the generalisability of our results is yet to be determined: are these patterns consistent globally, or specific to geographical or cultural contexts? Lastly, the reliability and validity of self-reported measures should be approached with caution. Future research might benefit from integrating mixed methods (e.g., Csutora et al., 2021) t o ensure a comprehensive understanding of sustainable behaviour.

5 CONCLUSION

In examining changes in sustainable behaviours after recent crises, our study revealed both stable and changing behavioural patterns in the German population. Our findings revealed that a substantial proportion of individuals maintained their pre-crisis behaviours. Distinct clusters were identified, representing individuals who either adopted more sustainable practices, did not change, or reverted to less sustainable ones. Individual factors, including climate change awareness and income, influenced these behaviours, but their limited explanatory power underscores the potential role of broader systemic factors. For a widespread transition to sustainability, policy measures addressing both individual and systemic aspects are crucial.

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REFERENCES

Arning, K., van Heek, J., & Ziefle, M. (2018). Acceptance profiles for a carbon-derived foam mattress. Exploring and segmenting consumer perceptions of a carbon capture and utilization product. Journal of Cleaner Production, 188, 171-184.

Bertoldi, P. (2022). Policies for energy conservation and sufficiency: Review of existing policies and recommendations for new and effective policies in OECD countries. Energy and Buildings, 264, 112075. https://doi.org/10.1016/j.enbuild.2022.112075

Bögel, P. M., & Upham, P. (2018). Role of psychology in sociotechnical transitions studies: Review in relation to consumption and technology acceptance. Environmental Innovation and Societal Transitions, 28, 122–136. https://doi.org/10.1016/j.eist.2018.01.002

Corbos, R.-A., Bunea, O.-I., & Jiroveanu, D.-C. (2023). The effects of the energy crisis on the energy-saving behavior of young people. Energy Strategy Reviews, 49, 101184. https://doi.org/10.1016/j.esr.2023.101184

Csutora, M., Zsoka, A., & Harangozo, G. (2021). The Grounded Survey–An integrative mixed method for scrutinizing household energy behavior. Ecological Economics, 182, 106907.

Csutora, M., & Zsóka, Á. (2023). Crises as incubators of sustainable mobility patterns? Evidence from two shock events. Sustainable Development.DOI: 10.1002/sd.2578

EEA, 2019, The European environment — state and outlook 2020: knowledge for transition to a sustainable Europe, European Environment Agency (https://www.eea.europa.eu/soer/publications/soer-2020) accessed 14.09.2023.

Ergen, T., & Suckert, L. (2021). „Crises" as catalysts for more sustainable futures? The case of the first oil crisis and the role of multilayered interpretative struggles. economic sociology. perspectives and conversations, 22(2), 15–23.

ESS Round 9: European Social Survey (2021): ESS-9 2018 Documentation Report. Edition 3.1. Bergen, European Social Survey Data Archive, Sikt - Norwegian Agency for Shared Services in Education and Research, Norway for ESS ERIC. doi:10.21338/NSD-ESS9-2018.

Geiger, S. M., Fischer, D., & Schrader, U. (2018). Measuring What Matters in Sustainable Consumption: An Integrative Framework for the Selection of Relevant Behaviors. Sustainable Development, 26(1), 18–33. https://doi.org/10.1002/sd.1688

Hamborg, S., Meya, J. N., Eisenack, K., & Raabe, T. (2020). Rethinking resilience: A cross-epistemic resilience framework for interdisciplinary energy research. Energy Research & Social Science, 59, 101285.

Hasselqvist, H., Renström, S., Strömberg, H., & Håkansson, M. (2022). Household energy resilience: Shifting perspectives to reveal opportunities for renewable energy futures in affluent contexts. Energy Research & Social Science, 88, 102498.

ICSED (International standard classification of education) (2011). Comparative Social Research, 30.

Liobikienė, G., Matiiuk, Y., & Krikštolaitis, R. (2023). The concern about main crises such as the Covid-19 pandemic, the war in Ukraine, and climate change's impact on energy-saving behavior. Energy Policy, 180, 113678. https://doi.org/10.1016/j.enpol.2023.113678

Moberg, K. R., Sovacool, B. K., Goritz, A., Hinojosa, G. M., Aall, C., & Nilsson, M. (2021). Barriers, emotions, and motivational levers for lifestyle transformation in Norwegian household decarbonization pathways. Climatic Change, 165, 1-25.

Monterde-i-Bort, H., Sucha, M., Risser, R., & Kochetova, T. (2022). Mobility Patterns and Mode Choice Preferences during the COVID-19 Situation. Sustainability, 14(2), Article 2. https://doi.org/10.3390/su14020768

Newell, P., Twena, M., & Daley, F. (2021). Scaling behaviour change for a 1.5-degree world: Challenges and opportunities. Global Sustainability, 4, e22. https://doi.org/10.1017/sus.2021.23

Puntiroli, M., Moussaoui, L. S., & Bezençon, V. (2022). Are consumers consistent in their sustainable behaviours? A longitudinal study on consistency and spillover. Journal of Business Research, 144, 322–335. https://doi.org/10.1016/j.jbusres.2022.01.075

Rayner, S. (2010). Trust and the transformation of energy systems. Energy Policy, 38(6), 2617-2623.

Raven, R., Reynolds, D., Lane, R., Lindsay, J., Kronsell, A., & Arunachalam, D. (2021). Households in sustainability transitions: A systematic review and new research avenues. Environmental Innovation and Societal Transitions, 40, 87–107. https://doi.org/10.1016/j.eist.2021.06.005

Renn, O., Engels, A., Mack, B., Becker, S., & Camier, C. (2022). Will short-term behavior changes during the COVID-19 crisis evolve into low-carbon practices?. GAIA-Ecological Perspectives for Science and Society, 31(3), 158-166.

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. Journal of environmental psychology, 29(3), 309-317.

Offermann-van Heek, J., Arning, K., Linzenich, A., & Ziefle, M. (2018). Trust and distrust in carbon capture and utilization industry as relevant factors for the acceptance of carbon-based products. Frontiers in Energy Research, 6, 73.

Venghaus, S., Henseleit, M. & Belka, M. (2022). The impact of climate change awareness on behavioral changes in Germany: changing minds or changing behavior?. Energy, Sustainability and Society, 12, 8.

ENERGY COMMUNITIES AS ENABLERS FOR INNOVATIVE TECHNOLOGIES?

The Case of Vehicle-to-Grid in Three European Countries

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Abstract

Vehicle-to-grid (V2G) is a particular form of smart charging, allowing a more efficient and sustainable energy system by integrating electric vehicles (EVs) as additional storage capacity into the electricity grid. Techno-economic analyses suggest numerous advantages of this technology, such as a more secure and flexible grid operation, higher potential of integrating renewable energies into the grid, and financial revenues. However, whether and why households are willing to participate in V2G is still being investigated. Therefore, we examined the factors underlying V2G acceptance, focusing on prior EV experience and membership in an energy community. Energy communities were shown to be an essential driver of a bottom-up energy transition in similar contexts. Therefore, we hypothesized that energy communities could facilitate the widespread acceptance and adoption of new technologies such as V2G. Specifically, people who are part of an energy community might actively promote technologies that benefit the energy transition and be more likely to accept potential constraints. We surveyed German, French, and Swiss households (total N = 1,134, some of whom were also energy community members) in June 2023 to investigate the role of energy community membership on the acceptance of V2G. We compared V2G acceptance in the three countries with an extended theory of planned behavior. Hierarchical regression analyses showed that community-related factors, such as community identification, significantly predicted the intention to adopt V2G for energy community members, whereas it did not for non-members.

1 INTRODUCTION

The transport sector significantly contributes to CO_2 emissions in Europe and worldwide. To achieve current climate goals, one strategy is to electrify transport. For example, the German government aims for 15 million electric vehicles (EVs) (SPD, Bündnis 90/Die Grünen and FDP, 2021) and the French government for 7.5 million EVs by 2030 (Ministère de la Transition Écologique et de la Cohésion des Territoires, 2022). This will lead to increased electricity demand, which in turn will add stress to the electricity grid. Utilizing the EV's battery as additional storage could potentially provide additional short-term flexibility, thus enabling the increased integration of renewable energy sources (RES) into the grid and improving grid stability.

In this context, vehicle-to-grid (V2G) is seen as a promising technology. V2G can be defined as a mobile storage with a bidirectional power flow (Kempton & Tomić, 2005; Sovacool & Hirsh, 2009). In other words, EVs that are connected to the grid can both charge and feed electricity back into the grid when necessary. This provides temporal and distributed flexibility (Knezovic et al., 2017), and thus, V2G can be seen as an essential technology to foster the energy transition. However, besides providing flexibility for ancillary services, the EV primarily needs to satisfy users' mobility needs. This tension raises the question of whether and why electric vehicle users and owners would be willing to participate in V2G.

Solutions such as V2G symbolize the changing landscape of the energy system. This transformation is characterized by many but small production units, decentralized and cross-border markets, smaller transmission lines and regional supply, bidirectional distribution, and active prosumers (Friends of the Earth Europe et al., 2019). This broader transformation is also actively shaped by energy communities aiming to increase decentralized renewable energy production, contribute to climate goals, and promote collaborative social transformations (Koirala et al., 2018; Lowitzsch et al., 2020). Energy communities can be defined as "bottom-up energy-related projects driven towards local needs, characterized by strong citizen participation, local ownership, decision-making with a single vote per actor, and sharing of collective benefits" (Reis et al., 2021, 2 f.).

Engaging in energy communities is often motivated by collective long-term benefits (Goedkoop et al., 2022; Sloot et al., 2019). Correspondingly, V2G could contribute to the energy system as a whole by providing ancillary services. However, it could also add a benefit to communities' objectives, for example, by scheduling load operations in off-peak periods or according to local energy generation (Reis et al., 2021; Schram et al., 2021), or by providing flexibility to enable electricity sharing within a community (Huber et al., 2019). Therefore, we hypothesize that the community context can act as a unique enabler for V2G technology. More specifically, we hypothesize that the community context acts as a motivational basis, influencing individuals' intention and behavior to adopt V2G, and that these individuals base their decisions on specific, community-related values.

Moreover, as recent literature suggests, EV experience is another critical factor for informed decision-making and interest in V2G (Chen et al., 2020; Noel et al., 2019; Wong et al., 2023). We therefore elaborate on this factor as well, distinguishing between people with no EV experience, people who already gained experience with EVs during, e.g., test drives or car sharing, and people who own an EV. It is suggested that the intention to adopt V2G is less likely when people have not yet encountered EVs.

In this paper, we bring these aspects together by asking the question of whether energy communities could be a driver for V2G technology, and what role EV experience has for the intention to adopt V2G. Our paper elaborates on this question for three European countries — Germany, Switzerland, and France. We do so because, even though these countries have direct borders, their energy systems are quite different. To answer our research question, we built a model based on the theory of planned behavior (TPB). We extend this model with community-specific constructs: membership in an energy community, community identification, and community sustainable energy motivation. Furthermore, we analyze the influence of EV experience on the intention to participate in V2G processes.

The paper is structured as follows: First, we provide an overview of the theoretical background of the model. Second, we describe our method, including the study design, participants, measures, and analysis method, before describing and discussing our results. We summarize this paper with a conclusion and policy implications.

2 CONCEPTUAL BACKGROUND

To assess the unique role of community-related values that might underlie the intention to participate in V2G, we started out with a theory of planned behavior model, as this theory has been studied in numerous contexts, including energy behavior and technology acceptance. We extended this model with two further items: community identification, and community sustainable energy motivation. We describe the theoretical basis of our model below.

2.1 Theory of planned behavior

The theory of planned behavior (TPB) is an established model for explaining decision-making processes (Azjen, 1991). Moreover, it allows the inclusion of further variables explaining behavioral intention, which makes it attractive for different contexts. For example, the TPB has been used to explain electric vehicle adoption (Haustein et al., 2021; Lee et al., 2023). In the context of V2G, van Heuveln et al. (2021) used this model to identify potential factors affecting V2G acceptance qualitatively. We adopt the model by Hasan (2021) and Haustein et al. (2021), using attitudes towards bidirectional charging, subjective norms, and perceived behavioral control as predictors of intention, whereby perceived behavioral control is modified to perceived functional barriers, as suggested by Haustein et al. (2021) (see also Section 3.3).

2.2 Social identification and community sustainable energy motivation

As energy community members' intention to engage in V2G might not only be explained by individual attitudes, subjective norms, and perceived functional barriers but also by community factors, we included community-specific variables in our model. Being part of an energy community might shape one's identity and act as a guide for appropriate behavior (Goedkoop et al., 2022; Sloot et al., 2018). For these energy community members in particular, what they perceive their community to value and to what extent they feel attached to it might motivate their interest in V2G. We therefore included community sustainable energy motivation and social identification in the model next to the TPB variables and, in a subsequent step, distinguished between those involved in an energy community and those uninvolved. Previous research combined social identity with the theory of planned behavior to explain involvement in environmental protection (Fielding et al., 2008). However, even though these measures are well established, there has been no research until now combining these measures into one model in the context of V2G.

3 METHODS

To address the research question, we conducted a study to evaluate different values guiding the intention to adopt V2G. Specifically, we compared a sample including energy community members, and a sample including homeowners who are not part of an energy community, which we called "non-members". Furthermore, we analyzed the role of EV experience as another predictor of the intention to adopt V2G.

3.1 Survey design

In June 2023, we conducted an online survey with an interdisciplinary and international research team of students and scientists from Switzerland, France, and Germany. As the survey was distributed among German, French, and Swiss households and energy communities in these countries, the survey was translated into German and French from an English version. To increase the number of participants from energy communities, we combined randomized and purposive data sampling (Maxwell, 2009). Thus, data was collected in two ways: First, data was collected through a commercial marketing panel company. This data is representative of the respective national populations with regard to age and gender, but is restricted to homeowners in these countries. Second, we distributed the survey among German, Swiss, and French energy communities. The energy community members received a monetary incentive to increase the participation rate.

The survey consisted of four parts. In the first part, we assessed participants' age, gender, and current home country. Moreover, we asked them whether they were part of any energy community and to what extent they had experience with electric vehicles. The second part included an introduction to V2G, and a comprehension question to test the technical understanding. In the next part, which is irrelevant to this study, participants had to rate nine scenarios about different V2G options. The fourth part measured individual motivations, beliefs, values, and barriers (such as the TPB and the VBN), as well as community motivations (community identification and community sustainable energy motivation). Lastly, we assessed further household characteristics and further socio-demographic characteristics.

3.2 Participants

Table 1: EV experience levels and energy community membership according to country

	Germany (N=359)		France (N=271)		Switzerland (N=352)	
	Amount	%	Amount	%	Amount	%
EV experience levels						
No EV experience	215	59.9	163	60.1	170	48.3
EV experience	92	25.6	47	17.3	103	29.3
EV owner	52	14.5	61	22.5	79	22.4
Energy community membership						
Member	52	14.5	79	29.2	101	23.6
No member	307	85.5	192	70.8	251	71.3

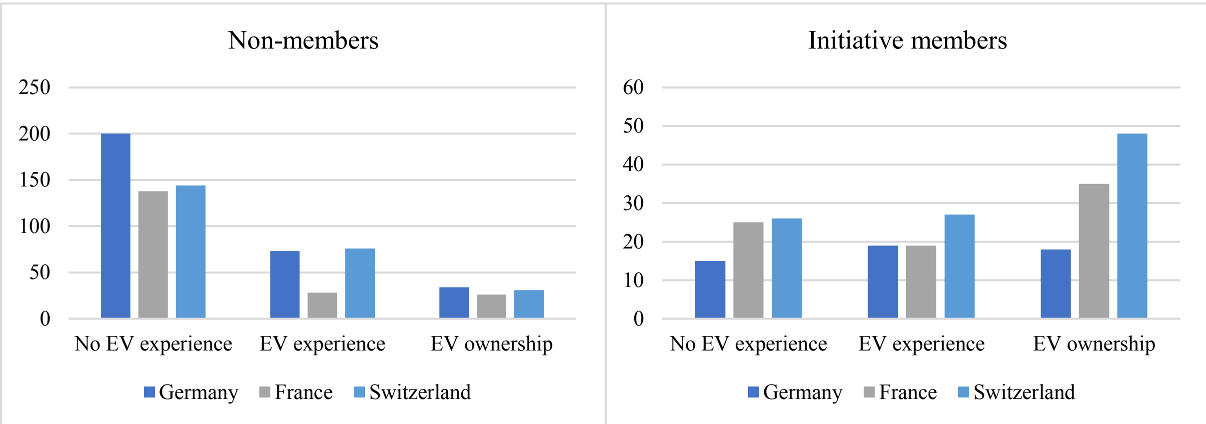

Figure 1: EV experience levels by community membership and country

Our sample is comprised of two sources. The majority of answers were collected with the help of a panel company (*N*=1,351). Furthermore, in order to increase the number of persons who are part of an energy community, we distributed the survey among several energy communities in Germany, France, and Switzerland (*N*=47). After data cleaning, we retained a final sample of *N*=982. As we are especially interested in analyzing the effect that energy community membership and EV experience have on V2G adoption, we show the distribution of energy community members and EV experience among the three countries in Table 1. As can be seen, we have nearly the same number of responses from Switzerland and Germany, while there are fewer responses from French people in our sample. Astonishingly, the share of energy community members in the German sample is far smaller than in the other two countries. Finally, as can be seen in Figure 1, there seems to be a strong correlation between energy community membership and the level of EV experience, independent of the country. For all three countries, EV experience is lower when people are not part of an energy community, while EV experience increases for energy community members.

3.3 Measures

Table 2: Measures and their respective sources

Scales	Source
Theory of planned behavior	
Subjective norms	Hasan, 2021
Perceived behavioral control / perceived functional barriers	Haustein et al., 2021
Attitude	Hasan, 2021
Intention	Haustein et al., 2021
Social Identification	Postmes et al., 2013; Goedkoop et al., 2022
Community sustainable energy motivation	Goedkoop et al., 2022

In this manuscript, we focus on concepts from different theories: TPB variables as well as the social identity concepts community identification and community sustainable energy motivation. The constructs were measured based on the sources provided in Table 2. We adapted the TPB constructs to the case of V2G, including the term “bidirectional electric vehicle” in the four constructs: attitudes, subjective norms, perceived behavioral control, and intention. Finally, as suggested by Haustein et al. (2021), we changed the construct of perceived behavioral control to perceived functional barriers, referring to functional barriers regarding the use of an EV, which is able to charge bidirectionally.

To measure community-related factors, we used two measures: For community identification, we used the three-item scale suggested by Postmes et al. (2013), which was adapted to the community context by Goedkoop et al. (2022). As a second community-related measure, we chose the community sustainable energy motivation scale, as suggested by Goedkoop et al. (2022).

To measure energy community membership, we asked the participants of the survey in the beginning whether they were part of an energy community. We provided a definition of “energy community” in German, English, and French.

To identify the level of EV experience, respondents were first asked whether they had already gained experience in driving an EV, followed by the question of whether they owned an EV. Based on these two questions, we grouped participants into three groups – people who did not have any experience with EVs, people who have had experience with EVs but did not own one, and people who owned an EV. This approach was based on Baumgartner et al. (2022).

3.4 Method of analysis

All statistical analyses were conducted using IBM SPSS 29. First, we conducted a correlation analysis to test for the strength of the relationships between variables. Second, we conducted a hierarchical multiple regression analysis testing the extended TPB. In the first step, we included two dummy variables to control for the fact that participants were from three different countries. In the second step, we included the dummy variables for EV experience, and EV owner, before entering the psychological variables, starting with the basic model of the TPB. In the last step, we entered the community-specific variables, namely community identification and community sustainable energy motivation. We first tested the model for the whole sample. Second, we split the file to compare the model for the energy community members and non-members.

4 FINDINGS

As outlined in Section 3.4, we performed three hierarchical regression analyses for the whole sample and the two subsamples of non-members and members, respectively. The four steps of the hierarchical regression were identical for each of the three models. Table 3 displays the results for the whole sample. As can be seen, participants' country was not a significant predictor of the intention to participate in V2G. The opposite is true for EV experience and EV ownership, which are both highly significant and remain significant even when further variables are entered. As expected, the TPB model is highly significant, F_{change}=347.378, p<.001. All three predictors have a strong effect size, with attitudes having the highest standardized coefficient with ß=.413, p<.001 in Step three and ß=.404, p<.001 in Step four. As expected, perceived functional barriers had a negative effect on intention (ß=-.208, p<.001). Step four did not add any variation to model three, and community sustainable energy motivation and community identification were not significant predictors of intention. Overall, the model explained 59% of the variation.

The results for non-members (Table 4) were similar to the results of the total sample. The

Table 3: Hierarchical multiple regression analysis predicting intention – Total sample

Step	Predictor	R^2	R^2 change	F change	df	p	Step 1ß	Step 2ß	Step 3ß	Step 4ß
1	Germany vs. France	0.003	0.003	1.537	979	0.251	0.032	0.014	-0.026	-0.029
	Germany vs. Switzerland						0.063	0.022	-0.032	-0.029
2	No EV experience vs. EV experience	0.121	0.118	65.477	977	<0.001		0.163***	0.074****	0.074***
	No EV experience vs. EV owner							0.354***	0.094***	0.087***
3	Attitudes	0.594	0.471	347.378	974	<0.001			0.413***	0.404***
	Subjective norm								0.331***	0.316***
	Perceived functional barriers								-0.208***	-0.209***
4	Community sustainable energy motivation	0.594	0.002	2.575	972	0.077				0.018
	Community identification									0.039

*p<0.05; **p<0.01; ***p<0.001.

country was not a significant predictor of intention, while EV experience and EV ownership were. However, the effect of EV experience decreases in Step three and four, while EV ownership remains highly significant. The TPB predictors are highly significant, again with attitudes having the strongest effect on intention and with perceived functional barriers having a negative sign. Including community sustainable energy motivation and community identification in the model did not change the effect of the TPB predictors significantly. These last two predictors were, again, not significant and did not explain any additional variation compared to Model 3.

Table 5 shows the results of the hierarchical regression analysis for individuals who were part of an energy community (i.e., members). Again, the participant's country of origin did not predict intention. However, the picture changes for EV experience and EV ownership. While

Table 4: Hierarchical multiple regression analysis predicting intention – Non-members

Step	Predictor	R^2	R^2 change	*F* change	*df*	*p*	Step 1ß	Step 2ß	Step 3ß	Step 4ß
1	Germany vs. France	0.002	0.002	0.776	747	0.461	-0.026	-0.025	-0.038	-00.041
	Germany vs. Switzerland						0.028	0.014	-0.040	-0.039
2	No EV experience vs. EV experience	0.101	0.099	41.115	745	<0.001		0.115***	0.053*	0.053*
	No EV experience vs. EV owner							0.318***	0.101***	0.097***
3	Attitudes	0.599	0.498	307.580	742	<0.001			0.413***	0.406***
	Subjective norm								0.328***	0.315***
	Perceived functional barriers								-0.203***	-0.203***
4	Community sustainable energy motivation	0.601	0.01	1.358	740	0.258				0.063
	Community identification									0.011

*p<0.05; **p<0.01; ***p<0.001.

Table 5: Hierarchical multiple regression analysis predicting intention – Energy community members

Step	Predictor	R^2	R^2 change	*F* change	*df*	*p*	Step 1ß	Step 2ß	Step 3ß	Step 4ß
1	Germany vs. France	0.002	0.002	0.284	229	0.753	0.061	0.063	0.037	0.034
	Germany vs. Switzerland						0.024	0.011	0.020	0.025
2	No EV experience vs. EV experience	0.058	0.055	6.645	227	0.002		0.209**	0.164**	0.164**
	No EV experience vs. EV owner							0.272***	0.124	0.103
3	Attitudes	0.437	0.380	50.401	224	<0.001			0.415***	0.388***
	Subjective norm								0.301***	0.287***
	Perceived functional barriers								-0.217***	-0.232***
4	Community sustainable energy motivation	0.453	0.015	3.118	222	0.046				-0.043
	Social identity									0.153*

*p<0.05; **p<0.01; ***p<0.001.

EV experience remained significant overall, EV ownership turned from highly significant (ß=.272, p<.001) to non-significant in Steps three (ß=.124, p=.063) and four (ß=.103, p=.130). Model 2, however, was significant, with F_{change}=6.645, p=.002. Also, in this case, the TPB variables significantly predicted intention. However, the R^2-value was smaller than in the previous models, explaining less variation. Finally, Step 4 was significant as well, with F_{change}=3.118, p=.046. This is due to the fact that community identification was a significant predictor of intention, with ß=.153, p=.016. Community sustainable energy motivation was, again, not significant. One explanation for the non-significant effect of community sustainable energy motivation on intention might be the strong correlation between this predictor and subjective norm, undermining the effect on intention.

The results support our hypothesis that individuals' decision is guided not only by individual motivations but also by their identification with their community if they belong to a specific energy community. People who are part of an energy community thus consider their community in their decision-making process regarding future V2G charging.

5 CONCLUSION

The current study drew on a well-established socio-psychological model to explain the intention to adopt V2G. As we had a special focus on energy community members, we extended the model with community-specific constructs, namely community identification and community sustainable energy motivation. Furthermore, as we collected data in three countries – Germany, Switzerland, and France – and asked participants about their experience with EVs, we included these measures as well in our model. Overall, the revised model accounted for the intention to participate in V2G, explaining 59% of the variance in the total sample, 60% of the variance in the sample, including non-members, and 45% of the variance in the sample, including energy community members. The results support our hypothesis that the decision of an individual who is part of an energy community is guided by their social identity, specifically the way in which they define themselves as part of a local community and, therefore, consider the communities' objectives.

Energy communities unite individuals pursuing similar goals. Besides aims to foster bottom-up energy transitions, protect the environment, and achieve climate goals, communities enable individuals to connect and act collectively. Our study showed that apart from individual motives, identification with the community or the neighborhood is another important factor guiding individuals' behavior. We exemplified this based on the intention to adopt V2G.

Finally, we included a country comparison in our model as well as the level of EV experience. We defined three levels of EV experience – no EV experience, EV experience, and EV ownership. As expected, the country did not predict the intention to adopt V2G, whereas EV experience and EV ownership did. This is true for the total sample and the sample comprised of non-members. For energy community members, the effect of EV experience on intention was smaller than in the other two models, whereas the effect of EV ownership diminished.

Our research is, however, not without limitations. For example, in our research, we talked about the energy community as it was one entity. Yet, even though we provided a definition of an energy community, energy communities can be very different in their form and size. Moreover, energy communities might differ between countries and might, due to the different energy systems, pursue different goals. Moreover, V2G is very abstract to most people. Although we provided a definition and explanation of V2G and people had to answer a comprehension question, they might not foresee the benefits and consequences of such a technology. Thus, evaluating such a novel technology is necessarily hypothetical and might not reflect peoples' actual decisions. Finally, our sample is not representative for homeowners in the three countries, as we supplemented the main sample with additional energy community members. Yet, combining purposive and randomized sampling methods facilitates our objective to assess the role of energy community membership in shaping individual's decision to engage with V2G technology.

In spite of these limitations, we can summarize that our results show the importance of energy communities and local neighborhoods for stimulating V2G charging, even when considering individuals with different levels of EV experience and from different countries. Our results have important policy implications, as they suggest that energy communities can act as enablers of novel energy technologies. Being a member of an energy community seems to strengthen the link between community identification and V2G intentions. Practitioners could thus emphasize the value of V2G for local communities and link it to existing energy communities currently focusing on other aspects of the sustainable energy transition.

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6 REFERENCES

Azjen, I. (1991). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*(50), 179–211.

Baumgartner, N., Kellerer Franziska, RUPPERT, M., HIRSCH, S., & Mang, Stefan, Fichtner, Wolf (2022). Does experience matter? Assessing user motivations to accept a vehicle-to-grid charging tariff. *Transportation Research Part D: Transport and Environment*, *113*, 103528. https://doi.org/10.1016/j.trd.2022.103528

Chen, C., Zarazua de Rubens, G., Noel, L., Kester, J., & Sovacool, B. K. (2020). Assessing the socio-demographic, technical, economic and behavioral factors of Nordic electric vehicle adoption and the influence of vehicle-to-grid preferences. *Renewable and Sustainable Energy Reviews*, *121*, 1–13. https://doi.org/10.1016/j.rser.2019.109692

Fielding, K. S., McDonald, R., & Louis, W. R. (2008). Theory of planned behaviour, identity and intentions to engage in environmental activism. *Journal of Environmental Psychology*, *28*(4), 318–326. https://doi.org/10.1016/j.jenvp.2008.03.003

Friends of the Earth Europe, Greenpeace EU, REScoop.eu, & Energy Cities. (2019). *Europa entfesselt: Die Energiewende in Bürgerhand.*

Goedkoop, F., Sloot, D., Jans, L., Dijkstra, J., Flache, A., & Steg, L. (2022). The Role of Community in Understanding Involvement in Community Energy Initiatives. *Frontiers in Psychology*, *12*, 775752. https://doi.org/10.3389/fpsyg.2021.775752

Hasan, S. (2021). Assessment of electric vehicle repurchase intention: A survey-based study on the Norwegian EV market. *Transportation Research Interdisciplinary Perspectives*, *11*, Article 100439. https://doi.org/10.1016/j.trip.2021.100439

Haustein, S., Jensen, A. F., & Cherchi, E. (2021). Battery electric vehicle adoption in Denmark and Sweden: Recent changes, related factors and policy implications. *Energy Policy*, *149*, Article 112096. https://doi.org/10.1016/j.enpol.2020.112096

Huber, J., Schaule, E., Jung, D., & Weinhardt, C. (2019). Quo Vadis Smart Charging? A Literature Review and Expert Survey on Technical Potentials and User Acceptance of Smart Charging Systems. *World Electric Vehicle Journal*, *10*(4), 85. https://doi.org/10.3390/wevj10040085

Kempton, W., & Tomić, J. (2005). Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. *Journal of Power Sources*, *144*(1), 280–294. https://doi.org/10.1016/j.jpowsour.2004.12.022

Knezovic, K., Martinenas, S., Andersen, P. B., Zecchino, A., & Marinelli, M. (2017). Enhancing the Role of Electric Vehicles in the Power Grid: Field Validation of Multiple Ancillary Services. *IEEE Transactions on Transportation Electrification*, *3*(1), 201–209. https://doi.org/10.1109/TTE.2016.2616864

Koirala, B. P., Araghi, Y., Kroesen, M., Ghorbani, A., Hakvoort, R. A., & Herder, P. M. (2018). Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. *Energy Research & Social Science*, *38*, 33–40. https://doi.org/10.1016/j.erss.2018.01.009

Lee, S. S., Kim, Y., & Roh, T. (2023). Pro-environmental behavior on electric vehicle use intention: Integrating value-belief-norm theory and theory of planned behavior. *Journal of Cleaner Production*, *418*, 138211. https://doi.org/10.1016/j.jclepro.2023.138211

Lowitzsch, J., Hoicka, C. E., & van Tulder, F. J. (2020). Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future? *Renewable and Sustainable Energy Reviews*, *122*, 109489. https://doi.org/10.1016/j.rser.2019.109489

Maxwell, J. (2009). Designing a Qualitative Study. In L. Bickman & D. J. Rog (Eds.), *The SAGE handbook of applied social research methods* (2. ed., pp. 214–253). Sage. https://doi.org/10.4135/9781483348858.n7

Ministère de la Transition Écologique et de la Cohésion des Territoires. (2022). *Données et études statistiques: Pour le changement climatique, l'énergie, l'environnement, le logement, et les transports*. https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-le-parc-automobile-francais-au-1er-janvier-2022

Noel, L., Papu Carrone, A., Jensen, A. F., Zarazua de Rubens, G., Kester, J., & Sovacool, B. K. (2019). Willingness to pay for electric vehicles and vehicle-to-grid applications: A Nordic choice experiment. *Energy Economics*, *78*, 525–534. https://doi.org/10.1016/j.eneco.2018.12.014

Postmes, T., Haslam, S. A., & Jans, L. (2013). A single-item measure of social identification: Reliability, validity, and utility. *The British Journal of Social Psychology*, *52*(4), 597–617. https://doi.org/10.1111/bjso.12006

Reis, I. F., Gonçalves, I., Lopes, M. A., & Henggeler Antunes, C. (2021). Business models for energy communities: A review of key issues and trends. *Renewable and Sustainable Energy Reviews*, *144*, Article 111013. https://doi.org/10.1016/j.rser.2021.111013

Schram, W. L., Aghaie, H., Lampropoulos, I., & van Sark, W. G. (2021). Insights on the capacity value of photovoltaics, community batteries and electric vehicles. *Sustainable*

Energy, Grids and Networks, *26*, 100421. https://doi.org/10.1016/j.segan.2020.100421

Sloot, D., Jans, L., & Steg, L. (2018). Can community energy initiatives motivate sustainable energy behaviours? The role of initiative involvement and personal pro-environmental motivation. *Journal of Environmental Psychology*, *57*, 99–106. https://doi.org/10.1016/j.jenvp.2018.06.007

Sloot, D., Jans, L., & Steg, L. (2019). In it for the money, the environment, or the community? Motives for being involved in community energy initiatives. *Global Environmental Change*, *57*, Article 101936, 2–10. https://doi.org/10.1016/j.gloenvcha.2019.101936

Sovacool, B. K., & Hirsh, R. F. (2009). Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. *Energy Policy*, *37*(3), 1095–1103. https://doi.org/10.1016/j.enpol.2008.10.005

SPD, Bündnis 90/Die Grünen and FDP. (2021). *Koalitionsvertrag: Daring more progress. Alliance for freedom, justice and sustainability.*

van Heuveln, K., Ghotge, R., Annema, J. A., van Bergen, E., van Wee, B., & Pesch, U. (2021). Factors influencing consumer acceptance of vehicle-to-grid by electric vehicle drivers in the Netherlands. *Travel Behaviour and Society*, *24*, 34–45. https://doi.org/10.1016/j.tbs.2020.12.008

Wong, S. D., Shaheen, S. A., Martin, E., & Uyeki, R. (2023). Do incentives make a difference? Understanding smart charging program adoption for electric vehicles. *Transportation Research Part C: Emerging Technologies*, *151*, Article 104123, 1–22. https://doi.org/10.1016/j.trc.2023.104123

OVERCOMING COMMUNICATION AND INFORMATION BARRIERS IN THE DUTCH ENERGY TRANSITION:

A Study on Online Sources of Energy-Efficient Retrofits in Homeowners' Associations

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Abstract

This paper focuses on the information and communication challenges in the Dutch energy transition in the built environment, with a specific focus on energy-efficient retrofits (EER) in homeowners' associations (HOAs). The research surveyed the literature on barriers and drivers related to information and communication in EERs. It systematically investigated the information sources and communication channels provided by governmental and non-governmental institutions on financial subsidies, step-by-step guidelines, home evaluation tools, and participation guidelines. Lastly, the research categorised and evaluated the interfaces designed to deliver the information to the Dutch homeowners' associations. The research also explored the barriers and drivers related to trust issues in EERs as the correlation between trust and information and communication emerged as one of the most prominent factors affecting EERs' acceptance. The paper analysed the online information sources based on readability, credibility, and interactivity, focusing on accessibility and the ability to generate tailor-made suggestions. The analysis revealed that the online information sources are disorganised and dispersed. The online platforms rarely provide information on prior case studies and more on financial subsidies, guidelines, and EER benefits. Lastly, we discussed the main barriers and potential solutions for these challenges.

1. INTRODUCTION

The Dutch government set the climate goals of 95% mitigated emissions in 7 years and being gas-free in 27 years. Regarding these targets, the central government designs policies and funds for citizens to ease the financial burdens of renovating their houses for more energy efficiency. Energy-efficient renovations (EER) are complicated processes, and despite the financial aid from the local or central government, homeowners tend to postpone this process due to nuisance, information overload or social reasons. The Dutch government's targets for mitigating the emissions and gas-free heating transition deeply rely on renovating the existing building stock. Around 1.4 million houses need to improve their energy efficiency label to/above C in the next seven years, approximately 200,000 houses per year, which is very ambitious (RVO, 2022). Besides the financial, material, labour and management challenges, there are 143.000 homeowners' associations (HOAs, *Vereniging van Eigenaren (VvE) in Dutch*) in the Netherlands (de Statistiek, 2016), and these multi-family settlements, depending on the year they built, require 80% consent from the homeowners to be able to proceed in renovation processes.

The barriers in EER are diverse and challenging to overcome; on top of it, HOAs require more effort to apply EERs due to the challenges in group decision-making processes. The barriers in EER are related to financial barriers, process barriers, social barriers, and finally, information barriers (Prieto et al., 2023). However, information barriers play a fundamental role due to their effect on the acceptance and application of EER (Jia et al., 2021). Local authorities initiated one-stop shops (OSS) to cope with these challenges and aimed to go to citizens and talk to them in their neighbourhood and answer their specific questions. This approach worked well due to the personal relationship that citizens have with the authorities and their physical appearance (Kwon & Mlecnik, 2021). On the commercial side, the concept of OSS also helped citizens hire intermediaries in EER and discuss their renovation projects under Integrated Home Renovation Services (IHRS). One of the reasons behind the success of the IHRS is the ability of these intermediaries to curate and convey information about EER and deliver tailored guidelines to homeowners or associations (De Wilde & Spaargaren, 2019). The experts working at IHRS intermediaries provide the relevant topics and the experience they had to their customers. IHRS also eases the EER process due to their ability to offer packages that include all the services homeowners need during the EER, from auditing to the execution of the renovations. Moreover, these intermediaries also help citizens to apply for the related funding scheme and go through the entire process. Intermediaries' role in information delivery is crucial due to the complicated nature of EERs.

The importance of conveying relevant information to avoid 'information overload' is a fundamental factor in any field (Levy, 2008), as stated in EER research (De Wilde, 2019). In this manner, the IHRS intermediaries are crucial in EER. Yet, it is also stated that homeowners who aim to go through an EER process start with gathering information, generally from online sources (Arning et al., 2020); also, the initial phase is similar to the members of HOAs (Paradies et al., 2017). Even though they get information from IHRS businesses, these individuals verify the knowledge they got from the intermediaries by checking trustworthy official websites such as Milieu Centraal and Vereniging Eigen Huis (De Wilde, 2019, p. 19). The neutrality of these platforms provides more trust to homeowners. So, the delivery of the information from a trusted party becomes crucial for any homeowner, especially homeowners who are in need of orientation, to come to a consensus to apply EER in HOAs. The differences between the members' level of knowledge in sustainable buildings, motivations for EERs and income level. From a social practice theory (SPT) point of view, Shove et al. argue that sustainable practices require materials, meanings given to the practice and competency to 'perform' the practices (Shove et al., 2012). However, to disseminate the practice, individuals need to perform the practice, share the meanings and let others join to spread the practice. The channels to disseminate knowledge, therefore the practice, is one of the fundamental parts of SPT. In the digital information age, the dissemination of practice via digital platforms is inevitable. In our case, this research aimed to explore the online sources published by governmental institutes and non-profit organisations to understand how these official institutions disseminate information based on the practice of EERs.

In this paper, we investigated the information and communication problems from the SPT perspective to understand how these practices are disseminated via governmental or non-profit organisations' websites and for which kind of audiences. Furthermore, we will analyse the contents of the websites accessible via popular search engines in the Netherlands on EER in HOA and the tools and representation methods used. Therefore, the research question is: *What kinds of information do governmental online sources disseminate on energy-efficient renovations in homeowners associations in the Netherlands, and how do the online sources convey information to various audiences?* This research aims to highlight the gap in scientific research on the accessible information online for citizens and the tools or representation methods used to convey information. The methodology of web-based content analysis is used in exploratory research for the preliminary research stage. The importance of the contribution of this paper is that the information published online for society on critical topics such as EERs in HOAs should also be investigated scientifically to exploit gaps and future potentials.

2. INFORMATION BARRIERS IN EER AND HOA

In the EU and the Netherlands, the construction industry is developing carbon-neutral, or positive, solutions to housing, yet the existing housing stock suffers from low energy efficiency. The European Commission (EC) and Netherlands Enterprise Agency (RVO) are funding research to understand the barriers and motivators for individual homeowners, housing corporations, HOAs, and social housing. There are various categorisations of barriers in the literature from the individual level to the institutional level, yet the information to apply EER is too complex for citizens, thus hindering action (De Vries, 2020). The information complexity includes financial instruments, building information, renovation technologies, and the renovation process (Jia et al., 2021), and the information on the EERs can be complicated for people who have no expertise in the field as well (De Wilde, 2019).

Regarding the HOAs, there are other barriers to group dynamics in decision-making (Paradies et al., 2017). Therefore, there are differences in the renovation phases between individual homeowners and HOA members, such as the orientation of the members and the voting process. However, the initial phase is similar to what Arning et al. described, getting informed and creating a motivation for EER. Although the decision-making dynamics are different, the information needed is similar to an extent, except for participation and voting steps. Moreover, The amount of information to understand can be overwhelming for individuals (De Vries, 2020) The barriers in EERs are not the same at every stage of the EER process. There are early stages that encapsulate the awareness and information collection stages, followed by the stages of audits, planning, and concept designs (Arning et al., 2020; Prieto et al., 2023), which require homeowners, designers, and constructors to communicate (Jensen et al., 2013). In these stages, communication and coordination issues in EERs are among the most mentioned barriers in the literature (Prieto et al., 2023). The complexity of implementation of EERs (Ebrahimigharehbaghi et al., 2019), the administration of the process (Liu et al., 2020), or not being able to participate in the decision process due to lack of knowledge (Xue et al., 2022) are also major challenges for EERs.

The barriers mentioned above were also challenged by the EU, Dutch national and regional governments, municipalities, NGOs, and private entrepreneurs with new policies, subsidies, and communication channels. Moreover, the complicated process of EERs created a new opportunity for middle actors, called intermediaries, to help ease some of the barriers mentioned above. Intermediaries are bridges connecting different levels of actors where direct interaction is missing (Kivimaa et al., 2019). In the EER context, intermediaries are actors who help citizens unburden some of the complicated procedures of the EER process and gather reliable information (Arning et al., 2020; De Wilde & Spaargaren, 2019). It is not just the individuals these intermediaries influence but also other intermediaries and policy actors can be influenced by these binding middle actors (Janda & Parag, 2013). The research also points out that the lack of actors who help lead the EER process hampers decision-making (Laizane et al., 2016). The intermediaries help homeowners in the information-gathering phase by providing reliable information (Arning et al., 2020) and connections with the supply side of the process (De Wilde & Spaargaren, 2019). Decuypere points out the effect of intermediaries in EER decisions is important for the energy transition (Decuypere et al., 2022).

One of the effects of intermediaries in EERs is their ability to create trust. Arning et al.’s findings show that homeowners' trust in the intermediaries during information navigation and decision-making better facilitates EERs (Arning et al., 2020). Several scholars state that social interactions and the person who delivers the message play an important role in the acceptance of EER (De Vries, 2020; Ebrahimigharehbaghi et al., 2019). The social influence of individuals or neighbours is an essential factor in EER, and therefore, it is important to look at the interactions between trusted parties, such as governmental organisations and individuals from the social environment. Although it depends on public trust in governmental organisations, the reliability and credibility of the information is one of the critical factors that make the information search phase difficult (Jia et al., 2021). Dutch homeowners feel the need to check the credibility of information if the source is not coming from an unbiased non-profit organisation or a neighbour (De Wilde, 2019). This also points out that online information sources have a role in informing homeowners in times of doubt.

The in-person interaction is more impactful, yet the need for local online websites is vital in community engagement. Kwon and Mlecnik also argue that even the offline consultancy for EERs is effective, it requires higher budgets, and since local administrations have more trust in the digital content they share, using web-based technologies to inform homeowners has considerable potential (Kwon & Mlecnik, 2021). It is evident that information delivery and communication play a pivotal role in EERs. However, the research on Dutch online resources in the energy transition literature is limited. Despite research on the barriers and underlying reasons for these barriers, there are 1.4 million homes with an energy label below 'C' to renovate in the Netherlands (RVO, 2022). Even though the number of houses undergoing energy renovations increases every year in the Netherlands, the percentages for medium and deep renovation rates stand at 0.8% and 0.1%, respectively (European Commission. Directorate General for Energy. et al., 2019). The number of experts, the required budgets, and the number of renovations needed to reach the goals of Klimaat Akkoord seem problematic. Therefore, this paper tried to investigate the online governmental information sources accessed via popular search engines and analysed the content based on the format of the information, the types of information, the targeted audience and the date of publication to understand the distribution of information on EERs for the HOA members.

3. METHODOLOGY

The methodology used in this research aimed to understand the information conveyed by governmental, non-profit and commercial institutions from the user's perspective, in our case, the homeowners in HOAs. Therefore, web-based content analysis has investigated the knowledge shared online by these institutions. Web-based content analysis is unobtrusive yet unstructured as well (I. Kim & Kuljis, 2010). The method has been applied in sustainability research to investigate the sustainability measures in hotels (Hsieh, 2012), university organisations (Hasim et al., 2018), and campuses (A. A. Kim et al., 2018). In this study, the aim is not to analyse the content of specific institutions but the content homeowners can access on EER in HOAs. The internet content accessed by individuals was investigated via popular search engines regarding public health awareness (Buchbinder & Bourne, 2018). In this paper, we acquired the website URLs using keywords through search engines rather than the institutions. Search engine data collection has its limitations due to the dynamic nature of page ranking algorithms; however, it is helpful to find practice-based content using specific keywords (Falco & Kleinhans, 2018).

The methodology for analysing the data focuses on the information types found essential in EER (Jia et al., 2021). The type of information can stimulate the homeowners to engage, yet the amount of information is a criterion. The textual explanations written for experts and scientific purposes differ from the general audience, and to be able to achieve inclusive information communication, we compared the word counts on the website to understand how the audience is a factor in word counts. Following the word counts, it is important to incorporate other types of knowledge representations, and for that reason, we also analysed the usage of other representational techniques, illustration, visualisation and videos, Table 1. Lastly, we analysed whether interactive tools have been implemented in the webpages to directly interact with the audience and what kind of audience has been targeted in these websites.

For the content analysis, we conducted two kinds of approaches. Initially, we checked the existence of textual, visual, and interactive tools: text language, illustrations, visualisations, step-by-step guidance, tailored advice, and chatbot. In the second part, we coded the content on websites based on information types: benefits of EERs, information on finance, technology, processes, and buildings, and reviews of citizens or finished projects. The content is analysed from the translated versions of the texts or translated versions of the video content. The texts were coded as they included any information on the types above. The content is coded based on information regarding:

- The benefits of energy savings applications or renovations,
- The financial tools to get a loan or subsidy, or information about 'Euro' currency as a cost or a gain
- The technologies to implement during EER or introduce techniques to apply EER,
- The EER process, such as steps to initiate the EER or the possible step that gives knowledge about the EER process,
- The existing building stock or related to the existing building,
- Finished projects or citizen reviews based on a previous EER experience

4. DATA COLLECTION

The dataset is collected by manually selecting all the textual information from the website via an incognito browser (Google Chrome and Microsoft Edge). The research aimed to find out the content users' access via popular search engines in the Netherlands using **"vve energiezuinige renovatie"** *(HOA energy-efficient renovation)* keywords, which can be seen in Figure 1. Therefore, we collected the URLs of the search results only from the first page of the search engines. Google Search, Bing Search and Startpagina.nl were used to conduct the search. All the browsers were used in 'incognito' mode, and the connection was done via the TU Delft network. This information is important for the repeatability of the research due to the varying results based on the location where the search is done by the search engines. The sponsored or advertised results were excluded as they do not reflect the page ranking algorithms.

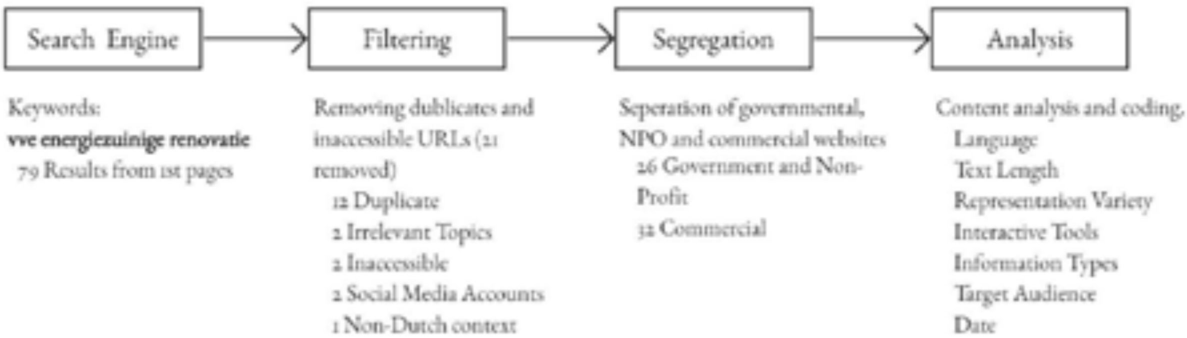

Figure 1: Data collection and filtering chart.

Each URL is aggregated in a .xls table via the URL (Appendix I). Every page is scraped in its original language, which is primarily Dutch; for later documentation, every webpage is printed as a PDF for later comparison if needed. All the websites have been scraped by the 'select all' action, which selects all the selectable elements in the webpage and then pasted into a word counter (Microsoft Word) for textual content length, and the word count is done in the original language of the websites. Following the PDF documentation and word count, the contents were translated into English via 'Google Translate' or 'Microsoft Translate' on the web browsers Google Chrome and Microsoft Bing, respectively.

We reached 79 webpages via the first pages of search engines; 21 of the URLs were discarded due to being duplicates, social media links, inaccessibility, or irrelevancy to the Dutch EER in the HOA context. Out of 58 pages after the filtering, only 26 belonged to governmental or non-profit institutions. The research also analysed commercial websites (32 web pages) to be able to compare the tools used in information delivery; however, due to the marketing incentives that may affect the investigation, their content was analysed.

5. RESULTS AND DISCUSSION

The results show that the websites lack interactive tools and representation methods other than textual explanations. Regarding the analysed webpages, textual explanation is the essential element, yet the lengths of the texts do not vary greatly based on the webpage format, see Table 1. The important factor to point out is that the word count changes drastically if the information is conveyed via a PDF document; in that case, the word count goes from 5,000 to 18,000. These PDFs are mostly reports; therefore, they tend to have larger text bodies and can be addressed to other audiences. Due to this huge difference in numbers, we excluded these in the word count numbers. The use of other information representations is not very common, such as illustrations, visualisation, and videos. Even though sharing a video created by another official entity can easily be embedded on the website. The usage of a chatbot, tailored guidance, or step-by-step (SbS) guidance is low. Chatbots are not implemented in any governmental web pages, and only 10% of commercial websites implemented this innovative technology.

	Average Word Count (no PDF)	Textual Explaination	Illustration	Visualization	Video Explaination	Chatbot	TailoredGuidance	Step-by-Step Guidance	Benefits	Fin. Info	Tech. Info	Process Info	Building Info
Governmental and NPO (26)	653 words	100%	19%	12%	4%	0%	0%	23%	62%	69%	46%	42%	19%
Commercial (32)	718 words	100%	10%	13%	3%	10%	0%	3%	55%	45%	52%	13%	26%

Table 1: Web-based content analysis comparison of governmental and commercial webpages.

The number of examples from previous projects and citizen reviews was mentioned in only 12% of the government or non-profit organisation websites, although the effectiveness of familiarity or social influence was argued in the literature for several years. The customer reviews in commercial websites are not analysed in due to the possible marketing incentives. The websites were all in Dutch language, and even though several have English as a language option, the content accessed was not specifically posted in multiple languages; the language options were designed to link to the home page of the website in English and not the content in the first link. Moreover, the target audience of the websites was mainly HOA members, 85%, yet experts were 4%, and non-specified content was 12%. Even though the homeowners have been addressed in the websites, the information about collective decision-making and its challenges were only mentioned in 38% of the websites. The HOAs in the Netherlands have different legal frameworks based on the year they are built, and this is identified as one of the legal barriers to EER in HOAs (Siewers, 2022). Despite the research, there is a lack of this legal knowledge. The need for interactive tools to curate the knowledge of homeowners can be seen.

The analysis showed that dates provided on the websites and only 12% of the web pages were from 2023, dates between 2022 and 2023 were 15%, and pages before 2022 were 15%. Unfortunately, 58% of the web pages did not provide any dates. This is also important due to the changing deadlines for applying certain subsidies from the Dutch government, especially for HOAs. The Dutch government's site provides two dates, one for publication and another for the update.

Warmtefonds.nl's 'Frequently Asked Questions' (FAQ) page, which inherits an extensive FAQ section with a search engine embedded in the FAQ section, is one of the most comprehensive web pages amongst the URLs. However, due to the methodology for the word count of webpages, Warmtefonds's page is not high; the page design is based on expandable questions and answers, where 72 questions and their answers are provided just for the HOAs. The concept of an in-house search engine helps the knowledge base to be more accessible towards personal queries, yet if the query does not match directly with the intended answer, then the result section may be empty. Therefore, it is practical to consider intelligent systems that can correct misspellings and match synonyms in the knowledge base. This is an important aspect of websites if they look for engagement from the user.

Intelligent systems are needed to widen the targeted audience. All the websites analysed in this paper were originally in Dutch; this may be a result of the search keywords in search engines, yet there were rarely multilingual options, and these options were not related to the content. It is unsurprising to see all the content in Dutch, yet the Netherlands have many residents who are not competent enough to understand the content about EER in HOA. There are text translation tools we use to analyse the content, yet the accuracy of these tools is not verified, and regulations and legislation should not be misunderstood, especially where a process such as EER in HOA has many to consider.

The lack of interactivity or personalisation is a serious problem. However, the lack of exemplary projects and citizen reviews is a missing part of content generation. The research also suggests that the customer reviews on EER may help other citizens to understand how other citizens had their processes, yet also points out how this development would be financially burdening small and medium local authorities (Kwon & Mlecnik, 2021). Therefore, the knowledge base created in the governmental webpages should consider disseminating citizen reviews via their trusted platforms without marketing concerns. Moreover, since the search engines give priority to the paid links on their web pages, this can be an opportunity for governmental websites to promote their official pages. The implementation of customer reviews on governmental websites can also trigger social influence among citizens and raise interest in EERs.

6. CONCLUSIONS

This research aimed to explore the information conveyed online on EER in HOAs based on the barriers related to information overload and reliability by many researchers. The Dutch government is supporting the energy transition in the built environment with different funding schemes for various types of housing, and there are many websites to convey this information to citizens looking for information. This research investigated what kinds of information is disseminated about EER in HOA by governmental organisations in the Netherlands. The findings highlight several aspects of how information is presented and disseminated through governmental or NPO websites, and the results offer insights into the information homeowners find about EER in HOAs with a specific scope. The dissemination of the information is mainly via web pages. There are comprehensive websites that try to cover all the topics needed, yet it is not easy to navigate to find the required information on demand.

From the perspective of SPT (Shove et al., 2012), the practices can only be disseminated and embraced if there are material, aligned meanings between individuals and the competencies when they are performed. The performance of the practice is essential for the local community to accept the practice. Therefore, the lack of past practices, experience or reviews can hinder the social influence and acceptance of EERs due to the absence of visible performance. The potential of local administrations can be amplified if the reviews are presented via their websites (Kwon & Mlecnik, 2021). SPT points out that the locality matters due to the shared context, such as social connections, and the information curated and generated for the local context is relevant to the people. Here, we must point out that Kwon & Mlecnik also point out that Dutch local administrations have challenges in designing modular websites that have the potential to grow with modules. This scalability problem is crucial when the Netherlands aims to renovate millions of houses.

The lack of intelligent agents, such as civil servants or chatbots, that help individuals find related information in a language they can understand can be an initial step for EER in HOAs to cope with the information overload. Even though technologies like chatbots are applied in the public sector (Makasi et al., 2022), the governmental webpages investigated in this paper still need to implement such technologies. The information delivery with intelligent systems is also becoming context-specific. Chatbots such as ClimateBert are being tailored for specific uses to convey information about complex documents like the IPCC Report 2022, with around 600 pages (Vaghefi et al., 2023). The information can be interactively extracted with dialogue with the chatbot from a comprehensive document, which, in our case, the reports, legal documents and other technical information can be a source for interactive information gathering.

On the other hand, intelligent agents are not the only technique to ease the information challenges; the representation techniques seem to be lacking. Although the benefits that videos, illustrations, or visualisations can provide in communication, these representation modes are not discussed in this paper and require further assessment of the impacts of these different modes. The language barriers in information communication may also be eased with the use of varying knowledge representations, increasing inclusiveness.

This research aimed to understand the online information search phase of EER in HOA using standard search engines and evaluate the governmental content that citizens access. The paper also investigated the tools, representation methods, target audience and information types these websites convey and compared several features between governmental and commercial web pages. The investigations found that the information on webpages is not easy to navigate or not personalised to curate information based on the needs of the individuals. Furthermore, the information on the websites has the potential to contain old information and a scalable method to check the viability of the information found missing. This exploratory study is a preliminary study for the AI-supported information organisation and communication in EER in HOA; therefore, the results reveal a need for more comprehensive research on the homeowners' perspective on accessing information using the internet, either with semi-structured interviews and user data from trusted websites. Although the existing intermediaries in the EER ecosystem play a crucial role, digital platforms can support the acceptance of EERs in HOAs by providing interactive and tailored information based on the context of the homeowners. Future research related to this research will focus on organising the information associated with EER in HOAs and applying a conversational AI method (chatbot) to engage with the citizens based on their questions. After all, this paper pointed out that interactive agents can be a part of the energy transition process where the knowledge can be disseminated considering the context of the individuals.

7. REFERENCES

Arning, K., Dütschke, E., Globisch, J., & Zaunbrecher, B. (2020). The challenge of improving energy efficiency in the building sector: Taking an in-depth look at decision-making on investments in energy-efficient refurbishments. In *Energy and Behaviour* (pp. 129–151). Elsevier. https://doi.org/10.1016/B978-0-12-818567-4.00002-8

Buchbinder, R., & Bourne, A. (2018). Content analysis of consumer information about knee arthroscopy in Australia. *ANZ Journal of Surgery*, *88*(4), 346–353. https://doi.org/10.1111/ans.14412

de Statistiek, C. B. voor. (2016). *Aantallen en kenmerken van Verenigingen van Eigenaren – een verkennend onderzoek*. Den Haag/Heerlen/Bonaire: Centraal Bureau voor de Statistiek.

De Vries, G. (2020). Public Communication as a Tool to Implement Environmental Policies. *Social Issues and Policy Review*, *14*(1), 244–272. https://doi.org/10.1111/sipr.12061

De Wilde, M. (2019). The sustainable housing question: On the role of interpersonal, impersonal and professional trust in low-carbon retrofit decisions by homeowners. *Energy Research & Social Science*, *51*, 138–147. https://doi.org/10.1016/j.erss.2019.01.004

De Wilde, M., & Spaargaren, G. (2019). Designing trust: How strategic intermediaries choreograph homeowners' low-carbon retrofit experience. *Building Research & Information*, *47*(4), 362–374. https://doi.org/10.1080/09613218.2018.1443256

Decuypere, R., Robaeyst, B., Hudders, L., Baccarne, B., & Van De Sompel, D. (2022). Transitioning to energy efficient housing: Drivers and barriers of intermediaries in heat pump technology. *Energy Policy*, *161*, 112709. https://doi.org/10.1016/j.enpol.2021.112709

Ebrahimigharehbaghi, S., Qian, Q. K., Meijer, F. M., & Visscher, H. J. (2019). Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making? *Energy Policy*, *129*, 546–561. https://doi.org/10.1016/j.enpol.2019.02.046

European Commission. Directorate General for Energy., IPSOS., & Navigant. (2019). *Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU: Final report.* Publications Office. https://data.europa.eu/doi/10.2833/14675

Falco, E., & Kleinhans, R. (2018). Digital Participatory Platforms for Co-Production in Urban Development: A Systematic Review. *International Journal of E-Planning Research*, *7*(3), 52–79. https://doi.org/10.4018/IJEPR.2018070105

Hasim, M. S., Hashim, A. E., Ariff, N. R. M., Sapeciay, Z., & Abdullah, A. S. (2018). Commitment to sustainability: A content analysis of website for university organisations. *IOP Conference Series: Earth and Environmental Science*, *117*, 012046. https://doi.org/10.1088/1755-1315/117/1/012046

Hsieh, Y. (Jerrie). (2012). Hotel companies' environmental policies and practices: A content analysis of their web pages. *International Journal of Contemporary Hospitality Management*, *24*(1), 97–121. https://doi.org/10.1108/095961112

Janda, K. B., & Parag, Y. (2013). A middle-out approach for improving energy performance in buildings. *Building Research & Information*, *41*(1), 39–50. https://doi.org/10.1080/09613218.2013.743396

Jensen, P. A., Gohardani, N., Björk, F., Kanarachos, S., & Fokaides, P. A. (2013). SUSTAINABILITY EVALUATION OF RETROFITTING AND RENOVATION OF BUILDINGS IN EARLY STAGES. *Proceedings of 7th Nordic Conference on Construction Economics and Organisation*. Nordic Conference on Construction Economics and Organisation.

Jia, L., Qian, Q. K., Meijer, F., & Visscher, H. (2021). How information stimulates homeowners' cooperation in residential building energy retrofits in China. *Energy Policy*, *157*, 112504. https://doi.org/10.1016/j.enpol.2021.112504

Kim, A. A., Sadatsafavi, H., Medal, L., & Ostergren, M. J. (2018). Impact of communication sources for achieving campus sustainability. *Resources, Conservation and Recycling*, *139*, 366–376. https://doi.org/10.1016/j.resconrec.2018.08.024

Kim, I., & Kuljis, J. (2010). Applying Content Analysis to Web-based Content. *Journal of Computing and Information Technology*, *18*(4), 369. https://doi.org/10.2498/cit.1001924

Kivimaa, P., Boon, W., Hyysalo, S., & Klerkx, L. (2019). Towards a typology of intermediaries in sustainability transitions: A systematic review and a research agenda. *Research Policy*, *48*(4), 1062–1075. https://doi.org/10.1016/j.respol.2018.10.006

Kwon, M., & Mlecnik, E. (2021). Modular Web Portal Approach for Stimulating Home Renovation: Lessons from Local Authority Developments. *Energies*, *14*(5), 1270. https://doi.org/10.3390/en14051270

Laizane, M., Vardanjana, I., & Laizane, I. (2016). Social aspects of multi-family apartment building renovation. *Proceedings of the International Scientific Conference*.

Levy, D. M. (2008). Information Overload. In K. E. Himma & H. T. Tavani (Eds.), *The Handbook of Information and Computer Ethics* (1st ed., pp. 497–515). Wiley. https://doi.org/10.1002/9780470281819.ch20

Liu, G., Li, X., Tan, Y., & Zhang, G. (2020). Building green retrofit in China: Policies, barriers and recommendations. *Energy Policy*, *139*, 111356. https://doi.org/10.1016/j.enpol.2020.111356

Makasi, T., Nili, A., Desouza, K., & Tate, M. (2022). *Public Service Values and Chatbots in the Public Sector: Reconciling Designer efforts and User Expectations*. Hawaii International Conference on System Sciences. https://doi.org/10.24251/HICSS.2022.292

Paradies, G., Beekman, L., Ooms, M., de Koning, N., Mulder, G., van Baar, M., Brester, C., Cremers, R., Schneijdenberg, J., & van Winden, J. (2017). *De duurzame VvE: Rapportage eerste fase*. Topsector Energie - Samenwerking Topsector Energie en Maatschappij (STEM).

Prieto, A., Armijos-Moya, T., & Konstantinou, T. (2023). Renovation process challenges and barriers: Addressing the communication and coordination bottlenecks in the zero-energy building renovation workflow in European residential buildings. *Architectural Science Review*, 1–13. https://doi.org/10.1080/00038628.2023.2214520

RVO. (2022). *Monitor verduurzaming gebouwde omgeving 2022*. Ministerie van Buitenlandse Zaken.

Shove, E., Pantzar, M., & Watson, M. (2012). *The dynamics of social practice: Everyday life and how it changes*. SAGE.

Siewers, C. (2022). *Balans in het appartementsrecht: Wijzigen van de splitsingsakte vereenvoudigd : flexibiliteit en zekerheid in de rechtsverhouding tussen appartementseigenaars*. Stichting tot Bevordering der Notariële Wetenschap ; Wolters Kluwer.

Vaghefi, S. A., Wang, Q., Muccione, V., Ni, J., Kraus, M., Bingler, J., Schimanski, T., Colesanti-Senni, C., Webersinke, N., Huggel, C., & Leippold, M. (2023). *chatClimate: Grounding Conversational AI in Climate Science* (arXiv:2304.05510). arXiv. http://arxiv.org/abs/2304.05510

Xue, Y., Temeljotov-Salaj, A., & Lindkvist, C. M. (2022). Renovating the retrofit process: People-centered business models and co-created partnerships for low-energy buildings in Norway. *Energy Research & Social Science*, *85*, 102406. https://doi.org/10.1016/j.erss.2021.102406

11. APPENDIX

It can be accessed via the link below after the proceedings:
https://github.com/cemalkoraybingol/Behave2023_Paper_Appendix/blob/main/Behave2023_appendix.xlsx

The Ghost in the Heat Pump: Examining social flexibility potential in thermal comfort practices through an experiment of remote-controlled heating in detached houses

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Abstract

Utilizing energy flexibility in households through smart steering of appliances has received attention as one way to reduce power peaks and adapt demand to a renewable energy system. Heating is a big part of the electricity consumption in households, and heat pump technology is growing in popularity for heating detached houses. While there is ongoing research calculating the technical potential for energy flexibility from heat pumps, few studies combine remote control of heat pumps with qualitative research on how households experience this control. The purpose of this study is to find out how long-term steering of heat pumps is experienced by households, how it affects their heating practices, and how they make sense of remote steering as a service. The data originates from an interdisciplinary project combining a field trial where heat pumps of selected Swedish households were remotely controlled for two winter periods, with qualitative interviews with the households. We conducted interviews with 12 participants, before and after the trial. The results show that households were overall positive towards offering flexibility through remote-controlled heat pumps, and that the steering of the heating blended well with normal temperature variation associated with having a villa in Sweden. However, the respondents were mystified by the procedure, which created 'a ghost in the heat pump'. Furthermore, remote steering as a service comes with challenges related to reliability, security, and agency over the heat pump. Important social conditions for adopting flexibility through remote steering of heat pumps are discussed.

1. INTRODUCTION

The residential sector represents a large amount of emissions globally; in 2021, 27% of final energy use in the EU was from households, and about 64% of this energy was used for space heating (Eurostat, 2023). The energy transition from fossil fuels to 100% renewable energy sources presents challenges in terms of fluctuation and variability in power supply (Mathiesen et al., 2015). Offering energy flexibility to the grid through e.g., load shifting in households is often suggested as a way to meet these challenges. In addition, utilising thermal inertia in households through smart steering of heating systems has received attention as one way to reduce power peaks and adapt demand to a renewable energy system (Reynders et al., 2018).

Heat pumps are popular for heating detached houses in countries such as Sweden, and they can be controlled to avoid critical periods of high demand and enable energy use during favourable times of the day. This can be done through built-in functions of smart steering in the heat pump itself, or through remote control by an external aggregator. This paper focuses on the use of external remote steering of heat pumps. While the technical effectiveness of heat pumps in combination with flexibility or demand response (DR) events is investigated in many studies, there are few qualitative studies exploring how householders in detached houses experience external control of their heat pump. This perspective is important as expectations of thermal comfort evolve through the introduction of new technologies and infrastructures (Strengers, 2013) as well as previous experience (Luo et al., 2018). In addition, how residents experience remote steering of heat pumps and other flexibility interventions in essential systems such as heating is both a matter of energy justice and may affect public acceptance of such systems (Calver et al., 2022; Hagejärd et al., 2021). New technologies and energy efficient systems may be both unsuccessful and unfair if they are based on wrong assumptions about how people prioritise and behave regarding heating practices (Mallaband & Lipson, 2020). The aim of this study is therefore to find out how remote steering of private heat pumps is experienced by households in detached houses, how it affects their thermal comfort practices, and finally how they make sense of remote controlling as a service.

2. FLEXIBILITY AND HEATING THROUGH A SOCIAL PRACTICE LENS

Several previous studies have specifically examined heating experiences during DR and flexibility trials. For example, Hagejärd et al (2021) measured thermal perception in households before and after a two-week trial with DR events. They found that participants generally felt they had too little control over the heating at home. They also saw that different times of day were perceived as colder or warmer, indicating that some hours might be unsuitable for indoor temperature reduction from DR events (Hagejärd et al., 2021).

Regarding flexibility in heat pumps, the main body of existing work is technical, with few exceptions. Calver et al (2022) interviewed households participating in a DR project combining heat pumps with gas boilers. Their results showed both increased comfort and less use of secondary heating. However, they also found that the system's efficiency was reduced when participants regularly turned off the heating system or used the override function. Prior heating practices had not been sufficiently translated into the settings of the system (Calver et al., 2022). Furthermore, they saw the need to ensure informed consent, to consider vulnerable users, to protect households from unknown risks, and to ensure that essential energy provision is secured. In another study on smart heat pump systems, Parrish et al also found risks of users misunderstanding the functions of the technology and adopting practices that may make the system less efficient (Parrish et al., 2021).

One way to analyse how domestic low-carbon innovation systems including flexibility services are received and configured into daily life of households is with the help of social practice theory (Watson et al., 2012). In short, social practice theory uncovers how practices consists of overarching and interacting elements (meaning, material, competences), and how different practices in turn are bundled and even dependent on each other, forming a rhythm of daily life (Watson et al., 2012). Viewing human behaviour through the lens of social practices can help explain why it seems difficult to change electricity consumption merely through change of attitudes, and what is needed to promote a shift to more sustainable energy practices in households (Watson et al., 2012). In this study, social practice theory is therefore used to understand how heating practices are interacting with the remote-controlled heat pump system.

3. METHODS

This study reports on the results from an interdisciplinary research project conducted at RISE (Research Institutes of Sweden). Seven households in detached houses participated. The houses were located in parts of Sweden that are specifically vulnerable to bottlenecks in power transmission and power peaks. The households were recruited through heat pump manufacturers, who were partners in the project. They contacted households who recently had bought a heat pump, asking them if they were interested in participating. The main recruitment criterion was owning a type of heat pump that was possible to steer remotely. Interested households received further information about the project and gave their consent to participate in interviews and share their data with RISE. Participation was voluntary. The remote steering of the heat pumps took place during two winter periods: January-March 2022, and January-March 2023. Due to technical challenges during the first round of steering, only two households were controlled while the rest acted as a form of control group. In the second winter, heat pumps in all households were controlled.

3.1 Remote controlling of heat pumps

The participating households' heat pumps were controlled using the built in manufacturers cloud connection. A custom-built software was created that could control all of the heat pumps simultaneously by using the heat pumps' Application Programming Interface (API). It must be noted that the parameters that can be controlled this way are limited, which was one major obstacle during the project. The heat pumps behaviour can only be indirectly controlled by mainly changing their target temperature. As such, the heat pumps behaviour, including, for example, the production of domestic hot water, cannot be fully predicted.

Several control strategies were implemented during the two winter periods. These included shifting target indoor temperatures of the heat pump to provoke increased or decreased production, and therefore electricity consumption, of the heat pump and to analyse the resulting shift in temperatures in the households. Other control strategies were to provoke complete shutoffs of the heat pump during certain time windows with different methods of either increasing production of the heat pump before these shut-offs to compensate for the loss of provided heat during these periods, or by compensating by increasing production after the shut-off period.

The buildings where the heat pumps were installed were monitored in terms of temperature, humidity at several locations in the building as well as the electricity consumption of the heat pump itself. This information was then passed on using mobile data connections to a central database. The effect on the indoor temperature from the different control strategies can in short terms be described as hard to predict. The temperature in the houses varies significantly even when not controlling the heat pump. When controlling the heat pumps by changing the set temperature, the resulting change in heat production from the heat pump was relatively slow and as such it was hard to attribute the changes in temperature to the actual control. When forcing the heat pumps to go into shut-off mode, clear declines in temperature could be identified. The slope of these declines varied a lot between the households as well as the ongoing change of outdoor temperature.

3.2 Semi-structured interviews

The collection of user experiences of the steering was conducted through two rounds of interviews and through a series of check-ins done via text messages. All adults in the households were invited to participate, however two adults declined, resulting in 12 first round + 12 follow-up interviews in total (see Table 1). The first round of interviews was conducted in late November 2021 to January 2022. During these first interviews, respondents were asked to describe a typical day in their life, to provide a context for their practices and activities at home. The respondents were then asked questions about how they perceive their thermal comfort at home in general, and about any experiences of uncomfortably high or low temperatures. In the conversation about indoor temperatures and everyday life, thermal comfort practices such as choosing certain rooms for e.g., work or socializing, using blankets and fireplaces were revealed. During the steering in the first winter, all participants were sent a text message every other week, asking how they perceived the temperature and if they had noticed anything different during the past week. It should be noted that although only two heat pumps were actually controlled, all participants believed that they were steered in the first winter. Due to very similar responses and generally no noticeable changes, no text messages were sent out during the second winter. However, by then the respondents had good contact with the project team and were encouraged to notify about any unusual or uncomfortable heating events. The second round of interviews took place after the remote steering was finished, in May 2023, although one interview was conducted later due to scheduling challenges. The follow-up interviews focused on the experience of the steering, as well as the respondents' thoughts on a potential service involving remote-control. All interviews were recorded and transcribed, except for one where the researcher's notes were used instead due to technical issues.

Table 1. Participating households (pseudonyms)

Household	1	2	3	4	5	6	7

Respondent	Simon Anna	David	Sam	Rickard Lina	Kristina Josef	Philip Emily	Tina William
Children	No	Yes	Yes	No	No	No	No
Occupation (1st interview)	Work	Work	Parental Leave	Work /Leave	Work	Work	Retirement /Work
House construction year	1964	1970s	1930s	1970	1974	1910 (main part)	1929
Building envelope, façade	Tiles, wooden façade, additional insulation	Concrete and Tiles	Concrete and Tiles	Concrete and tiles	Concrete and tiles, wooden beams	Wood, concrete, stone, wooden beams	Wood, stone, wooden beams
Fireplace/wood burning stove	Fireplace	No	Stove	No	Stove	Stove	Stove

3.2.1 Analysis of interviews

The interviews were analysed through thematic analysis (Braun & Clarke, 2006). The data (transcriptions of two rounds of interviews + SMS during the first winter) was categorised into different themes and sub-themes, where the overarching categories were thermal comfort practices prior to the experiment, experiences of the steering, and perspectives on remote-steering as a service, based on the interview guide and the aim of the study. The analysis first yielded several specific sub-themes, including “the importance of comfort, unwillingness to reduce comfort”, “the importance of control”, and “normal temperature variation in the house”. The sub-themes were then re-analyzed into larger themes such as “agency”, “reliability”, or re-described from a practice perspective. For example, the use of additional heating was then seen as a part of a heating practice rather than a separate activity. The initial analysis was primarily carried out by the first author, while the second author participated in re-analysing and re-labelling after the initial analysis round.

4. RESULTS

4.1 Heating and thermal comfort practices before the trial

Most of the respondents emphasized that indoor comfort and access to hot water are important and essential things at home that need to always work. While for example Simon and David stated they would not like to compromise indoor temperature very much, others like Tina and Rickard reasoned that it depends on the room and its activities, where lower temperatures were more acceptable in e.g., bedrooms compared to living rooms.

The respondents also had different experiences of having a cold or warm home. Some, like William, explained that he was used to a colder indoor climate due to insufficient insulation in the UK where he used to live. Others, like Lina, had a memory of a malfunctioning heating where temperatures dropped to 14 degrees, and was therefore convinced that her comfort limit would be somewhere around 17 degrees. It was a common experience in these households that the temperature in the house varies between different rooms, different times of day and different times of the year. For example, William and Tina’s house had a conservatory in which the temperature would be either colder or warmer than the rest of the house, and they would sometimes even use it as a fridge during cold days. Several of the households also had secondary heating sources, such as fireplaces. Philip and Emily used their fireplace often, especially in the afternoons when coming home from work, so much so that they turned off certain radiators to replace it with the heating from the fire. This was connected to different practice elements, both material, as they previously had access to free firewood from Emily's father, knowledge, because Philip had experience working with fireplaces, and meaning, that they both found it cozy and liked making up the fire. Meanwhile, Rickard already set his heat pump to an automated steering which would turn off the heat pump based on electricity price. The householders also mentioned regulating thermal comfort with clothing, blankets, slippers, opening windows or choosing which rooms to do what activity in.

4.2 Experience of remote steering: First winter

During the first winter when the steering was initially tested, households 5 and 6 were controlled, while the rest acted as a form of control group. Every other week the households got questions via text message asking how they felt the temperature had been the past week. The responses from all households were rather similar, regardless of whether heat pumps were controlled or not. Households 5 (Josef & Kristina) and 6 (Philip & Emily) did not notice much difference in temperature, and when they did, they were unsure of whether it was caused by the steering, their anticipation, or simply the weather. Josef for example explained that he felt that it was colder at one point, but when he checked the thermometer, it was 21 degrees as normal. Emily did report one occasion when she felt that the house was a bit colder than usual in the evenings, and that other parts were warmer in the mornings, which she suspected had to do with the steering. Other weeks she answered that she felt everything was as usual. Josef stated that although he noticed it being a bit cold some days, he argued that it is just how it usually is when the weather changes. Philip wrote a similar reply: *"It is a little cold when you get home, it requires a fire. That is how it usually is, so it is nothing specific for last week"*. Kristina stated that she had not noticed anything and added that she always has a light sweater nearby to regulate her warmth. Households in the control group would also sometimes report feeling a bit colder or warmer than usual, without knowing the reason. Although this is not a statistical study and the control group cannot verify or discard any effect of the steering, it is worth noting that responses were strikingly similar. Overall, it was difficult for respondents (both steered and not) to know the reason behind any perceived comfort changes.

4.3 Experience of remote steering: Second Winter

Heat pumps in all seven households were steered by the engineers in the research team during the second winter. All respondents except three stated that they had not noticed the steering at all, at least not through any perceived changes in temperature. In fact, most stated that they had expected to notice it more. Respondents tended to forget that the steering was in place, and some of them like David wondered if the project was still running, as they could not really know what was happening with the heat pump or what was going on. Several respondents said that they expected more noticeable changes in temperature, and even said that they would have accepted more variation, even if it meant periods of colder temperatures. For example, Sam stated that he was positive towards the idea of more steering, even if it required him to dress his children in warmer clothing.

Slight changes in indoor temperature or thermal comfort due to weather changes and temperature variations throughout the day and season seemed to be a normal part of owning a house with a heat pump in the Swedish countryside, especially if the house is older. Differences in temperature in different rooms was also described as normal by the respondents, for example due to fire making, cooking, or windows. Because of this, a small variation in temperature was not questioned by most respondents or necessarily attributed to the steering, but rather just a normal part of the daily rhythm in the house, as illustrated by: "*(...) you don't really know what affects it, you have impact from the weather changes and that it (the heating) does not really keep up with the temperature changes, so that is completely normal, so I haven't noticed anything"* – Josef, 2nd interview. Furthermore, during the winter 2023, Sweden (and Europe) was in a strained energy situation with fluctuating and high prices and even warnings of power cuts. As a response, some respondents like Kristina, Josef, Philip, David and Emily had turned down temperature settings overall or shut off radiators in certain rooms, to reduce their electricity consumption. These activities also interacted with the heating and further obscured the effects of the steering. Of the three respondents who said that they did notice the steering, Emily explained that she mainly noticed it the first year on a few occasions and argued that it might be that she worked more from home during that winter and compared it to how it feels when the weather changes. David argued that his badly insulated windows probably made the steering more noticeable. Lina said that she felt that it had been a bit colder than usual, but reasoned that it was a good thing and that it did not bother her much. Simon and Sam had noticed the steering because they, out of curiosity, had walked past their respective heat pump and noticed that it seemed to be turned off or set to a deviating temperature. Certain material conditions also made the steering less noticeable. Five households had a fireplace of some kind, and some, like Philip and Emily, used it frequently during the winter season. This is likely to make the steering impact such households less because they could always use their fireplaces as a "heat insurance" in case something happens or if they feel cold.

4.4 Perspectives on remote steering as a service

While respondents seemed positive towards participating in research and were rather satisfied with the steering during the trial, new aspects of the steering came up when discussing it in the form of a future service.

4.4.1 Financial compensation and understanding of the service

Surprisingly, respondents did not seem too concerned about what they would save or earn financially from such a flexibility service, and all respondents understandably also had a difficulty estimating how much they would expect to earn or save. Simon, Anna, Philip, and Emily did not expect any compensation, beyond saving some money on the electricity bill in the end, even if that was not so important. Tina argued that the financial compensation does not need to be substantial. Josef said that it may be of importance to those who have a strained economy, but that he simply saw it as a plus if you could save a little. Others like Sam stated that although he would want to save something, he did not know how much he would need to save for the steering to be worth doing.

The way respondents were unsure or uninterested in the financial benefits of the service may be connected to what meaning was attributed to the service. Some, like Anna, Emily and Tina described it as a way to help the grid and energy system by reducing power peaks, and others like Simon and Philip described as a way of optimizing and making the heating system more efficient. For Anna and Emily, the sustainability aspect and societal contribution were more important than any financial gains: "*No, I don't need to earn anything. (...) what I earn is that I can contribute to a power equalization, or whatever you call it*" – Emily, 2nd interview.

Confusion around the novelty of such a service, regarding who is the supplier and who is the customer, may also be a reason why financial compensation seemed less important. As previously mentioned, some respondents like David believed the steering was directly connected to the electricity market price, and would probably save them money on the electricity bill, although that might not always be the case. When asked about costs and savings respondents did not expect the service would compensate them at all, even though they are the ones "selling" their flexibility to the hypothetical aggregator. The initial response to this question was rather that respondents did not want to pay for such a service: "*It's like it always is, these services are all very well, but if they want 200 SEK a month for fixing this… These types of subscriptions I am a bit allergic to*" – Philip, 2nd interview.

4.4.2 Reliability

Reliability was one important aspect of the service raised by the respondents. It was emphasized that the steering needs to function and be reliable, and not require too much engagement or effort from the household's part. Respondents like Simon, Philip, Sam and Lina argued that they wanted the system to be efficient, smooth, smart, and not need much engagement from them. Additionally, Simon and Philip reasoned that there is a limit to how much disturbances or problems a system can cause before customers will be annoyed. These types of comments may be related to experiences of problem during the trial where participants were required to restart certain parts of the system, which was viewed as acceptable for the sake of research, but not in a professional service. It was also important that the system operator is reliable, and that you could easily contact them to adjust or get help, as discussed by Kristina and Emily. Kristina, for example, envisioned a scenario where one is at home ill and needs a higher temperature. This also reflects that respondents expected the system to work well with their everyday life activities and personal needs.

4.4.3 Security

When discussing the service respondents also raised issues of security, mainly regarding what company would be offering the service, concerns about data integrity and cyber security. Some respondents like Anna expressed trust in the research team conducting the experiment but were unsure about what company they would be comfortable signing up for a steering service. Others like Simon and Philip were not as concerned about what company would offer the service, but still suggested a familiar company like the electric trading company to be a comfortable choice. William, Philip, and Anna stated that they would prefer a Swedish company as opposed to an international one.

Data integrity issues and by extension security risks were also raised as "red flags" by some respondents. Anna and Emily were somewhat concerned about whether their data would be sold or shared with someone else, if their data would be used for monitoring their activities, and if AI entities would be involved in controlling their heating. Similarly, Sam argued that he would do some research on the company first to make sure that he and his data is protected. However, he also added that he does not know much about cyber security. These statements reflect the householders' concern about unknown risks and how difficult it may be as a private consumer to know what you are agreeing to.

4.4.4 Agency

Respondents had different and sometimes contradictory ways of understanding the service of remote-steered heat pumps. While some, like Josef, understood that the system will not be efficient if the household interferes or opts out too much, still he, and other respondents like Rickard, Emily, Kristina, David and Sam expressed that they were unwilling to give up control completely. Being able to opt out, adjust, and participate in the "steering strategy" were mentioned by these respondents as important, both to ensure comfort but also to increase efficiency and maybe steer more "ambitiously" than the aggregator's default setting. Examples were being able to tell the system when you are away from home, only participate seasonally or adjust settings when you have guests or when you are at home, ill in bed and may want a higher temperature. Furthermore, Rickard and Josef both argued that a reduced comfort is easier to accept if it is your own active choice rather than someone else's initiative.

Respondents also questioned why someone else should do the steering if they could manage it themselves, indicating a preference for having total control themselves. In fact, David and Rickard stated that they would never let anyone else control their heating, in Rickard's case partly because of his technology interest, and because he would want access to turn off things whenever he wanted to. Emily in turn wondered why she would bother with the extra steps if she could do it herself. Overall, it was clear that respondents would want to participate or have access to the steering in one way or another. The way they discussed their participation and engagement in the steering revealed that they wished for the steering to take consideration of their practices and activities, for it to be an attractive option. Examples were going on holiday, having guests or family visiting, being ill, or knowing what rooms should be cold or warm due to what activities are performed there.

5. DISCUSSION

In this study, seven households participated in an experiment with remote-controlled heat pumps during two test periods in late winter/early spring in Sweden. We conducted interviews before and after the steering periods and sent out text messages to find out how they experienced the steering, if and how it affected their practices, and how they understand remote steering as a service. Our results show that participants were largely unaware of what was happening with the steering of the heat pump and all except for three reported that they did not notice much difference in temperature. Respondents admitted they sometimes wondered if the steering was working, especially as they expected to notice more variation in indoor temperature. Because the steering was happening remotely and was done by someone else, it seemed invisible and somewhat mystified to these households. The most technically interested participants would, out of curiosity, notice changes when they looked at the heat pump settings – but not because of the indoor temperature. Furthermore, slight variations in indoor temperature seem to be a normal part of having a detached house in the Swedish countryside during winter. Weather changes, building properties and activities will affect what room will be warmer or cooler during different times of day and during different seasons. This meant that while some householders did notice differences in temperature here and there, they had a difficulty attributing it to the steering of the heat pump, as this variation may have occurred anyway. The steering thus blended very well with the "normal" variability of indoor temperatures in these houses, and the experience of the steering was mostly described in positive terms. This finding supports previous research that showed how different experiences of thermal comfort will shape expectations, perception and satisfaction with indoor temperature (Luo et al., 2018). These findings also indicate that there is social potential in offering flexibility from steering of heating systems in some form.

However, while the experience of the experiment and steering was described as largely positive or uneventful, the conversations about a possible service shed light on more critical aspects. Our results show that financial compensation, while of some interest to households, did not seem to be the most important aspect of having remote controlling of your heat pump as a service. Rather, some respondents interpreted the service as a contribution to a more resilient grid, keeping prices down for all, or reducing their own electricity bill. These understandings and meanings can be related to previous research showing how users' interpretation of new systems may affect their willingness to participate, their expectations, and the efficiency of the system (Calver et al., 2022; Parrish et al., 2021).

Aspects that did seem to be of great importance to households for adopting remote controlling of their heating were instead *reliability, security,* and *agency*. *Reliability* revolved around how well the system functions, how much engagement it would require from the household if something does not work, and how efficient the system will be. Concerns of *security* had to do with the difference in trust when comparing for example the research team to a private company acting as aggregator who would do the steering if it was a service on the market. Other related security concerns related to integrity, monitoring, and cyber security. While these issues were raised at a general level, not all participants raised them and risks were not specified in any detail, perhaps because the households have a limited knowledge. This relates to what Calver et al (2022) argue – that it is a matter of energy justice to ensure that households participating in smart grid systems are protected from risks, especially the ones they are unaware of. *Agency* refers to the respondents' wish to participate actively in the steering and remain in control over chosen situations. Some discussed how they would need access to be able to change things or adjust steering depending on their plans and activities at home. Some respondents requested easy ways of contacting the operator if anything goes wrong or a possibility to make their own adjustments. Others simply preferred to do the steering themselves and did not see the point of outsourcing it to someone else. These findings align well with the previous studies on automation, smart energy systems and demand response, which emphasize risk, agency, control, trust, and familiarity as important factors for engaging in flexibility systems (Adams et al., 2021; Hagejärd et al., 2021; Parrish et al., 2020).

Our results also have implications for flexibility service design. In line with Calver et al (2021), we argue that our results shed light on how a system such as remote controlling of heat pumps needs to blend in with practices to be acceptable to households. While the steering in our trial worked well with the participants' houses in terms of temperature, these results should be understood in the context of this scientific experiment in which the steering only happened for a limited period. When considering a future service offering such steering, there are other important parameters to consider in terms of reliability, security, and agency. To what degree the household will be able to cooperate and interact with the aggregator and the system, how the system's reliability is achieved and communicated to households, and how households' integrity and security is ensured, are important challenges to address for such a service to be successful, efficient, and fair.

The type of flexibility service offered by remote-controlled heat pumps is sometimes conceptualized as a form of commodification of flexibility (Jalas & Numminen, 2022). As infrastructural services like electricity adopt dynamic pricing schemes to a larger extent, technologies like smart or remote control of appliances may become more attractive. However, as Jalas and Numminen (2022) emphasize, these price schemes and services are at best difficult to understand and in worst case completely hidden from the household. Therefore, it is understandable that households do not know the potential benefits or disadvantages there may be in signing up for flexibility services (Adams et al., 2021; Calver et al., 2022; Jalas & Numminen, 2022). These arguments are in line with our results, where the service was somewhat mystified to households. They were unsure of how the service would work and on what terms, what to expect and what benefits and drawbacks would be associated with it. In line with Calver et al (2022), we argue that it is not reasonable to expect households to know what to demand from such service or to ensure their integrity or fairness, especially since such services may be motivated by sustainability values which seem very important to some of our participants. As other studies show, emerging smart grid solutions based on IoT and control of appliances also come with many risks in terms of cyber security (Kimani et al., 2019). Ensuring security and transparency when developing such flexibility setups for energy provision is therefore important and should be of interest for policymakers as well as practitioners wanting to engage households in energy flexibility.

6. CONCLUSION

Our results show that participants were mostly accepting the temperature variation at home that was caused by the remote controlling of heating in this project, in part because it seemed to blend rather well with the experience of normal temperature variation in these houses. This indicates that there is social flexibility potential in using heating in detached houses to offer flexibility to the grid. However, there are other conditions in terms of reliability, security, and agency that determine whether they would be willing to participate fully in such a service outside of research purposes. Householders need such a service to be considerate of practices that affect the heating, as well as the households' needs and integrity. This has implications for how such flexibility service systems are designed and how user perspectives are considered.

7. REFERENCES

Adams, S., Kuch, D., Diamond, L., Fröhlich, P., Henriksen, I. M., Katzeff, C., Ryghaug, M., & Yilmaz, S. (2021). Social license to automate: a critical review of emerging approaches to electricity demand management. *Energy Research & Social Science*, *80*, 102210.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Calver, P., Mander, S., & Abi Ghanem, D. (2022). Low carbon system innovation through an energy justice lens: exploring domestic heat pump adoption with direct load control in the United Kingdom. *Energy Research & Social Science*, *83*, 102299.

Eurostat. (2023). *Energy consumption in households*. Retrieved 2023-08-16 from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

Hagejärd, S., Dokter, G., Rahe, U., & Femenías, P. (2021). My apartment is cold! Household perceptions of indoor climate and demand-side management in Sweden. *Energy Research & Social Science*, *73*, 101948.

Jalas, M., & Numminen, S. (2022). Prime-time access for whom? Rhythms fairness and the dynamic pricing of infrastructure services. *Local Environment*, *27*(10-11), 1355-1371.

Kimani, K., Oduol, V., & Langat, K. (2019). Cyber security challenges for IoT-based smart grid networks. *International journal of critical infrastructure protection*, *25*, 36-49.

Luo, M., Wang, Z., Brager, G., Cao, B., & Zhu, Y. (2018). Indoor climate experience, migration, and thermal comfort expectation in buildings. *Building and Environment*, *141*, 262-272.

Mallaband, B., & Lipson, M. (2020). From health to harmony: Uncovering the range of heating needs in British households. *Energy Research & Social Science*, *69*, Article 101590. https://doi.org/10.1016/j.erss.2020.101590

Mathiesen, B. V., Lund, H., Connolly, D., Wenzel, H., Østergaard, P. A., Möller, B., Nielsen, S., Ridjan, I., Karnøe, P., & Sperling, K. (2015). Smart Energy Systems for coherent 100% renewable energy and transport solutions. *Applied Energy*, *145*, 139-154.

Parrish, B., Heptonstall, P., Gross, R., & Sovacool, B. K. (2020). A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response. *Energy Policy*, *138*, 111221.

Parrish, B., Hielscher, S., & Foxon, T. J. (2021). Consumers or users? The impact of user learning about smart hybrid heat pumps on policy trajectories for heat decarbonisation. *Energy Policy*, *148*, 112006. https://doi.org/https://doi.org/10.1016/j.enpol.2020.112006

Reynders, G., Lopes, R. A., Marszal-Pomianowska, A., Aelenei, D., Martins, J., & Saelens, D. (2018). Energy flexible buildings: An evaluation of definitions and quantification methodologies applied to thermal storage. *Energy and Buildings*, *166*, 372-390.

Strengers, Y. (2013). Comfort expectations: the impact of demand-management strategies in Australia. In *Comfort in a lower carbon society* (pp. 77-87). Routledge.

Watson, M., Pantzar, M., & Shove, E. (2012). The dynamics of social practice: Everyday life and how it changes. *The dynamics of social practice*, 1-208.

Energy dashboard or mom-planner?

Shifting norms towards more inclusive and gender-sensitive designs of residential smart energy management systems

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Abstract

Residential demand-side flexibility – shifting of household energy consumption - is an important part of the transition towards less carbon intensive energy systems. It necessitates the adoption of digital systems to manage the patterns and volumes of energy generation, storage and consumption. This paper presents the results of an interdisciplinary collaboration under the IEA UsersTCP Gender & Energy. Taking a socio-technical approach, household energy management is understood in the context of everyday household practices. On the basis of qualitative research in two Dutch residential smart-grid pilots and among Swedish households, supported by recent literature, we discuss how residential smart energy management affects and is affected by household management practices. The findings point out, among others, that smart grid-related expertise tends to accumulate in one person in a household, often along gendered lines. However, for smart energy solutions to be effective, all household members need to be engaged in a process of shared learning and change. Current residential smart grid designs – including interfaces such as energy dashboards - insufficiently acknowledge this, resulting in gender-blind and exclusive 'solutions. A research and design approach following norm-critical and norm-creative design-thinking has been adopted to design an alternative for energy dashboards, starting with an alternative normative framework based on the empirical analysis, explicitly addressing conditions for more inclusive and gender-sensitive design. Several iterative rounds have resulted in a prototype for shared planning, monitoring and management of household activities, that includes attention for energy as well – as an alternative for the conventional in-home energy dashboards. Both this prototype as well as the research and design approaches adopted hold promise for more inclusive and effective residential smart energy systems, in line with distributional justice considerations.

1. INTRODUCTION: SMART GRIDS AS A PROCESS

1.1 Upscaling change or improving widespread adoption and replication

Household practices and day-to-day behaviours constitute a central part of sustainability transitions. Upscaling behaviour change as part of the necessary socio-technical sustainability transitions is not a one-size-fits-all approach, but rather requires tailored strategies considering diverse actors and contexts.

This paper explores a specific challenge related to the adoption of systems supporting smarter energy management in homes, encompassing energy generation, storage, and consumption patterns. The adoption of solar panels, heat pumps, household - or collective batteries, in combination with energy management systems enable household smart energy management, contributing to less carbon-intensive energy systems. This transition involves changes in everyday practices, with unique challenges in household settings due to existing relationships and activities.

The focus of this paper is on how residential smart energy management affects and is affected by household management practices. It adopts a socio-technical approach to understand these changes within the context of daily household routines and conventional (often gendered) divisions of household tasks.

Section 2 sets out how we combine a socio-technical perspective with norm-critical design thinking to inquire into the ways in which new arrangements around smart grids evolve. Next, we briefly point out how gender is a crucial issue to consider and we present the organisation of our research and design process. Section 3 discusses empirical findings from Dutch smart grid pilot focus groups and workshops conducted with Swedish users. This research culminated in a prototype "household planner" aimed at fostering inclusive and gender-sensitive household engagement in smart grids, offering an alternative to conventional energy dashboards (that are developed for households so that they can monitor and manage their energy and participate in energy flexibility).

Section 4 presents conclusions on enhancing residential smart energy management to achieve improved effectiveness and attractiveness. In addition, we explore the potential for replicating this IEA task[i]-initiated design trajectory across various settings where household energy flexibility is introduced. This approach holds promise for innovative, norm-creative, and participatory design processes.

1.2 Residential smart grids: full of surprise rather than ready-and-steady

Smart grids have been proposed as useful tools to mitigate climate change, through the optimisation and balancing of the electricity grid (Skjølsvold et al., 2015). Furthermore, with the increase in installed capacity of intermittent renewable energy, the need for ‘real’ time monitoring at both grid and household level has become more urgent (Smale et al., 2017). *Residential* smart energy networks have been proposed to help solve network constraints by balancing supply and demand locally through demand side flexibility. They entail energy management within the home, involving a digital communication network that

[i] https://userstcp.org/gender-energy-task/

Intern gebruik

connects sensors, appliances, installations, enabling remote monitoring and control by householders and others (Gram-Hanssen and Darby, 2018). Residential smart energy networks are envisaged first and foremost to deliver 'value for the grid' and residential users are expected to help provide such value (Boekelo et al., 2022). However, as shown in this paper and other literature, these users do not necessarily behave as the 'imagined co-managers' of these smart grid technologies (Smale et al., 2017, p.132), at least not in the ways envisioned by technology developers and policy makers. In addition, it is far from clear what types of benefits and values they will enjoy when doing so – individually or collectively as an energy community (Skjølsvold et al., 2017; Mourik et al., 2020; Hansen & Hauge, 2017).

Another point to consider is that residential smart grids are presented as an 'all-in-one' phenomenon, and partially a black box that does things to and for the existing household practices. However, residential smart grids still have a long way to go from the experimental phase to an established set of new practices. Rather well-organised ready-made solutions, it makes more sense to regard residential smart grids as a (partially open-ended) process characterised by lots of trial-and-error. Even when implemented, residential smart grids are best seen as experimental pilots which experience all sorts of (unexpected) challenges and changes in the use-phase – as evidenced by the Dutch smart grid pilots discussed in this paper (see also Breukers et al., 2020).

Having this in mind, we are interested in questions such as: How do users experience and appreciate the (envisaged/planned) smart grid interventions? How do they perceive of this smartness in real-life situations when it interferes with their daily household practices?

2. CONCEPTUAL FRAMEWORK AND METHODOLOGY

2.1 Smart grids as socio-technical reconfiguration

Residential smart grids can be considered as socio-technical configurations-in-the-making for some years to come and as part of this process, various elements like values, practices, technology, infrastructure, and institutions undergo changes. This "reconfigurational work" is deeply influenced by local contexts and histories, and builds upon existing household practices and resources.

At the household level, new configurations are adopted, transformed, and integrated into day-to-day household practices, or not (when they are rejected). Residential smart grids, with their technical, digital, and infrastructural components, require specific skills and capabilities and entail or invite (new) practices, new norms and rules. The reconfigurational process is furthermore affected by values and social norms - not those that relate to energy management but also social norms that are part of household practices.

These components come together within local systems tailored to individual households or communities, where collective meaning-making occurs. (De Vries et al., 2016; Mackenzie and Wajcman, 2012) However, since residents are often not involved in the initial technology design and organization into smart grids, conflicts and difficulties easily arise in the adoption and appropriation process, when these solutions do not align with established household management practices and the division of tasks and roles. That is why it is important to distinguish between on the one hand solutions that do not consider norms and therefore disregard established routines and on the other hand norm-creative solutions that explicitly recognize and challenge norms in order to allow these norms to shift or widen.

2.2 Household work and gender

Generally speaking, women carry a larger load (physical and mental) of the everyday household work. They are more active in both the material and cognitive housekeeping - the latter refers to the management and organization of all household labour and the mental load associated with it. Men appear to have more interest and involvement in the control and operation of smart home technologies, including smart energy systems (Christensen et al., 2017; Kennedy et al., 2015). Even when this gendered division is not apparent, we still see that some household tasks are more likely to be concentrated with one person (e.g., washing practices) in the household than other tasks (e.g., dishwashing practices) – which relates to the relevance of the build-up expertise around this practice.

Digital housekeeping tasks also tend to become concentrated with one person in the household – and to the extent this is with men, this reproduces and reinforces existing gendered patterns and roles. However, this is not a static given, and digital housekeeping also can become a shared or re-negotiated practice between household members over time (Kennedy et al., 2015; Sinanan and Horst, 2021).

Smart grid pilot developers work on the basis of their expectations about possible changes in everyday household practices to enable the provision of the required flexibility (Smale et al., 2019). Smart grid designs are still strongly based on a male reference model of the end-user – resembling what Strengers (2014) called 'Resource Man': a man who has interest in monitoring and managing energy, who is technically and digitally competent, comfortable with the language of kWh and energy prices, and who is responsive to incentives and information (Strengers, 2014; Silvast et al., 2018). One of the implications of this is the impact this can have on existing gendered household labour division.

While women more often take on the role of "project manager", shouldering much of the mental load to organize day-to-day responsibilities and of decision-making, men tend to make long-term and occasional decisions of larger financial magnitude (Clancy and Roehr, 2003). Over time, this has contributed to a male-coded approach in smart technologies for the home, but also towards the overall energy transition, which is strongly oriented towards technology solutions conceived for the systemic level – such as smart grids that deliver 'value for the grid', while paying less attention to how people at the level of households are affected in their day-to-day lives. It is against this background that our inquiry into the process of adoption and domestication of smart grid technologies is to be understood.

2.3 Design thinking for social-technical sustainability transitions

Design thinking dates back to the fifties and sixties (Dam and Siang, 2022). Herbert A. Simon introduced design as a way of thinking in 'The Sciences of the Artificial' (1969), positioning the basic principles of design thinking with rapid prototyping, an iterative approach allowing for learning-by-doing. Increasingly it is proposed to help address complex problems. Design-thinking approaches have become more focused on inclusion, participation (e.g. user-centred design), attending to interrelated social and physical-technical systems, to address systemic challenges at multiple-levels in an approach that has attention for the improvement of well-being and quality of life (Irwin, Tonkinwise, & Kossoff, 2015). These and other recent approaches are characterised by more attention to different perspectives (including underlying values and norms) on a specific problem area – e.g., through empathic research with all stakeholders including end-users (Dorst, 2015) – asking what it is that makes a problem complex and which aspects contribute to the sustained continuation of that problem. This can help to acquire a new perspective and it can help to connect different stakeholders with one another.

An example of such a frame-innovative approach is the so-called *norm-critical* and *norm-creative* design approach. This approach starts with a research phase, in which the dominant norms on a particular theme are being questioned. This norm-critical phase is then followed by an effort to design and develop solutions that provide an alternative for these dominant norms – and as such actively creating norms (Nilsson and Jahnke, 2018).

2.4 Research and design-process

Within the context of the IEA Task on Gender and Energy, our research and design efforts aimed at interdisciplinarity by fostering collaboration between social scientists and designers. To facilitate this cross-disciplinary exchange of knowledge, numerous workshops and meetings were organized, over a period of 2.5 years, bringing together all participating partners. These gatherings served as forums for the sharing of research findings and the cultivation of a shared perspective. In particular meetings between DuneWorks and Boid were instrumental in translating research into tangible prototypes and to validate the design proposal.

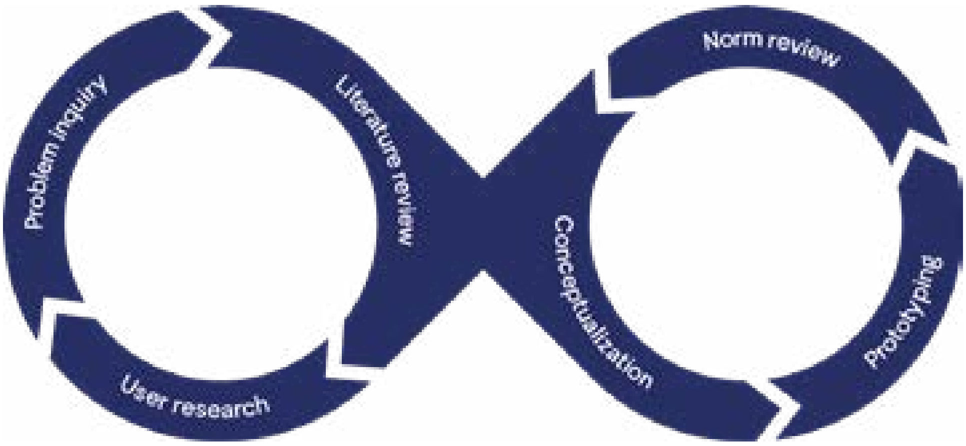
Our research endeavours have also embraced transdisciplinarity, fostering an inclusive approach that involves designers, social scientists, household users, and technology developers.

1. **Engaging Residents in Smart Grid Pilots in the Netherlands:** We conducted focus groups, workshops, and interviews with residents participating in smart grid pilots in the Netherlands (see Table 2 in Annex 1). These interactions were essential for capturing the first-hand experiences and discerning the unique needs of the users involved in our study.
2. **Prototype Testing with Swedish Residents (see Annex 2)**: Combined findings from the pilot studies and literature review of the project group at large led to an early concept for an alternative interface for energy communication. To assess the practical applicability of our design proposal, tests with a prototype were conducted in April of 2022 with Swedish residents. These sessions provided valuable insights and feedback, enabling us to refine the prototype to better suit the needs and preferences of different user groups.
3. **Ongoing Testing in Swedish Households:** The refined second prototype will be tested

between October and November 2023 within three Swedish households. This study not only ensures the practicality and usability of the design but also allows us to adapt and improve the proposed solution based on real-world feedback and in co-creation with potential users.

Figure I shows the interchanging cycles of the iterative design and research process, where findings from the literature reviews lead to conceptualization and prototyping that repeatedly undergo norm reviews by the designers and the broader IEA Gender and Energy group as well as user research to be able to identify problem areas that may require additional literature study that lead to concept and prototype improvement.

Figure 1: Iterative design and research process



The next section discusses the empirical research results from the focus groups in Dutch smart grid pilots as well as the workshops done with Swedish users.

3. EMPIRICAL WORK: HOUSEHOLD MANAGEMENT AND ENERGY MANAGEMENT AND HOW THE TWO COMBINE

3.1 Analytical approach for Dutch case study: experiences, expectations and needs

One way to learn about the process of adoption and domestication of smart grid technologies is by zooming in on the experiences, expectations and needs of household members in residential smart grid pilot project. This was done for two Dutch residential smart grid pilots[ii]. To structure this inquiry, we introduced three categories based on literature review (Breukers et al., 2022). First, *interest and expertise* in relation to smart grid solutions, referring to interest in the workings and possibilities of smart grid solutions and the related build-up of expertise over time. As smart energy management involves not-yet fully engrained patterns and practices, it makes sense to address how interest in and expertise

[ii] DuneWorks was a partner in two European H2020 programmes, which secured access to these pilots

builds up for different householders, to what extent this is gendered and what that means for experiences of control and trust.
Second, the notion of e*xperienced control* refers to the ability to understand and control appliances and the energy management system, as well as being capable to assess malfunctioning. Control in relation to residential smart energy technologies relates to the gendered roles and in technical maintenance and digital housekeeping – as generally speaking, men are more 'in control' of these housekeeping practices (Gram-Hanssen and Darby., 2018; Kennedy et al., 2015). This intersects with age and educational background. In addition, control also refers to being in control of the home environment, and this relates to comfort in the sense of home-making and caring practices (ensuring comfort for others in the home, including provision of emotional care) (Ellsworth-Krebs, 2015) - and how this is affected when new technologies are introduced into the home (Aggeli et al., 2021). Furthermore, differences between men and women in temperature preferences, ventilation needs, lighting preferences can affect experiences of control when smart technologies affect the ways in which these can be easily influences or adapted.
The third category is about *trust* in the technologies and the providers of the technologies. Residential smart energy systems are still in an experimental phase with a lot of trial-and-error. Where things go wrong, this can undermine *trust* in the technologies (Boekelo et al., 2022). With smart grid configurations, it is not only the functioning of the individual appliances but the (physical and digital) network of appliances that matters. The reliability depends on (their interoperability with) the many parts that together form an interconnected, intelligent system. Due to their complexity, such systems are not very transparent to the user (Kloppenburg and Boekelo, 2019). Users depend on the providers of these systems and experiences of trust therefore not only relate to the technologies but also to these providers.
In the Dutch pilots, residents shared their experiences, collected through interviews, focus groups, and workshops. We analysed this data using three categories: interest and expertise, experienced control, and trust in technologies/providers. We also examined gender differences in responses. Observations revealed gendered roles, with some women considering their husbands to be the one to interview, regarding them to be more proficient when it comes to their home smart grid. In one Dutch pilot (Voorhout), we explored women's learning needs for feeling capable in managing the smart grid in their homes, now and in the future when the pilot phase is over.
Based on these case findings, summarised in 3.2[iii] with illustrative quotes, we discuss how specific smart grid elements interact with household contexts and affect household practices, particularly in terms of gendered roles in coordination and management of housekeeping. We reflect on aligning energy management with household practices, asking if and how shared learning can help to align the configurational work around smart grids better with household practices and needs – while also allowing for conventional role patterns to change. The (possible)roles of intermediary actors (people or artefacts) in this learning is addressed here as well.

[iii] A more extensive presentation of the method, analysis and findings is available in Breukers et al., 2022.

3.2 Summary of findings

Interest and expertise

Many respondents felt overwhelmed by the complexity of the energy management systems, as the following quote shows: *"We did not expect that there would be so much technology in the house that we don't understand anything about."*

Overall, both men and women lacked energy and digital skills, with the few proficient users being men. Generally speaking, a gap was observed between digital/technical and material/cognitive housekeeping, with those handling the latter tasks not being active in the former. This gap was more pronounced in Voorhout than in Schoonschip. Some female respondents felt incompetent due to their lacking proficiency – even feeling ashamed in some cases: "*My first feeling is that of failure, I feel it is my responsibility because others can do it and I cannot.*" This illustrates a perceived social norm about the level of digital and technical proficiency that one should have.

Experienced control

The issue of control relates to how things in the home are adopted and subsequently domesticated, and how new/changed practices become normalised. Peoples' responses to several incidents (e.g. overheated home batteries) showed that those that felt competent were more likely to take action to regain control – this was also gendered, mostly in Voorhout, with the example of a respondent feeling incompetent and deciding to take no action but endure the cold during the weekend when heat pump was not functioning well. Some women did not give themselves credit for their active and effective role in identifying problems related to the smart grid – in cases they were the first to notice malfunctioning: "*I am 'forced' to deal with the digital stuff in our home, but I also don't know much about it. And when I find out such things (underperforming battery), then I think: why is this not generally known here?"* Some female respondents furthermore experienced an increased dependence on their male counterparts or others as a result of the smart grid: *"However, I also need to understand some things, in case he is not around or away or whatever …then I also need to understand it all a bit (...)"* In one case this went as far as fully undermining experienced control: *"These homes were supposed to allow you to be independent (longer) during your old age… but that's not how I feel here. (....). I mean, I need to be self-reliant and then I would like to stay here. But eh….if things stay the way they are now, and he passes away (I hope not)…but in any case, then I will be gone. Then I will leave."*

Trust in technology and technology providers

The overwhelming complexity and creation of new dependencies clearly was not conducive to trust, especially where respondents experienced a loss in terms of control, comfort and safety. In both pilots, trust in the technologies and smart grid system had been challenged by various incidents, misunderstandings, technical malfunctioning and mis-communications. This in turn resulted in a weakening of trust in the technology providers.

3.3 Translating findings into norm-critical design suggestions

Based on the findings discussed above, an overarching direction for improved smart grid design would be enabling shared and/or distributed forms of learning/expertise accumulation within households – countering the identified gap between digital/energy and material/cognitive housekeeping. Table 1 below sums up for each of the three categories how existing expectations or norms could be challenged as part of a norm-critical design process. These suggestions formed a basis the norm-critical phase in the design trajectory – focusing on a prototype user interface of a household energy monitoring and management system (often this is an energy dashboard). The prototype aimed at informing decision making following the idea of creating a smart user which may be an important missing piece to smart grids (or other smart home technology).

Table 1: Norm-critical suggestions for prototype development

	Consideration for norm-criticism	Addressed in the prototype
Interest and expertise	Rather than catering for one user (or treating the household as one unitary actor) who becomes the expert in smart energy management, it makes much more sense to aim for more distributed way of learning	Yes
	Rather than taking the needs of the larger energy system as starting point (providing value for the grid), and in line with that taking energy management as a starting point, it makes more sense to try and improve elements of the smart energy management in such a manner that it fits better with existing household management and practices	Yes
Control	Rather than only focusing on educating people to improve energy literacy and digital literacy in order to have them adopt a pre-designed smart energy management system, a focus on household management and planning is needed in which energy related information (including e.g., Demand Response notifications and requests) is integrated	Yes
	Information provision is to be tailored to diverse knowledge and educational levels, and take into account different learning styles (text, visuals, graphs, numbers)	Yes
	Rather than opting for technical and digital solutions only, preferences for rules-of thumb over digital notifications and requests should be taken seriously as well	Yes
	Considering that a lot of information on smart energy is not directly put to use, the fact that people forget about this information means that some form of rehearsal and repetition over time is necessary	No
	Empower homeowners to self-monitor energy management, including receiving notifications of any malfunctions and knowing whom to contact, rather than relying on an external provider or actor.	Yes
	Rather than trying to control the household management through a complex digital system that is opaque to householders, it makes sense to only include what is necessary in the energy management system and leave other decisions up to the users (based on e.g., rules-of-thumb such a looking at the weather forecast and decide when to do the laundry,	Yes

	whereby other household-logistical considerations can be taken into account as well – no smart digital device is necessary for this)	
Trust	Rather than considering experiences of not feeling safe and comfortable as exceptions, place these experiences central and take them seriously	Yes
	Rather than assuming trust, check with residents how much trust they have in the technologies and providers	Yes
	Rather than assuming what is needed to make a home energy management system work, collect suggestions not only from the most vocal and proficient users, but from all types of household end-users (including those in a situation of vulnerability)	Yes

The design work taken on after the Dutch case study explicitly aimed at including the norm-critical considerations from Table 1 (above). This meant among others to aim for engaging the entire household, ensuring that all relevant information is available to each individual person regardless of age, gender, interest or knowledge. Furthermore, the design process has taken as a point of departure the role of the household planner and associated responsibilities (a role most often fulfilled by women), which allows for taking household management rather than energy management as a point of departure.

By doing so, an approach was chosen that also addresses gendered inequalities within households and that aims first at making these inequalities visible and then at distributing energy planning and responsibility for behavioural adjustments more evenly among household members, as the next sections will show.

3.5 From norm-criticism to norm-creative design work

The design research categorized household energy activities into three types: active consumption (cooking, electronics), passive consumption (heating, lighting), and responsibility and planning (bills, upgrades, behavioural adjustments) Within the last category, parallels with gender-coded household responsibilities were identified, where men prioritize long-term, financially motivated decisions, and women focus on daily behavioural adjustments (Clancy and Roehr, 2003). This male interpretation has been predominant in the climate crisis narrative, but both approaches are crucial for accelerating the transition to renewable sources and adapting to evolving energy dynamics. That is why the design approach emphasizes the role of smart users, not just smart homes.

This division of responsibilities in the household is such that it necessitates consistent thinking and planning (i.e. cognitive housekeeping), leading to the term "the thinking project manager." This role tends to be predominantly held by women. The thinking project managers of the household, handle most activities benefiting the entire household. Such activities often require significant energy. Consequently, any behavioural shifts such as timing these household activities due to varying energy prices over the course of the day, bear heavier on the thinking project manager and add to their mental load. Hence, focus lies on planning and taking responsibility for energy consumption at the intersection of gender and energy research in the design work.

After a literature review phase, the team from the IEA UsersTCP on Gender and Energy joined in a three-day co-creation workshop in September 2021 discussing the intersection of planning and responsibilities between household gender norms and energy consumption. Key takeaways from the discussions highlighted the importance of involving all household members, the evolving nature of household tasks, the need for justice and sufficiency in energy solutions, and the potential of energy donations to drive behavioural change within communities.

Next, a weeklong design sprint was conducted in December 2021 to create a conceptual design intervention addressing gender-related power dynamics in households by visualizing the effects of energy-demanding activities through a centrally located interface. This prototype aimed to promote communication, respect, and energy optimization among household members while aligning with the smart electricity grid's load and pricing dynamics.

3.6 Prototyping: from energy visualization towards integrated household planning

A first prototype was designed and built between January and May 2022 by a group of students, resulting in an energy clock with a touch screen interface and an additional physical indicator for energy pricing, aiming to provide users with at-a-glance information. Usability testing involved interviews and prototype interaction with users, followed by a five-day in-home trial. An analysis of feedbacks collected from the users revealed both successes and challenges. Successes included spatial inclusion of household members by placing the interface centrally in the participants' home, using energy-conserving e-paper screens, and openness to behaviour adjustments. Challenges encompassed complexity, especially in interpreting energy data from afar ("At a Glance"), an unsuccessful clock integration, round interface format limitations, and prototype constraints. The focus was mainly on technical aspects, with limited attention to norm-creative features. Missing elements were the lack of clear responsibility allocation for activities and the inability to plan energy consumption in advance for optimization.

Another design sprint was conducted in September 2022 and another co-creation workshop held in Oktober 2022 with the expert team from the IEA UsersTCP Gender & Energy, this time focusing on a more simplified, norm-creative and home integrated version of the planner. It resulted in a shift from the clock energy interface to a calendar energy interface. This aligns with the goal of emphasizing future energy consumption planning, enhancing visibility of energy activities, linking activities to household members, and better supporting the thinking project manager.

The focus encompassed several key aspects, with the aim of prompting behavioural shifts challenging the prevailing male interpretation privilege of sustainable energy consumption. Additionally, we prioritized spatial and cognitive inclusion to involve all household members, empowering the thinking project manager and making responsibility visible. Lastly, proactive energy planning was emphasized, where the user gradually gains understanding of energy supply, cost, and environmental impact which allows for behavioural change, rather than focus on drastic interventions.

By integrating energy information with a calendar rather than a tool to track past consumption in numbers and graphs, it shifts from being an energy visualization tool to

being an integrated household planner. Just like we have identified planning as a common theme for both gender and energy challenges, we want to combine aspects from both, common energy information interfaces and planning tools directed at the "thinking project manager". These planning tools, often referred to as "mom planner" help with organizing the schedule and activities of household members as well as meal planning and keeping on track with chores and events. We call the resulting tool a household planner.
The household planner design consists of four sections: An "At a Glance" overview of current energy pricing, environmental impact, date, time, weather conditions and reminders. A weekly calendar with a view of activities and energy and weather forecasts, supporting color-coded personal calendars, long-term planning, and intuitive task management. A detailed activity pop-up view for in-depth calendar planning, enabling activity prioritization and assignment to household members. And finally, lists and routines for managing routine and future tasks, such as shopping, chores, checklists, and to-do items.
The proposed design is displayed on a framed energy efficient e-paper screen that is placed at the heart of the home, such as the kitchen or the hallway, accessible to all household members. The design is meant to be a starting point that is adaptable to both user needs and systemic needs to ensure it will be integrated in household routines to provide long term behavioural change and contribute to more sustainable and empowered households.

3.7 Future work and outlook of the household planner

The household planner will undergo testing from October to November 2023, spanning two weeks in three households, each with a unique composition of occupants. To develop the prototype, we have tailored the design for black and white e-paper reader. Employing a hierarchy similar to poster design, essential information for quick decision-making is visible from a distance, while more detailed data for planning necessitates close-up interaction. The design includes a top section with artwork that changes with the current weather. In the centre, users can view a visual icon, shifting in colour from white to grey to black, providing information about energy costs (high, medium, or low) and its environmental impact at a glance. The more detailed information encompasses an hourly weather and energy forecast, along with a calendar view highlighting daily activities for each household member and their relation to the energy forecast. Users can also switch to a weekly calendar view, which may be filtered by household member.
In addition to the current functionalities, in the future the household planner could serve not only as an interface between energy, household activities and household members but also as a platform for energy providers, technicians and users to interact. This functionality would provide information and security for people with questions about their energy consumption or production, lowering the hurdle for people of a less technical mindset to also engage in such activities concerning systemic changes and investment in technology such as the installation of solar panels for example.
The household planner could serve as a means of broadening gender norms around sustainable energy monitoring and management, inviting all household members to engage on a behavioural level as well as equipping companies and potential customers for technical upgrades with a way of communicating at a household anchored and inclusive level.

3.8 Distributed and shared learning within the household: designing for diversity

The proposed design aims to address key findings from the smart grid studies conducted in Voorhout and Schoonschip. Given that respondents with energy and digital skills showed gendered experiences of control, comfort, safety, and trust in digital interfaces, we aimed to enhance the approachability of the household planner by adopting design aesthetics resembling a traditional calendar, diverging from the conventional digital UX design approach. This approach may also help bridge the gap between digital and material housekeeping.

A recurring issue is that a balance needs to be struck between simplicity and flexibility. Users require flexibility to maintain a sense of control, while also needing simplicity to prevent feeling overwhelmed—an issue frequently debated within design communities, particularly in the context of energy dashboard design. The household planner was significantly simplified to reduce potential feelings of shame associated with lacking digital literacy and to mitigate the risk of any household members becoming overly reliant on others. By presenting hierarchical information at various levels of detail and incorporating simple language and visual aids, users can apply rules of thumb to facilitate straightforward decision-making but also plan with more accuracy.

4. CONCLUSION AND DISCUSSION

4.1 Household management that challenges smart-grid technology design

This paper aims to contribute to improved design practices that take better account of diverse household user needs, ambitions and expectations, which is necessary from both a normative viewpoint that calls for distributive justice as well as from a more instrumental viewpoints that calls for improved effectiveness of smart grid solutions that contribute to less carbon-intensive energy systems.

We have explored how residential smart energy management affects and is affected by household management practices, understanding these changes within the context of daily household routines and conventional (often gendered) division of household tasks. Empirical inquiries with household end-users in two pilots, structured by conceptual categories (interest and expertise; experienced control; trust) resulted in a diagnosis of the challenges of integrating smart grids into household settings.

Next, this diagnosis provided a start for norm-critical and norm-creative design work, culminating in the development of a prototype "household planner" for more inclusive and gender-sensitive household engagement in smart grids. Although still explorative and in need of further development, this prototype provides an interesting alternative to energy dashboards.

What we can conclude from our efforts is, first of all, that system-oriented design fosters social innovation necessary for a gender-sensitive energy transition. Conventional technology design approaches that limit participation to discussions on how energy-related information is communicated via an energy dashboard, do not adequately challenge assumptions about behaviour embedded in daily practices and related norms, ways of doing, needs and skills. Conceptually connecting behaviours to systemic change through norm-

critical and -creative approaches can facilitate transformative learning.
The Dutch empirical pilot case analyses revealed the need for gender-sensitive and inclusive smart grid design. Current approaches often lack "household-management-literacy" perpetuating gendered roles and hindering effective demand-side flexibility. Improved design approaches are needed in all phases of smart grid development, emphasizing shared learning and aligning with household management rather than remaining solely focused on energy management.
The prototype differs from current approaches by focusing on household planning over energy monitoring. Further development and real-life pilot testing are suggested to align smart grid configurations better with household needs and promote role pattern changes. Taking a norm-creative design research approach can then help to reshape both smart grid technologies and everyday household management practices.

4.2 How norm-critical and norm-creative design can help upscale behavioural changes

How can the efforts described contribute to upscaling? First of all, the household planner prototype holds the potential to enable shared learning, fostering enhanced engagement of all household members in smart energy management. Second, the research and design approach as presented (section 2.4) can be used in other settings where household energy flexibility is being introduced, as a norm-creative and participatory approach towards the co-design of energy transition pathways. The approach can be elaborated in guidelines that are of use for designers, energy and smart grid providers, customers, policy makers and other stakeholders. This in fact is what we plan to do in the upcoming work as part of the IEA UsersTCP Gender and Energy.

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REFERENCES

Boekelo, M., Breukers, S., Young, J., Mourik, R., (2022) A just energy trading platform – or just an energy trading platform? Paper presented at the ECEEE Summer Study on energy efficiency 2022, June 6-11, European Council for an Energy Efficient Energy Economy (ECEEE).

Breukers, S., Boekelo, M., Oberti, B. (2022). Gender, expertise and control in Dutch residential smart grid pilots. Paper presented at the ECEEE Summer Study on energy efficiency 2022, June 6-11, European Council for an Energy Efficient Energy Economy (ECEEE).

Clancy, J., Roehr, U. (2003). Gender and Energy: is there a Northen Perspective? *Energy for Sustainable Development,* 7(3), 44-49. https://doi.org/10.1016/S0973-0826(08)60364-6

Dam, Rikke Friis; Yu Siang, T. (2022). The History of Design Thinking. https://www.interaction-design.org/literature/article/design-thinking-get-a-quickoverview-of-the-history. Accessed 01.10.2023.

Dorst, K. (2015). *Frame Innovation: Create New Thinking by Design*. The MIT Press. https://doi.org/10.7551/mitpress/10096.001.0001

Ellsworth-Krebs, K., Reid, L., & Hunter, C. J. (2015). Home -ing in on domestic energy research: "House," "home," and the importance of ontology. *Energy Research & Social Science*, 6, 100–108. https://doi.org/10.1016/j.erss.2014.12.003

Gram-Hanssen, K., & Darby, S. J. (2018). "Home is where the smart is"? Evaluating smart home research and approaches against the concept of home. *Energy Research & Social Science*, *37*, 94–101. https://doi.org/10.1016/j.erss.2017.09.037

Hansen, M., & Hauge, B. (2017). Scripting, control, and privacy in domestic smart grid technologies: Insights from a Danish pilot study. *Energy Research & Social Science*, *25*, 112–123. https://doi.org/10.1016/j.erss.2017.01.005

Irwin, T., Tonkinwise, C., & Kossoff, G. (2015). Transition Design: An Educational Framework for Advancing the Study and Design of Sustainable Transitions. 6th International Sustainability Transitions (IST) Conference, (pp. 1-36). Sussex.: https://www.academia.edu/15283122/Transition_Design_An_Educational_Framework_for_Advancing_the_Study_and_Design_of_Sustainable_Transitions_presented_at_the_STRN_conference_2015_Sussex_

Kennedy, J., Nansen, B., Arnold, M., Wilken, R., & Gibbs, M. (2015). Digital housekeepers and domestic expertise in the networked home. *Convergence: The International Journal of Research into New Media Technologies*, 21(4), 408–422.

https://doi.org/10.1177/1354856515579848

Kloppenburg, S., & Boekelo, M. (2019). Digital platforms and the future of energy provisioning: Promises and perils for the next phase of the energy transition. *Energy Research & Social Science*, 49, 68–73. https://doi.org/10.1016/j.erss.2018.10.016

Mourik, R. M., Breukers, S., van Summeren, L. F. M., & Wieczorek, A. J. (2020). Chapter 2.5—The impact of the institutional context on the potential contribution of new business models to democratising the energy system. In M. Lopes, C. H. Antunes, & K. B. Janda (Eds.), *Energy and Behaviour. Towards a Low Carbon Future*. Academic Press. pp. 209–235.

Mackenzie, D., Wajcman, J., Introductory essay: the social shaping of technology. In *Soc. Shap. Technol*., 2nd ed., Open University Press, Buckingham, 2012: pp. 1–48.

Nilsson, Å. W., & Jahnke, M. (2018). Tactics for Norm-Creative Innovation. *She Ji: The Journal of Design, Economics, and Innovation*, *4*(4), 375–391. https://doi.org/10.1016/j.sheji.2018.11.002

Schumann, M., Šipetić, M., Arniani, M., Boekelo, M. (2021) Pilot specific demonstration scenarios, Deliverable 1.3 for the H2020 HESTIA project. June 30, 2021.

Silvast, A., Williams, R., Hyysalo, S., Rommetveit, K., & Raab, C. (2018). Who 'Uses ' Smart Grids ? The Evolving Nature of User Representations in Layered Infrastructures. *Sustainability*, 10(10), 3738. https://doi.org/10.3390/su10103738

Sinanan, J., & Horst, H. A. (2021). Gendered and generational dynamics of domestic automations. *Convergence: The International Journal of Research into New Media Technologies,* 135485652110304. https://doi.org/10.1177/13548565211030451

Skjølsvold, T. M., Jørgensen, S., & Ryghaug, M. (2017). Users, design and the role of feedback technologies in the Norwegian energy transition: An empirical study and some radical challenges. *Energy Research & Social Science*, *25*, 1-8.

Strengers, Y. (2014). Smart energy in everyday life: Are you designing for resource man? *Interactions*, 21(4), 24–31. https://doi.org/10.1145/2621931

Online document Strengers, Y. and Kennedy, J. (2021). The "smart wife" in crisis: Outsourcing wifework to digital voice assistants during the pandemic. https://www.abc.net.au/religion/yolande-strengers-and-jenny-kennedy-the-smart-wife-in-crisis/12565292

Annex 1: Dutch pilots and respondents

Table 2: Dutch pilot cases and data collection

Pilot 1 Voorhout: 33 homes; large majority of participants are pensioners. Most of them moved into the senior homes because of the characteristics of the homes and surroundings (not because of the SG). Solar PVs; home batteries; heat pumps; (EV & charging poles; collective battery)	Interviews	10 interviews with households June-July 2021 (7 female; 7 male; 9 households); 3 interviews with technology developers (male, 2021)
	Field visits	Field visits as part of the participant recruitment; visit to exemplar smart home (June 2021 – ongoing)
	Workshops	1x workshop with residents (September 2021)
	Focus groups	2x focus group with women (February 2022)
Pilot 2: Schoonschip, NL 30 arks; 46 households. Participants are mostly heterosexual couples with children. Progresssive urban residents, with DIY attitude and lifestyle. Circularity, strong sense of community, idealistic. Home with solar PVs, home batteries, heat pumps. P2p, one connection to the grid	Interviews	5 in-depth interviews (1x residents, 1x local governance, 1x DSO, 2x technology providers) (June-August 2021)
	Focus groups	2x focus groups with residents (5 female; 9 male; 12 households) (August 2021)
	Field visits	Field visits as part of the focus group. Tour around Schoonschip by the resident interviewed (August 2021)

Annex 2: Swedish prototype test and data collection

Table 3: Participants in the Swedish pre-study interviews

Participant	Gender	Age	Type of home	Electricity plan
a	Female	45–65	House	Fixed
b	Male	45–65	House	Fixed
c	Male	25–44	Apartment	Fixed
d	Female	18–24	Apartment	Do not know
e	Male	25–44	Apartment	Do not know
f	Female	45–65	House	Fixed
g	Male	45–65	House	Fixed
h	Female	18–24	House	Flexible

i	Female	18–24	House	Flexible
j	Male	45–65	House	Flexible
k	Female	45–65	House	Flexible
l	Male	18–24	Apartment	Flexible
m	Male	18–24	Apartment	Flexible

User tests of the first prototype:

1.Hierarchical task analysis

(tasks: Turn off an activity; Check the electricity consumption for one day in the last week; Open a weekly newsletter; Change the power threshold) 2. Scenario-based interaction (tasks during scenarios:Interpret the forecast; Study active products, interpret which one is pulling the most at the moment; Turn off individual product; Interpret the history, how the consumption was during the last 24 hours

Interpret the history, how the consumption was during the last week; Lower the power threshold; Raise the effect threshold; Study active products, interpret which is drawing the least at the moment; Find and read specific weekly letters; Interpret and use the forecast)

2. Interviews

Evaluation first prototype

Table 4: Participants to the Swedish interviews around first prototype

Participant	Gender	Age
D1	Male	25–44
D2	Female	25–44
D3	Female	45–65
D4	Male	45–65
D5	Female	18–24
D6	Male	18–24
D7	Female	18–24
D8	Female	25–44
D9	Male	25–44
D10	Male	18–24
D11	Male	45–65
D12	Female	45–65

3. In-home trial

Type of home: House; test period:2 weeks

Table 5: Participants to the in-home trial

Participant	Gender	Age
1	Male	18–24
2	Male	45–65

3	Female	45–65

FAIR, RELIABLE, INDEPENDENT AND COST-EFFECTIVE?

Preferences of German citizens regarding the design of the energy transition

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Keywords: Energy transition, social acceptance, citizen survey, financial participation, policies

Abstract *The German energy transition (ET) comprises a bundle of activities such as increase in energy efficiency, expansion of renewable energy supplies, nuclear and fossil fuel phase-out, grid extension and enforcement, roll-out of smart grid and energy storage. Studies show a high general approval of the energy transition and its goals in Germany. However, what does the German population think about the different activities of the energy transition? And can groups of individuals be formed on the basis of the perceptions of these various activities? What is the socio-demographic structure of these groups? We aim to answer these questions based on a survey study in Germany (n=889) with a focus on the perception of so-called design elements of the energy transition, i.e. overall objectives and activities to achieve the energy transition. The data analysis shows a high cost sensitivity in society with regard to energy and a positive evaluation of energy independence. Measures, i.e. different types of policy instruments promoting the energy transition, achieved the least approval. A segmentation based on the perceptions of the design elements revealed four clusters: (1) "rejectors of the energy transition", (2) "energy transition enthusiasts", (3) "reserved environmental promoters" and (4) "price-sensitive supporters of energy independence". The clusters indicated that individuals struggle to comprehend and assess each specific design element independently; instead, they tend to hold a broad positive or negative attitude and evaluation of these elements.*

1. INTRODUCTION

To address climate change, Germany aims to achieve carbon neutrality by the year 2045. Reducing CO_2 emissions is one of the most important concerns to reach this goal (Die Bundesregierung 2023). Therefore, the energy system is to be transformed towards a low-carbon energy system (Tian et al. 2022). The German energy transition (ET) is part of its climate policy strategy that comprises a bundle of regulations and activities such as increased energy efficiency, expansion of renewable energy supplies, nuclear and fossil fuel phase-out, grid extension and enforcement, smart grid and energy storage (BMBF 2023). The motivations of the energy transition are grounded on the provision of sustainable, low-carbon, efficient, affordable and secure energy (BMWK 2023; UBA 2020; BMWK 2023; UBA 2020; European Commission 2015). Recently, sector coupling and decentralised generation and consumption structures became further important features of the German ET (Fraunhofer CINES 2020).

A broad public acceptance of the energy transition is key for a sustainable transition. Studies pointed to a high general approval for the ET and a high support among the German population for the expansion of renewable energies (RE) as one of its main goals (Wolf et al. 2021; Sonnberger und Ruddat 2016; AEE 2022). When it comes to the expansion of RE in the vicinity, however, the approval rates are somewhat lower (AEE 2022). Nonetheless, there is a gap in research on how citizens think about the different activities, here called design elements of the ET, and whether patterns emerge in respondents' evaluations.

In this contribution, we therefore investigate the perception of different design elements - i.e. overall objectives and activities in specific areas of the energy transition in Germany. Therefore, a representative online survey was conducted among the German population. Based on the perception of the design elements as well as on attitudes towards the energy transition we identify subgroups, i.e. clusters, in the sample.

Based on the European and German policy mix regarding the energy transition and its implementations, we have detected design elements that we sort into the seven dimensions. These are significant and important for the energy transition as they stand for overall objectives and areas of the energy transition (Breitschopf und Burghard 2023). 1) Distribution of burdens aims at understanding which type of burden sharing with respect to the additional costs of the energy transition is preferred, and, thus, includes fairness aspects in society and industry regarding financial issues. Research indicated that respondents prefer each household contributing to the costs according to its energy consumption and not according to its income (Wolf et al. 2021). 2) Independency suggests a secure energy supply that is not reliant on imports from abroad. The term abroad refers either to the EU or to all countries that are not part of the EU. Wolf and colleagues found that one third of Germans agree with this statement and another third assumes that the switch to RE sources will tend to increase energy dependence from abroad (2021). 3) Reliability includes the notion of affordability and autonomy of households and covers financial aspects (prices) as well as reliable, autonomous energy consumption. Research showed that the majority of respondents are not worried that the energy transition will jeopardize the secure supply of electricity and thermal energy in Germany (Wolf et al. 2021). 4) Actions refer to how the energy transition should be implemented, namely deploying RE, energy efficiency, flexibility and sufficiency. 5) Measures refer to different types of policy instruments promoting the energy transition. 6) Investors are key actors of the ET that take risks and might benefit from investments in the ET. 7) The dimension costs involves weighing low financial expenses against a transition that takes into account environmental, security, climate, and participatory factors, which may potentially result in higher costs (trade-off).

This paper starts with a background section on the acceptance of the energy transition, in which the state of research is presented. Based on this, we identify the research gap and develop research questions for the study. Section 3 presents the data and the methods of this paper. The results section contains the descriptive statistics as well as the factor formation and segementation results. At the end of this paper, we discuss the results, draw conclusions and identify policy implications.

2. ACCEPTANCE OF AND PREFERENCES FOR THE DESIGN OF THE ENERGY TRANSITION

This section establishes the background of our study in four steps. Firstly, we present established theories of technology acceptance and legitimation and explain our focus on both concepts. Secondly, we synthesize the empirical literature on the societal perception of the energy transition. Thirdly, the literature on the public's perception of various policies and instruments in the field of energy is summarized. Fourthly, we present the research gap and the research questions of this paper.

2.1 Theories of legitimation and social acceptance of the energy transition

In the following, the two concepts acceptance and legitimacy are defined and their commonalities and differences are presented.

The concept of acceptance is defined as "a favourable or positive response (including attitude, intention, behaviour and - where appropriate - use) relating to a proposed or in situ technology or socio-technical system, by members of a given social unit (country or region, community or town and household, organisation)" (Upham et al. 2015, p. 103). Wüstenhagen et al. distinguish between different acceptance dimensions (2007): socio-political acceptance (general social climate with regard to the acceptance object), community acceptance (reactions of those locally affected by the construction of a certain infrastructure) and market acceptance (acceptance of the market actors, i.e. suppliers and demanders, but also intermediaries such as network operators).

To define the concept of legitimacy, we present definitions that also include acceptance. For example, Bergek et al. define legitimacy as "a matter of social acceptance and compliance with relevant institutions" (Bergek et al. 2008, p. 581). However, also definitions exist that do not link both concepts, e.g. Scott defines legitimacy as the perceived congruence of a subject with its institutional environment, i.e. norms, values, beliefs and practices in its context (2013).

To compare both concepts, the concept of legitimacy focuses on the structural aspects of a (new) socio-technical system, i.e., physical infrastructures, regulations or institutions, with a more objective focus. In contrast, the concept of acceptance is mostly situational and psychological with a subjective focus on individuals and their cognitive, emotional, and behavioral responses to technologies. Thus, social acceptance seems to be the appropriate concept when it comes to the perception of the energy transition and certain energy technologies. In contrast, the concept of legitimacy is used when it comes to the perception of certain energy policies and instruments. [i]

2.2 Perception of the energy transition and energy technologies

Several studies exist that analysed (among other aspects) the perception of the energy transition overall. These studies found relatively high approval rates for the energy transition (Groh und Möllendorff 2020; Ali et al. 2023; Djurisic et al. 2020; Gölz und Wedderhoff 2018). Here, acceptance of the energy transition is often operationalised in terms of support for the expansion of renewable energies (Djurisic et al. 2020; Ali et al. 2023). Groh and Möllendorff (2020) investigated influencing factors on the acceptance of the energy transition and found that the perceived importance of climate policy goals is an important factor.

In addition, there are a number of studies that analyzed the societal perception of specific energy technologies and factors influencing it, for example battery storage, biofuel production and hydrogen fuel stations (Emmerich et al. 2020; Baur et al. 2022), ground-mounted solar plants (Ruddat und Sonnberger 2019), wind energy (Ruddat und Sonnberger 2019; Langer et al. 2018, 2016; Gölz und Wedderhoff 2018), photovoltaic systems (Gölz und Wedderhoff 2018), high-voltage power lines (Gölz und Wedderhoff 2018; Ruddat und Sonnberger 2019) and hydropower (Tabi und Wüstenhagen 2017). Furthermore, some researchers investigated more generally public preferences for RE technologies or energy sources (Ozcan 2019; Dubois et al. 2019; Dallenes et al. 2023; Lee und Reiner 2023).

Some of the studies focused on differences between community acceptance and socio-political acceptance (Wüstenhagen et al. 2007). A common finding is that the general acceptance of the energy transition or of certain energy technologies is higher than the local acceptance (Baur et al. 2022; Emmerich et al. 2020).

2.3 Preferences for the design of and perception of energy policies by citizens

Three studies were identified that investigate the public perception of energy policies or policy packages, referring to our dimension 4) actions. [ii] Kanberger and Ziegler (2023) found a high level of agreement for higher targeted shares of RE and for the nuclear phase-out in the German population, i.e. environmentally ambitious energy policy measures. Steffen and Patt (2022) examine the public perception of different clean energy policies in Switzerland possibly influenced by the Russia-Ukraine war, e.g. fossil fuel phase-out policies, government support for RE and coordination of electricity markets between countries. The support for policies

[i] Linked to the concept of legitimacy is the notion of acceptability, which is often used in connection with the perception of (energy) policies (Faure et al. 2022; Zawadzki et al. 2022).

[ii] Research on the perception of the public regarding the phase-out of fossil energies in different sectors (Rinscheid et al. 2020; Rinscheid und Wüstenhagen 2019; Tröndle et al. 2023) is not considered here. The same applies for studies that looked into the public perception of single policy instruments, such as carbon pricing (Dütschke et al. 2023) or low carbon transport policies in cities (Hochachka und Mérida 2023) or nation-wide policies (Jansson und Rezvani 2019; Kitt et al. 2021).

aiming at accelerating the expansion of RE was higher compared to the support for fossil fuel phase-out policies. This high level of approval remains the same when it comes to more specific measures, such as allowing for ground-mounted solar PV and streamlining the permitting process (Steffen und Patt 2022). Zawadzki et al. (2022) looked into the perception of energy policies in the Netherlands with different target behaviours, i.e. curtailment behaviour (changing behaviour to reduce energy use), use of energy efficient appliances, use of sustainable energy sources, or changing the time of energy use (consuming energy when RE is widely available). The authors found that policies targeted at efficiency behaviours or adoption of sustainable energy sources are evaluated more positively than policies focusing on curtailment and time of use (Zawadzki et al. 2022).

Also, the perception of policy attributes, such as national burden sharing rules was analysed in several studies (Kanberger und Ziegler 2023; Fanghella et al. 2023; Groh und Ziegler 2018). This relates to the dimension 1) distribution. Perceived distributional fairness of climate policies can increase the acceptance of policy measures of the energy transition (Fanghella et al. 2023). It was found that the polluter-pays rule (individual contributions to climate change is proportional to individual financial contributions to the costs of the measure) receives the highest approval, whereas other rules, such as the ability-to-pay or the equal-pay rule, are rated more negatively (Kanberger und Ziegler 2023; Fanghella et al. 2023; Groh und Ziegler 2018).

One study looked at the evaluation of different policy goals of the energy transition, such as environmental sustainability, economic sustainability, security of energy supply, and social sustainability (Groh und Möllendorff 2020). This relates back to our dimension 3) reliability. The authors found that environmental sustainability is most important for the support of the ET, whereas social sustainability is less important (Groh und Möllendorff 2020). Another study investigated the perception of different attributes of the energy transition, such as price and reliability of the electricity supply (Motz 2021), relating to the dimensions 3) reliability and 7) costs of our study. It was found that the evaluations of variations in the price and reliability of supply depend on the energy source used. That is, the highest price sensitivity was found for nuclear energy and the highest blackout sensitivity for wind energy (Motz 2021).

A considerable amount of literature has been published on the preferences for different policy types, referring to our dimension 5) measures. A common finding is that households evaluate non-coercive instruments (education and information programmes, standards) more positively that coercive ones (taxes and energy consumption limits) (Rhodes et al. 2017; Odland et al. 2023; Faure et al. 2022). Similarly, pull measures (e.g. decreasing the costs of energy efficient appliances) are prefered over push measures (e.g. increasing the costs of energy inefficient appliances) (Zawadzki et al. 2022). The acceptability of push policies depends on the perceived extent to which individuals benefit from the policy, i.e. revenues benefited individuals or the environment instead of general funds (Zawadzki et al. 2022). Ingold and colleagues asked about preferences for four instruments (information, tax relief, subsidies, or bans) to support RE. They concluded that subsidies are most and bans are least preferred (2019).

Further (empirical) literature refers to the perception of financing the energy system change (responsibility of the public, government and energy companies for financing) and thus relates to our dimension 6) Investors and 7) Costs (Becker et al. 2019). The authors found a lack of perceived distributive and procedural justice among the respondents and a lack of trust in energy companies and governments, resulting in a lower support of bearing additional costs. In addition, greater responsibility was assigned to the energy industry (Becker et al. 2019).

2.3 Research question

There is a gap in research on the public perception of the various elements of the German energy transition that are actually discussed or implemented. Moreover, it has not been researched whether patterns emerge in respondents' evaluations of the different aspects of the ET and whether groups can be identified based on these evaluations.

The research questions of this study is accordingly: How are different elements of the energy transition perceived by the German public? Which groups with similar preferences can be identified?

3. DATA AND METHODS

To answer the research questions, an online survey was conducted among the German population. The aim of the survey was to study the perception of different designs of the energy transition. The following sections describe the data collection and survey design, the sample population, and the operationalization of the measures of the conceptual model.

3.1 Data collection and survey design

The online survey was conducted in January 2022 in cooperation with a service provider for online polls. A sample of 1095 respondents was selected from an online panel of German citizens based on quotas with respect to socio-demographic features.

On average, respondents took 10 minutes to complete the questionnaire, which comprised in total 12 main questions that included sub-questions or statements. The questions covered the seven dimensions that are characterised by their design elements of the energy transition, different forms of financial participation in the energy transition, respondents' motivations to financially participate in the energy transition or not, as well as the perception of the energy transition. In addition, nine questions on socio-demographic data were included in the questionnaire. When using statements, we asked the respondents to agree or disagree on a 5-point Likert scale.

3.2 Data base and sample description

The data was cleaned by deleting cases with more than 75% missing values in the questions on attitudes, financial participation and design elements, as well as by deleting cases with extreme positive or negative or average response tendency in the questions concerning the design elements. Finally, a 10% quartile for speeders and a 5% quartile for slow replies were applied. The final data set consisted of 889 cases.

The sample is comparable with respect to age (>18 years), gender, home ownership (residents living in own dwelling) and education of individuals to the population in Germany. The socio-demographic variables are depicted in Table 4 in the Annex.

3.3 Measures

In this section, the measures in the questionnaire for the design elements and further variables for the cluster analyses are presented. 1) *Distribution* was measured with four items. The dimension 2) *Independency* was measured with four items. Six items were included in the questionnaire to measure the dimension 3) *Reliability*(Wolf et al. 2021; Motz 2021). 4) *Actions* were measured with four items. To survey perceptions of 5) *Measures* four items that were developed based on a policy typology (Bemelmans-Videc 2011) were included in the questionnaire. All items on the dimensions 1 to 5 were rated on a five-point Likert scale (1 ′Agree completely' to 5 'Do not agree at all"). The dimension 6) *Investors* was measured with seven items that were rated on a four-point scale (1 'Yes, predominantly these persons/organisations' to 4 'no, definitely not these persons/organisations'). The dimension 7) *costs* was measured with six items that were rated on a five-point Likert scale (1 ′Agree completely' to 5 'Do not agree at all").

In addition, *attitudes* towards the energy transition were measured with two items referring to promoting as well as slowing-down the expansion of RE (items translated and adopted from Sonnberger und Ruddat 2016; Ruddat und Sonnberger 2019), one item on the benefits of the energy transition for society (translated and slightly modified based on Sonnberger und Ruddat 2016; Ruddat und Sonnberger 2019) and one item referring to the interest in the topic energy transition (translated and reversed based on Sonnberger und Ruddat 2016). The respondents could indicate on a five-point Likert scale whether they agree or not (1 ′Agree completely' to 5 'Do not agree at all").

3.4 Data analysis

In a first step, for each of the dimensions 1) distribution, 2) independency, 3) reliability, 4) actions, 5) measures, 6) investors and 7) costs a separate explorative factor analysis (principal component analysis) was conducted with varimax rotation. Items were expected to have factor loadings of >0.6 on the relevant factor and no factor loading >.4 on other factors.

After that, in order to determine groups of individuals with different preferences regarding the design of the energy transition, various cluster-analytical evaluation methods were applied. The aim is to group classification objects (individuals) into homogeneous clusters (individual groups) (Bacher 2010). The application of cluster analysis procedures is exploratory, i.e. the number and characteristics of the clusters are unknown at the beginning of the analysis (Bacher 2010). We used two cluster analysis methods for this purpose: The hierarchical procedure was used to find outliers (for this, the single linkage method was chosen) and to determine the cluster number range (therefore, the Ward method was applied). For the hierarchical method, we chose the squared Euclidean distance measure (SEUCLID) (Bacher 2010). With the help of the partitioning procedure, the 'actual' cluster analysis took place, with which the clusters were determined and saved. In partitioning cluster analysis, a number of clusters (k) must be specified. The partitioning procedure carried out here is the k-means cluster analysis, in which the assignment of a case to the closest cluster was determined via the distance between case and (updated) cluster centre (Schendera 2010).[iii] All content-relevant variables that were not included in the cluster analysis were taken into account following the cluster analysis by calculating the correlation of the variables with the clusters.

4. RESULTS

We applied factor analysis to condense the number of items in the different dimensions which is described in the first section. The factors formed are the variables for the cluster analysis. In the following section we present descriptive statistics before the results of the cluster analysis are outlined.

4.1 Reliability and validity assessment

For the construct 1) distribution one factor was identified by the factor analysis; one item loaded on a second factor. [iv] For 2) independency, similarly, one factor was identified and one item loaded on another factor.[v] The construct 3) reliability formed two factors: Reliability - technology consits of four items and reliability - self-generation consits of two items. For 4) Actions one factor was identified, consisting of four items. The items for the construct 5) measures loaded on one factor consisting of four items. For the construct 6) investors, two factors were identified, each consists of three items: Investors - bottom-up energy transition and investors - top-down energy transition. One item had to be excluded due to unclear loadings on the factors.[vi] The construct 7) costs showed one factor consisting of five items. One item loaded on another factor. [vii] As Cronbach's α was not sufficient for the scales on distribution, reliability and investors - top-down energy transition these factors were excluded.

Next, the items for all constructs with sufficient reliability were added to a factor analysis simultaneously, which nearly led to the expected structure (varimax rotation, pre-defined number of factors extracted; items were expected to have factor loadings of >0.6 on the relevant factor and no factor loading >.4 on other factors). [viii]

For the construct *attitudes* another explorative factor analysis with varimax rotation was conducted. The negatively formulated items were recoded beforehand. For this construct one

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iii Since the cluster solution of the partitioning cluster analysis depends on the sorting of the data set (Schendera 2010), three random variables are calculated on the basis of which the sorting of the cases is organised. To check the stability of the cluster analyses, the distribution of cases into clusters within a solution is compared with the distribution of cases in other solutions. Subsequently, the solution with the smallest mean value is selected from the three solutions.

iv This was the following item: "Everyone who uses electricity pays depending on their consumption, there are no exceptions."

v This was the following item: "For an energy supply that is independent of foreign countries, it is important that the electricity and gas pipelines in Europe are well connected with each other so that European countries can help each other out when there is a surplus or lack of energy."

vi This was the following item: "Investment funds that finance sustainable, ecological or green projects, and in which citizens can also participate with small amounts of money."

vii This was the following item: "As cheap as possible."

viii The items in the constructs independency (except from one item with a factor loading slightly below .6), measures (except from two items with factor loadings slightly below .6), actions (all items show factor loadings slightly below .6) and investors-top-down energy transition loaded on one factor each.

factor was identified. All items and descriptive statistics as well as Cronbach's α values are provided in Table 6 in the annex. In Tables 7-12 in the annex the rotated factor loadings are shown for the constructs 1-7.

Reflecting the different factors, six new variables - independency, actions, measures, investors-bottom-up energy transition, costs, attitudes - were constructed by computing the mean scores of items that correlated higher than .60 with each of the six factors.

4.2 Descriptive statistics

29% of the repondents participate financially in the energy transition. Financial participation is defined as using or investing in one or several of the following options: Small photo-voltaic (PV) plant on the rooftop or a solar module at the balcony, holding a share in a wind or PV solar park or green investment fund, member in an energy cooperative, having an electric car, heating with heat pump, wood, pellet or biogas burner.

For the variables in the cluster analysis, descriptive statistics were examined (Table 1). In addition to the variables which represent a factor, the following item that was not included in a factor was included in the cluster analysis as well (Breitschopf und Burghard 2023): "How should the state promote the energy transition? As cheap as possible."

Table 1: Descriptive statistics for the cluster analysis (CA) variables (factors and one single item).

Variables	N	Mean	SD	Min	Max
Independency	881	2.0	0.9	1	5
Actions	887	2.2	0.8	1	5
Measures	879	3.0	0.9	1	5
Investors bottom-up energy transition	727	2.2	0.8	1	4
Costs	869	2.4	0.8	1	5
Attitudes towards energy transition	847	2.4	0.9	1	5
As cheap as possible	881	1.8	0.9	1	5

Note. Ratings range from 1 to 5, for investors from 1 to 4. Higher numbers indicate a more negative evaluation.

It can be seen that the variable as cheap as possible receives the most agreement, followed by the factor independence. Actions and investors have positive to medium approval ratings, followed by the costs factor. Measures achieve the least approval. The attitudes towards the energy transition also receive positive to neutral ratings.

4.3 Identifying groups with different preferences for the design of the energy transition

Cluster analyses were carried out to analyse which subgroups with different preferences for the design and attitudes towards the energy transition can be identified. Seven variables were selected as cluster variables: Five factors on the design of the energy transition - independency, actions, measures, investors bottom-up energy transition, costs - and the factor attitudes towards energy transition were selected. In addition, the variable "How should the state promote the energy transition? As cheap as possible." that did not went into the factor costs was also included in the cluster analysis.

Using a hierarchical cluster analysis, the optimal number of clusters was first determined as four.[ix] Subsequently, a cluster centre analysis was performed to optimise the cluster solution. The cluster centre analysis revealed four clusters[x] which were named as follows: (1) "rejectors of the energy transition" (26%), (2) "energy transition enthusiasts" (18%), (3) "reserved environmental promoters" (19%) and (4) "price-sensitive supporters of energy independence" (38%) (Table 2). [xi]

Table 2: Mean values with standard deviations in brackets of the cluster variables for each cluster.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
N	171	121	127	245
Independency	2.4 (0.8)	1.4 (0.5)	2.1 (0.7)	1.8 (0.6)
Actions	2.9 (0.6)	1.3 (0.4)	2.0 (0.6)	1.9 (0.5)
Measures	3.7 (0.6)	1.9 (0.6)	2.6 (0.7)	2.9 (0.6)
Investors bottom-up energy transition	2.5 (0.8)	1.8 (0.7)	2.1 (0.7)	2.2 (0.7)
Costs	2.8 (0.6)	1.4 (0.4)	2.3 (0.6)	2.2 (0.5)
Attitudes towards energy transition	3.1 (0.7)	1.5 (0.6)	1.9 (0.7)	2.1 (0.6)
As cheap as possible	1.5 (0.7)	1.5 (0.7)	3.3 (0.5)	1.4 (0.5)

Note. Ratings range from 1 to 5, for investors from 1 to 4. Higher numbers indicate a more negative evaluation.

All mean differences are significant, which indicates that by the cluster analysis such clusters are formed that differ as much as possible from each other. Regarding the factors actions, investors bottom-up energy transition and costs the mean values of cluster 3 and 4 differ do not significantly. In terms of the variable as cheap as possible, the mean values of cluster 1, 2 and 4 were not significant.

In cluster 1, political instruments and measures in particular are assessed quite critically and even more critical than in the other clusters. Also the ET as a whole is rated quite negatively compared to clusters 2 to 4 and the cost-effectiveness is very important to individuals in cluster 1. Persons in cluster 2 rate all dimensions very positively and have a positive attitude towards the ET. However, it is important to them that the ET is designed in such a way that financial burdens for consumers remain low. Cluster 3 is characterised by many ratings in the mid-range; measures are rated quite critically; however, more positively compared to cluster 1 and 4. In addition, for cluster 3 financial burdens are not a critical issue. Cluster 4 values energy independency and cost-effectiveness relatively highly and rate political measures in a rather critical way.

The clusters are described by other variables, such as socio-demographic and financial participation variables, and differences are identified (Table 3).

[ix] Before, four cases have been identified as outliers and were excluded from further analyses.

[x] The algorithm needed 10 iteration steps to calculate the solution. The ANOVA indicates that the variables/characteristics differ with respect to the clusters with a significance of p = .000. The eta_2 values are between .260 (factor actions) and .506 (factor investors bottom-up energy transition). The eta_2 values indicate a strong correlation between the output variables and the clusters, i.e. that the variables each have a strong 'influencing power' in clustering the cases.

[xi] All 7 variables used for the cluster analysis have missings. According to the default setting, the missings are excluded list by list and 664 cases remain in the data set for clustering.

Table 3: Proportions of the socio-demographic variables and the variable financial participation for each cluster.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Share female	48%	40%	48%	53%
Share 18-30 years	11%	16%	25%	14%
Share high education	20%	41%	46%	36%
Share own house or flat	25%	36%	10%	40%
Share single person household	39%	41%	31%	29%
Share household with children	22%	17%	23%	27%
Share rural municipality	25%	14%	14%	21%
Share big city	31%	39%	35%	33%
Share employed	57%	50%	58%	51%
Share not financially participating	83%	61%	55%	65%
Share financially participating in two or more aspects	7%	19%	16%	16%

This shows that people in cluster 1 are somewhat older, somewhat less educated, often live in the countryside and only a small proportion is financially involved in the ET. Cluster 2 is characterised by a rather low proportion of women, a higher proportion of single households and a more frequent residence in large cities. In addition, the share of people participating financially in several aspects in the ET is the highest. People in cluster 3 tend to be younger, more highly educated, more often living in large cities and less often in their own property. In addition, in this cluster the share of persons not participating financially in the energy transition is the lowest. Cluster 4 is characterised by a slightly higher proportion of women, a higher proportion of owned properties and a higher proportion of households with children.

Regarding age, education, occupation and financial participation the differences between the clusters are significant (chi_2-Test, $p<.05$). The differences in the variables gender, dwelling, household type and residential location are not significant.

5. DISCUSSION

In this section we discuss the results and present the limitations as well as the research contribution. The factor analysis shows that respondents do not differentiate between the diffferent elements of a certain dimension. This applies for the constructs independence and costs and indicates that individuals care about energy independence, but care less about the ways to achieve it. Similarly, it appears that individuals who accept somewhat higher costs do not differ greatly in the accepted trade-offs. For the constructs actions and measures all items loaded on one single factor. That is, individuals who support RE also support energy efficiency and behavioural adjustments in energy consumption. The different measures are assessed similarly, which contradicts the literature (Rhodes et al. 2017; Odland et al. 2023; Faure et al. 2022). However, Odland and colleagues identified three groups in a cluster analysis: supporters of all home decarbonization policies, supporters of voluntary policies only and opponents to all home decarbonization policies (2023).

Looking at the evaluation of the cluster variables, it was found that the variable as cheap as possible received the most agreement. This may be due to a high cost sensitivity in society with regard to energy (Becker et al. 2019). The factor of independence was rated somewhat more negatively, but still in the positive spectrum. This might be due to the public debate on energy security in the course of the Ukraine-Russia war. Actions and investors-bottom-up ET featured positive to medium approval ratings, followed by the costs factor. Measures achieved the least approval, possibly due to the items on bans and higher prices included in the factor - measures that are evaluated critically in general (Rhodes et al. 2017; Zawadzki et al. 2022). The attitudes towards the ET also received positive to neutral ratings, which corresponds to the literature (Wolf et al. 2021; Sonnberger und Ruddat 2016; Groh und Möllendorff 2020; Ali et al. 2023).

The cluster analysis revealed four clusters: (1) "rejectors of the energy transition", (2) "energy transition enthusiasts", (3) "reserved environmental promoters" and (4) "price-sensitive supporters of energy independence". In some factors some of the mean values between clusters do not differ significantly. This finding indicates that individuals struggle to comprehend and assess each specific design element independently; instead, they tend to hold a broad positive or negative attitude and evaluation of these elements. Regarding age, education, occupation and financial participation the differences between the clusters are significant. The differences in the variables gender, dwelling, household type and residential location are not significant. This shows that variables related to socio-economic status and financial participation are more relevant for the perception of the design of the ET than variables referring to the personal life and living situation. This is in line with former research (Breitschopf und Burghard 2023).

Our study features the following limitations: Some of the various design elements of the ET seem to be difficult for laypersons to assess. In this study, respondents were not given any further information about the design elements. This may have resulted in some respondents having difficulties answering the questionnaire. Notwithstanding this limitation, the study employs a distinct methodology to evaluate agreement with and acceptance of the German ET. It breaks the energy transition down into its constituent building blocs or dimensions, based on the objectives of the EU Energy Union and the pillars of the German energy transition. For each dimension, this study identified design elements that are actually discussed or implemented in the German ET.

6. CONCLUSION

The transition to a low-carbon society is one of the biggest challenges that modern economies face in this decade. Our analysis specifically refers to the German energy transition, a widely well-known climate policy measure comprising a series of regulations and being one of the most challenging and disputed instrument in Europe and also worldwide (Groh und Ziegler 2018). The findings underscore that the acceptance of the energy transition is less contingent on individual design elements and is instead influenced by the broader dimensions that mirror societal objectives and values. However, previous analyses with respect to the design elements within the dimension found a clear preferences for certain actions and measures (Breitschopf und Burghard 2023) that are in line with previous findings regarding the preference of non-coerxive instruments (Rhodes et al. 2017; Odland et al. 2023; Faure et al. 2022) and pull measures (Zawadzki et al. 2022). This study reveals opposing results, which call for further analyses and research of this topic.

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Appendix

Table 4: Overview on socio-demographic characteristics of the sample

Characteristic		Share
Gender	female	50.4%
Age	18-30 years	15.7%
	31-40 years	17%
	41-50 years	16%
	51-60 years	22.3%
	61-70 years	19.6%
	71-80 years	9.4 %
Education	low education	20.6%
	medium education	46.6%
	high education: baccalaureate and university degree	32.8%
Dwelling	own house or flat	32.6%
	rented house or flat	66.2%
Household type	single person household	34.5%
	with partners	35.9%
	with partner and children	19.8%
	alone with children	4.5%
	flat sharing community	5.3%
Residential location	rural municipality	18.3%
	small town	20.1%
	medium town	26.3%
	big city	35.2%
Occupation	employed	51.5%
	student	6.1%
	pensioner	29.8%
	unemployed	12.6%

Table 5: Items with descriptive statistics (M = mean, SD = standard deviation) and Cronbach's α for the scales

	α	M	SD
Distribution: How should the potentially higher costs for consumers resulting from the energy transition be distributed?	.60		
Everyone who uses electricity pays depending on their consumption,			
... but socially weaker groups receive a subsidy from the state for energy costs.		2.4	1.2
... but socially weaker groups pay a little less. The remaining electricity consumers pay a little more.		3.2	1.3

..., but large industrial electricity consumers (e.g. paper manufacturers, aluminium producers) pay less to remain competitive. The rest of the electricity consumers pay a little more.		3.7	1.2
Independency: For an energy supply that is independent of foreign countries, it is important	.72		
... that as little energy as possible (such as natural gas and electricity) is imported from other EU countries.		2.2	1.0
... that as little energy as possible (such as natural gas and electricity) is imported from countries outside the European Union (EU).		1.9	1.0
... that individual households have the possibility to generate their own electricity or even to store it (e.g. photovoltaic system and battery storage).		2.0	1.0
Reliability: It is important for a safe and reliable energy supply that	.68		
... a large number of power generation plants, including expensive ones, are available as a back-up so that they can always step in and supply enough electricity in the event of a power shortage.		2.1	1.0
... a large number of storage facilities, including expensive ones, are available to absorb bottlenecks.		2.4	1.0
... there are few price fluctuations for natural gas and electricity.		1.9	0.9
... households receive their heat via a district or local heating network, if this is possible.o		2.3	0.9
... households generate their own electricity with solar systems, if possible.	.65	2.3	1.0
... households generate their own heat with wood/pellet stoves.		2.8	1.1
Actions: How are we to achieve the energy transition in Germany?	.79		
Predominantly through investments in renewable generation technologies, such as wind and solar energy, and storage technologies.		2.0	1.0
By installing economical (efficient) heating systems, well-insulated buildings, energy-saving appliances.		1.8	0.9
By being more frugal with energy consumption, for example by lowering room temperatures in winter or using less lighting in the house.		2.5	1.2
By adapting my electricity consumption (e.g. washing machine, electricity heating, ...) to the times when sufficient electricity is available from solar or wind energy.		2.4	1.1
Measures: What measures should the state take to advance the energy transition?	.77		
Through regulations, for example by prescribing limit values (standards) for the energy consumption of electrical appliances or the CO2 emissions of heating systems.		2.5	1.2
Through bans, such as banning oil or gas heating in buildings, banning combustion engines in cars.		3.4	1.3
By informing and appealing to people to use less energy and only produce/buy clean energy.		2.4	1.1
Through higher prices for fossil energies (e.g. more taxes on oil, natural gas, diesel, petrol), so that it becomes too expensive to buy them.		3.5	1.3
Investors: Who should invest mainly in wind farms or photovoltaic plants?	.61		
National companies and private energy suppliers (e.g. E.ON, EnBW, Naturstrom).		1.6	0.7
Municipal energy supply companies in the public sector, such as public utility companies or municipal utilities.		1.7	0.7
International, large companies and energy corporations (e.g. Shell, BP).		1.9	1.0

Citizens' initiatives (citizens' energy parks) and energy cooperatives or similar non-profit organisations.	.76	2.3	1.0
Citizens who can install photovoltaic systems on their own roofs.		2.2	0.9
Villages or small towns as (co-)owners of solar or wind power plants erected on their territory		2.2	0.9
Costs: How should the state promote the energy transition?	.79		
Cheap, but it can still be a little more expensive if it means			
... we don't have a power cut, or our energy supply is independent of foreign countries (security of supply).		2.5	1.1
... we don't have strong fluctuations in electricity prices.		2.2	1.0
... such energy generation facilities are being built that have less of an impact on the landscape (for example, solar panels on buildings).		2.2	1.0
... a large number of citizens can participate directly financially in the energy transition in the form of cooperatives, citizens' parks or small-scale plants.		2.5	1.1
... the transformation of the energy system takes place faster than before.		2.4	1.1
Attitudes:	.82		
We need a consistent switch to renewable energies, even if it requires a lot of investment.		2.3	1.1
The expansion of renewable energies should be slowed down. (recoded)		2.2	1.2
I see the energy transition as positive for society.		2.4	1.1
I would like to deal with the energy transition as little as possible. (recoded)		2.5	1.1

Note. Ratings range from 1 to 5, for investors from 1 to 4. Higher numbers indicate a more negative evaluation.

Table 6: Rotated factor loadings of items measuring the construct independency

	Factor 1 Independency
For an energy supply that is independent of foreign countries, it is important	
... that as little energy as possible (such as natural gas and electricity) is imported from other EU countries.	.791
... that as little energy as possible (such as natural gas and electricity) is imported from countries outside the European Union (EU).	.838
... that individual households have the possibility to generate their own electricity or even to store it (e.g. photovoltaic system and battery storage).	.693
Cronbach's alpha	.72

Table 7: Rotated factor loadings of items measuring the construct actions

	Factor 2 Actions
Actions: How are we to achieve the energy transition in Germany?	
Predominantly through investments in renewable generation technologies, such as wind and solar energy, and storage technologies.	.769

By installing economical (efficient) heating systems, well-insulated buildings, energy-saving appliances.	.790
By being more frugal with energy consumption, for example by lowering room temperatures in winter or using less lighting in the house.	.775
By adapting my electricity consumption (e.g. washing machine, electricity heating, ...) to the times when sufficient electricity is available from solar or wind energy.	.812
Cronbach’s alpha	.79

Table 8: Rotated factor loadings of items measuring the construct measures

	Factor 3 Measures
Measures: What measures should the state take to advance the energy transition?	
Through regulations, for example by prescribing limit values (standards) for the energy consumption of electrical appliances or the CO2 emissions of heating systems.	.777
Through bans, such as banning oil or gas heating in buildings, banning combustion engines in cars.	.836
By informing and appealing to people to use less energy and only produce/buy clean energy.	.642
Through higher prices for fossil energies (e.g. more taxes on oil, natural gas, diesel, petrol), so that it becomes too expensive to buy them.	.815
Cronbach’s alpha	.77

Table 9: Rotated factor loadings of items measuring the construct investors

	Factor 4 Investors - top-down energy transition	Factor 4 Investors - bottom-up energy transition
National companies and private energy suppliers (e.g. E.ON, EnBW, Naturstrom).	.814	
Municipal energy supply companies in the public sector, such as public utility companies or municipal utilities.	.647	.366
International, large companies and energy corporations (e.g. Shell, BP).	.788	
Citizens' initiatives (citizens' energy parks) and energy cooperatives or similar non-profit organisations.		.767
Citizens who can install photovoltaic systems on their own roofs.		.807
Villages or small towns as (co-)owners of solar or wind power plants erected on their territory.		.846
Cronbach’s alpha	.61	.76

Table 10: Rotated factor loadings of items measuring the construct costs

	Factor 5 Costs
Cheap, but it can still be a little more expensive if it means	
... we don't have a power cut, or our energy supply is independent of foreign countries (security of supply).	.694
... we don't have strong fluctuations in electricity prices.	.715
... such energy generation facilities are being built that have less of an impact on the landscape (for example, solar panels on buildings).	.772
... a large number of citizens can participate directly financially in the energy transition in the form of cooperatives, citizens' parks or small-scale plants.	.736
... the transformation of the energy system takes place faster than before.	.780
Cronbach's alpha	.79

Table 11: Rotated factor loadings of items measuring the construct attitudes

	Factor 6 Attitudes
We need a consistent switch to renewable energies, even if it requires a lot of investment.	.869
The expansion of renewable energies should be slowed down.	.836
I see the energy transition as positive for society.	.851
I would like to deal with the energy transition as little as possible.	.647
Cronbach's alpha	.82

References

AEE (2022): Umfrage: Wunsch nach Versorgungssicherheit beflügelt Akzeptanz von Erneuerbaren Energien. Hg. v. Agentur für Erneuerbare Energien e.V. Online verfügbar unter https://unendlich-viel-energie.de/themen/akzeptanz-erneuerbarer/umfrage-wunsch-nach-versorgungssicherheit-befluegelt-akzeptanz-von-erneuerbaren-energien, zuletzt geprüft am 15.9.23.

Ali, Amjad; Esposito, Luca; Gatto, Andrea (2023): Energy transition and public behavior in Italy: A structural equation modeling. In: *Resources Policy* 85, S. 103945. DOI: 10.1016/j.resourpol.2023.103945.

Bacher, Johann (2010): Clusteranalyse. Anwendungsorientierte Einführung in Klassifikationsverfahren. 3., erg., vollst. überarb. u. neu gestalt. Aufl. München: Oldenbourg.

Baur, Dorothee; Emmerich, Philip; Baumann, Manuel Johann; Weil, Marcel (2022): Assessing the social acceptance of key technologies for the German energy transition. In: *Energ Sustain Soc* 12 (1). DOI: 10.1186/s13705-021-00329-x.

Becker, Sarah; Demski, Christina; Evensen, Darrick; Pidgeon, Nick (2019): Of profits, transparency, and responsibility: Public views on financing energy system change in Great Britain. In: *Energy Research & Social Science* 55, S. 236–246. DOI: 10.1016/j.erss.2019.05.013.

Bemelmans-Videc, Marie-Louise (2011): Carrots, Sticks, and Sermons. Policy Instruments and Their Evaluation. Somerset: Transaction Publishers (Comparative Policy Evaluation, v.1). Online verfügbar unter http://gbv.eblib.com/patron/FullRecord.aspx?p=4539746.

Bergek, Anna; Jacobsson, Staffan; Carlsson, Bo; Lindmark, Sven; Rickne, Annika (2008): Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. In: *Research Policy* 37 (3), S. 407–429. DOI: 10.1016/j.respol.2007.12.003.

BMBF (2023): German Energy Transition. Hg. v. Bundesministerium für Bildung und Forschung. Online verfügbar unter https://www.bmbf.de/bmbf/en/research/energy-and-economy/german-energy-transition/german-energy-transition_node.html, zuletzt geprüft am 15.9.23.

BMWK (2023): Systementwicklungsstrategie: Ein Rahmen für die Transformation zum klimaneutralen Energiesystem (strategy to system development: a framwork for the transformation towards a climate-neutral energy system). Hg. v. Bundesministerium für Wirtschaft und Klimaschutz. Online verfügbar unter https://www.bmwk.de/Redaktion/DE/Dossier/ses.html, zuletzt geprüft am 15.9.23.

Breitschopf, Barbara; Burghard, Uta (2023): Energy transition: financial participation and preferred design elements of German citizens. Unter Mitarbeit von Fraunhofer-Gesellschaft.

Dallenes, Hanne; Geerts, Robbe; Vandermoere, Frédéric; Verbist, Gerlinde (2023): The Energy Mix: Understanding People's Diverging Energy Preferences in Belgium. In: *Social Sciences* 12 (5), S. 260. DOI: 10.3390/socsci12050260.

Die Bundesregierung (2023): Wie steht es um unser Klima? Online verfügbar unter https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/bericht-des-weltklimarates-2172568, zuletzt geprüft am 15.9.23.

Djurisic, Vladimir; Smolovic, Julija Cerovic; Misnic, Nikola; Rogic, Suncica (2020): Analysis of public attitudes and perceptions towards renewable energy sources in Montenegro. In: *Energy Reports* 6, S. 395–403. DOI: 10.1016/j.egyr.2020.08.059.

Dubois; Holzer; Xexakis; Cousse; Trutnevyte (2019): Informed Citizen Panels on the Swiss Electricity Mix 2035: Longer-Term Evolution of Citizen Preferences and Affect in Two Cities. In: *Energies* 12 (22), S. 4231. DOI: 10.3390/en12224231.

Dütschke, Elisabeth; Preuß, Sabine; Brunzema, Iska; Piria, Raffaele (2023): Using the revenues from carbon pricing - Insights into the acceptance and perceptions of particularly burdened groups. In: *Energy Policy* 175, S. 113468. DOI: 10.1016/j.enpol.2023.113468.

Emmerich, Philip; Hülemeier, Anna-Gesina; Jendryczko, David; Baumann, Manuel Johann; Weil, Marcel; Baur, Dorothee (2020): Public acceptance of emerging energy technologies in context of the German energy transition. In: *Energy Policy* 142, S. 111516. DOI: 10.1016/j.enpol.2020.111516.

European Commission (2015): Energy Union Package. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. Brussels (COM(2015) 80 final. Brussels. Online verfügbar unter https://www.eea.europa.eu/policy-documents/com-2015-80-final, zuletzt geprüft am 16.9.23.

Fanghella, Valeria; Faure, Corinne; Guetlein, Marie-Charlotte; Schleich, Joachim (2023): What's in it for me? Self-interest and preferences for distribution of costs and benefits of energy efficiency policies. In: *Ecological Economics* 204, S. 107659. DOI: 10.1016/j.ecolecon.2022.107659.

Faure, Corinne; Guetlein, Marie-Charlotte; Schleich, Joachim; Tu, Gengyang; Whitmarsh, Lorraine; Whittle, Colin (2022): Household acceptability of energy efficiency policies in the European Union: Policy characteristics trade-offs and the role of trust in government and environmental identity. In: *Ecological Economics* 192, S. 107267. DOI: 10.1016/j.ecolecon.2021.107267.

Fraunhofer CINES (2020): Die deutsche Energiewende (The German energy transition). 13 Thesen: Wie die deutsche Energiewende gelingen kann. Hg. v. Fraunhofer CINES. Online verfügbar unter https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Fraunhofer-CINES-13-Thesen-Wie-die-Energiewende-gelingen-kann.pdf, zuletzt geprüft am 15.9.23.

Gölz, Sebastian; Wedderhoff, Oliver (2018): Explaining regional acceptance of the German energy transition by including trust in stakeholders and perception of fairness as socio-institutional factors. In: *Energy Research & Social Science* 43, S. 96–108. DOI: 10.1016/j.erss.2018.05.026.

Groh, Elke D.; Möllendorff, Charlotte v. (2020): What shapes the support of renewable energy expansion? Public attitudes between policy goals and risk, time, and social preferences. In: *Energy Policy* 137, S. 111171. DOI: 10.1016/j.enpol.2019.111171.

Groh, Elke D.; Ziegler, Andreas (2018): On self-interested preferences for burden sharing rules: An econometric analysis for the costs of energy policy measures. In: *Energy Economics* 74, S. 417–426. DOI: 10.1016/j.eneco.2018.06.026.

Hochachka, Gail; Mérida, Walter (2023): Navigating the razor's edge: Public acceptance of climate policies and the case of transport pricing. In: *Energy Policy* 178, S. 113616. DOI: 10.1016/j.enpol.2023.113616.

Ingold, Karin; Stadelmann-Steffen, Isabelle; Kammermann, Lorenz (2019): The acceptance of instruments in instrument mix situations: Citizens' perspective on Swiss energy transition. In: *Research Policy* 48 (10), S. 103694. DOI: 10.1016/j.respol.2018.10.018.

Jansson, Johan; Rezvani, Zeinab (2019): Public responses to an environmental transport policy in Sweden: Differentiating between acceptance and support for conventional and alternative fuel vehicles. In: *Energy Research & Social Science* 48, S. 13–21. DOI: 10.1016/j.erss.2018.09.009.

Kanberger, Elke D.; Ziegler, Andreas (2023): On the preferences for an environmentally friendly and fair energy transition: A stated choice experiment for Germany. In: *Energy Policy* 182, S. 113730. DOI: 10.1016/j.enpol.2023.113730.

Kitt, Shelby; Axsen, Jonn; Long, Zoe; Rhodes, Ekaterina (2021): The role of trust in citizen acceptance of climate policy: Comparing perceptions of government competence, integrity and value similarity. In: *Ecological Economics* 183, S. 106958. DOI: 10.1016/j.ecolecon.2021.106958.

Langer, Katharina; Decker, Thomas; Roosen, Jutta; Menrad, Klaus (2016): A qualitative analysis to understand the acceptance of wind energy in Bavaria. In: *Renewable and Sustainable Energy Reviews* 64, S. 248–259. DOI: 10.1016/j.rser.2016.05.084.

Langer, Katharina; Decker, Thomas; Roosen, Jutta; Menrad, Klaus (2018): Factors influencing citizens' acceptance and non-acceptance of wind energy in Germany. In: *Journal of Cleaner Production* 175, S. 133–144. DOI: 10.1016/j.jclepro.2017.11.221.

Lee, Juyong; Reiner, David M. (2023): Determinants of public preferences on low-carbon energy sources: Evidence from the United Kingdom. In: *Energy* 284, S. 128704. DOI: 10.1016/j.energy.2023.128704.

Motz, Alessandra (2021): Consumer acceptance of the energy transition in Switzerland: The role of attitudes explained through a hybrid discrete choice model. In: *Energy Policy* 151, S. 112152. DOI: 10.1016/j.enpol.2021.112152.

Odland, Severin; Rhodes, Ekaterina; Corbett, Meghan; Pardy, Aaron (2023): What policies do homeowners prefer for building decarbonization and why? An exploration of climate policy support in Canada. In: *Energy Policy* 173, S. 113368. DOI: 10.1016/j.enpol.2022.113368.

Ozcan, Mustafa (2019): Factors influencing the electricity generation preferences of Turkish citizens: Citizens' attitudes and policy recommendations in the context of climate change and environmental impact. In: *Renewable Energy* 132, S. 381–393. DOI: 10.1016/j.renene.2018.08.006.

Rhodes, Ekaterina; Axsen, Jonn; Jaccard, Mark (2017): Exploring Citizen Support for Different Types of Climate Policy. In: *Ecological Economics* 137, S. 56–69. DOI: 10.1016/j.ecolecon.2017.02.027.

Rinscheid, Adrian; Pianta, Silvia; Weber, Elke U. (2020): Fast track or Slo-Mo? Public support and temporal preferences for phasing out fossil fuel cars in the United States. In: *Climate Policy* 20 (1), S. 30–45. DOI: 10.1080/14693062.2019.1677550.

Rinscheid, Adrian; Wüstenhagen, Rolf (2019): Germany's decision to phase out coal by 2038 lags behind citizens' timing preferences. In: *Nature energy* 4 (10), S. 856–863. DOI: 10.1038/s41560-019-0460-9.

Ruddat, Michael; Sonnberger, Marco (2019): Von Protest bis Unterstützung – eine empirische Analyse lokaler Akzeptanz von Energietechnologien im Rahmen der Energiewende in Deutschland. In: *Köln Z Soziol* 71 (3), S. 437–455. DOI: 10.1007/s11577-019-00628-4.

Schendera, Christian F. G. (2010): Clusteranalyse mit SPSS. Mit Faktorenanalyse. München: Oldenbourg.

Scott, W. Richard (2013): Institutions and organizations. Ideas, interests, and identities. Fourth edition. Thousand Oaks: SAGE Publications, Inc.

Sonnberger, Marco; Ruddat, Michael (2016): Die gesellschaftliche Wahrnehmung der Energiewende : Ergebnisse einer deutschlandweiten Repräsentativbefragung. Unter Mitarbeit von Universität Stuttgart. Online verfügbar unter https://elib.uni-stuttgart.de/bitstream/11682/8911/1/KOMMA-P-Survey-Bericht_300916.pdf.

Steffen, Bjarne; Patt, Anthony (2022): A historical turning point? Early evidence on how the Russia-Ukraine war changes public support for clean energy policies. In: *Energy Research & Social Science* 91, S. 102758. DOI: 10.1016/j.erss.2022.102758.

Tabi, Andrea; Wüstenhagen, Rolf (2017): Keep it local and fish-friendly: Social acceptance of hydropower projects in Switzerland. In: *Renewable and Sustainable Energy Reviews* 68, S. 763–773. DOI: 10.1016/j.rser.2016.10.006.

Tian, Jinfang; Yu, Longguang; Xue, Rui; Zhuang, Shan; Shan, Yuli (2022): Global low-carbon energy transition in the post-COVID-19 era. In: *Applied Energy* 307, S. 118205. DOI: 10.1016/j.apenergy.2021.118205.

Tröndle, Tim; Annaheim, Jasmin; Hoppe, Janna; Hanger-Kopp, Susanne; Patt, Anthony (2023): Public preferences for phasing-out fossil fuels in the german building and transport sectors. In: *Environ. Res. Commun.* 5 (8), S. 81001. DOI: 10.1088/2515-7620/acec39.

UBA (2020): Häufige Fragen zur Energiewende (Questions and answers regarding the Energy Transition). Hg. v. Umweltbundesamt. Online verfügbar unter https://www.umweltbundesamt.de/themen/klima-energie/klimaschutz-energiepolitik-in-deutschland/haeufige-fragen-zur-energiewende#ziele-wege-und-instrumente, zuletzt geprüft am 15.9.23.

Upham, Paul; Oltra, Christian; Boso, Àlex (2015): Towards a cross-paradigmatic framework of the social acceptance of energy systems. In: *Energy Research & Social Science* 8, S. 100–112. DOI: 10.1016/j.erss.2015.05.003.

Wolf, Ingo; Fischer, Anne-Kathrin; Huttarsch, Jean-Henri (2021): Soziales Nachhaltigkeitsbarometer der Energie- und Verkehrswende 2021. Kernaussagen und Zusammenfassung der wesentlichen Ergebnisse. Hg. v. Kopernikus-Projekt Ariadne und Potsdam-Institut für Klimafolgenforschung (PIK). Potsdam. Online verfügbar unter https://ariadneprojekt.de/media/2021/08/Soziales_Nachhaltigkeitsbarometer_2021.pdf, zuletzt geprüft am 29.8.23.

Wüstenhagen, Rolf; Wolsink, Maarten; Bürer, Mary Jean (2007): Social acceptance of renewable energy innovation: An introduction to the concept. In: *Energy Policy* 35 (5), S. 2683–2691. DOI: 10.1016/j.enpol.2006.12.001.

Zawadzki, Stephanie J.; Vrieling, Leonie; van der Werff, Ellen (2022): What influences public acceptability of sustainable energy policies? The crucial role of funding and who benefits. In: *Energy Research & Social Science* 87, S. 102468. DOI: 10.1016/j.erss.2021.102468.

Nudging households for energy savings via smartphone apps and web portals: an empirical study

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Abstract

In this paper, we report evidence collected in the context of the Horizon 2020 NUDGE project about the effectiveness of digital tools such as smartphone apps and web portals to realize nudging interventions towards different energy efficiency goals: from the reduction of heating energy and electricity to the increase of self-consumption in energy prosumer households. We analyse recorded events from the interaction of participants with those tools in the context of three different pilot experiments.

We first assess the level of end user engagement with the apps and the portal, counting the number of distinct days that they interact with them. We find it to be highly heterogeneous, with up to 25% of participants in the Greek pilot and 12% in the Portuguese pilot not using the mobile app at all, and the rest forming three distinct groups of low, medium and high engagement. The interaction with the apps almost always lasts fractions of a minute and involves accessing a few app screens. We next turn to the actual users' exposure to the nudging features of the digital tools to find out that high percentages of users (up to 50%) exhibit zero or very occasional exposure to the app screens that implement nudges. The mobile app users, in particular, can be grouped into four clusters depending on the level of engagement with the app and their exposure to its nudging features. Disappointingly, more than half the pilot participants belong to the cluster combining low engagement with low exposure to nudging. Combining these data with self-statements of participants in post-intervention surveys, we find no significant correlation between the level of nudging exposure and the (self-stated) motivation/ intentions to save energy.

1. INTRODUCTION

The recent European energy crisis due to the war in Ukraine reinforced the value of energy savings and energy efficiency (IEA, 2022), pointing to the need for effective policies that could bring about sustainable behavioural change in this respect. Emphasis has been given to residential energy consumers (households) and how behavioural interventions could promote the energy efficiency goal (McAndrew *et al*., 2021). Nudging (Thaler and Sunstein, 2008) has been viewed as a promising path to deliver behavioural interventions. Prescribing a distinct set of choice architecture techniques for soliciting socially desirable behaviours and discouraging/confronting non-desirable ones, nudging has found broad applicability across different behavioural domains with several positive results (Mertens *et al*., 2022). With respect to energy efficiency, in particular, positive nudging effects are recorded in (Schleich *et al.*, 2013) (Frederiks *et al.*, 2015), (Kroll *et al.,* 2019) to mention but a few.

As most people have incorporated mobile phones and the world wide web in their regular routine, relying on mobile applications (apps) and web platforms for various daily activities, it is almost inevitable to use these tools to digitally deliver interventions to energy consumers (Mirsch, Lehrer & Jung, 2018; Weinmann et al., 2016). The spread of smart meter usage and the capability of mobile apps and web portals to monitor and visualize energy consumption data only strengthens the argument. The idea is that recruiting those digital tools, interventions can be more direct, more timely, and eventually more effective. Indeed, in (Fan et al., 2017; Kroll et al., 2019) end users are nudged to reduce their energy consumption by getting feedback about it through mobile applications; and (Rafsanjani et al., 2020) promote reminders on the smartphone as effective digital nudging practice towards energy saving. A similar concept of feedback nudges is proposed in (Fan et al., 2017; Kroll et al., 2019), where users are informed about their energy consumption through mobile applications. Furthermore, according to (Frederiks et al., 2015; Rafsanjani et al., 2020), reminders can also be an effective nudge for consumers to adopt a better energy-saving approach.

Whereas the existence and size of the nudging interventions effect is under debate in literature (Mertens et al.; Maier et al., 2022), in this work we take one step back and ask to what extent end users get engaged with mobile apps and web portals and actually get exposed to the interventions that are delivered through them. We argue that having a clear view about this engagement is an absolute prerequisite for correctly reasoning about the (non) effectiveness of an intervention. To this end, we work with data collected from three pilot experiments (pilots), carried out in Germany, Greece and Portugal, respectively, as part of the European Horizon 2020 research project NUDGE[1] which designs and delivers nudging interventions towards different energy efficiency goals leveraging mobile apps and web platforms. The data are logs of various events from the interaction of end users with the mobile apps and web platforms used in the pilots. Our two main goals are to assess the level of end user engagement with the apps and the portal and the extent to which they get exposed to their nudging features. Interestingly, there is a considerable number of users, in particular for the two apps, who are not using the apps at all (25% in the Greek and 12% in the Portuguese pilot), whereas the engagement with

[1] https://www.nudgeproject.eu

the portal is better in the German pilot. Then, those who do use the app differ broadly as to how often they use the app and how much they get exposed to its nudging screens/pages. We could identify four clusters of pilot participants considering these two features alone, i.e., engagement and nudge exposure. We correlate the findings from the app data with the responses of pilot participants to survey questions about their motivation and intention to save energy. These self-statements are a (weak) measure of the nudge effects[2] and offer first insights to whether the frequency of user interaction with the application/portal correlates with the nudging effect and could qualify as a predictor for it. Regarding app usage, differences occur based on the pilot and the intervention period. However, three groups (low/medium/high) of application use are identified for the three pilots. Furthermore, users are occasionally exposed to nudges, approximately 2 times per week.

The rest of the paper is organized as follows. Section 2 presents the datasets that were made available from the pilot experiments (pilots) in the three countries and the type of nudges applied to their participants. Section 3 presents and discusses the results from the analysis of mobile app data. Finally, section 4 concludes our work and outlines future work.

2. NUDGING INTERVENTIONS AND DATASETS

Three pilot experiments, in Greece, Portugal, and Germany, provided the data for the analysis we report in the sequel. Each pilot addresses a different aspect of energy efficiency and pursues it by means of nudging interventions (“nudges”). Specifically, the Greek pilot addresses gas consumption for heating purposes, the German pilot focuses on increasing the consumption of self-generated electricity from the households’ photovoltaic panels and the Portuguese one treats electricity consumption in conjunction with indoor air quality.

The pilot participants are exposed to different nudges through smartphone applications (mobile apps) and web portal. For the Greek (GR) and German (DE) pilots, existing commercial-use smartphone applications were adapted to realize the nudging interventions, while the mobile app for the Portuguese (PT) pilot was built from scratch to fit the experimentation requirements. Furthermore, for the DE pilot, users have access to a web portal, where they can be informed about their energy consumption based on real time data. Although the actual types of interventions vary across the three pilots, all three of them follow the rough timeline in Figure 1. Each pilot includes three nudging intervention periods, during which the pilot participants are exposed to interventions, the pre-intervention phase that precedes the launch of the first intervention, and the post-intervention period following the completion of the last intervention. Wash-out periods of no intervention activity typically alternate with intervention periods.

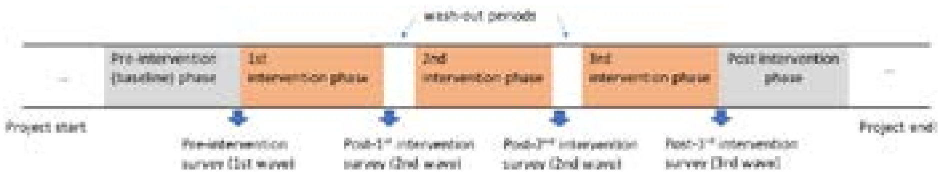
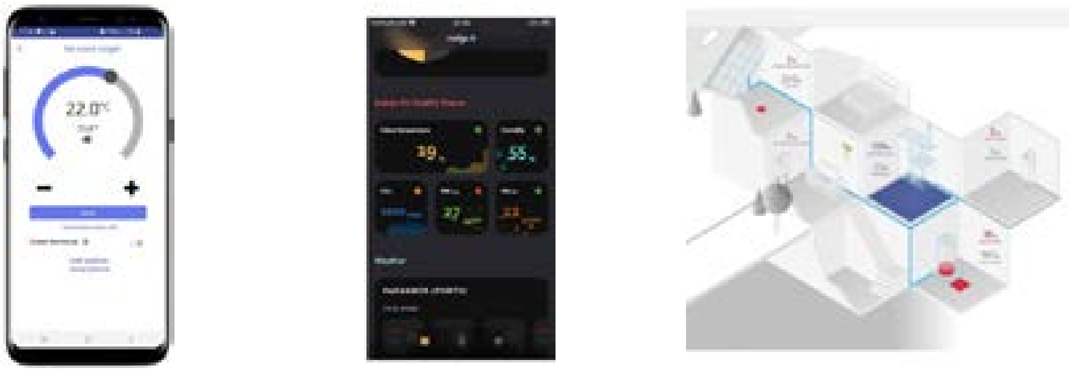


Figure 1. Common timeline of the nudging interventions for the three pilots.

[2] The ultimate assessment of nudging effects relies on sensor data, refer to the companion paper (Kesselring *et al.*, 2023)

All pilots collect three types of datasets. First, four waves of surveys are filled out by the pilot participants before the first intervention and after each one of them. Then, specific events out of the interaction of pilot participants with the mobile apps are recorded, e.g., the launch of the app and the exposure to different app screens. Finally, gas/electricity consumption and production (for the DE pilot) data, together with other types of pilot-specific measurement data, such as temperature or concentration of particles in the air, are continuously being logged by smart meters and other sensors at periods ranging from 1 min to 15 mins depending on the actual measurement. In this paper, we analyse the first two types of data sets, namely survey data and mobile app data. The analysis of the energy consumption data from smart devices is the subject of a companion paper (Kesselring et al., 2023). In the following sub-sections, we describe the nudging interventions that were mediated through the smartphone apps in each pilot and the collected datasets from each one of them.



(a) DOMX app (GR pilot) (b) nudge.it app (PT pilot) (c) Web portal (DE pilot)

Figure 2. Mobile apps and web portal interface used in the three NUDGE pilots.

2.1 Greek pilot on gas consumption for heating purposes

2.1.1 Mobile app and nudging interventions

The app of the GR pilot (Fig. 2(a)), called “DOMX”, is available through the app stores for Android and iOS. The app enables remote monitoring and control of the target temperature at the gas boiler thermostat, depending on the user’s heating demand, comfort limits, and personal preferences.

Each of the three nudges is implemented in the DOMX app as one or more application screens. Nudge 1 is a feedback and awareness nudge, providing information and statistics about the user’s energy consumption over time. Nudge 2 is a confrontation nudge that presents users with preventive just-in-time (JIT) prompts each time they are about to perform an action that would increase energy consumption. Finally, nudge 3 is realized through two types of push notifications, one presenting an energy-saving tip and another one congratulating end-users for proper energy consumption practices. These two notifications are also made available as messages on a separate screen.

2.1.2 Participation and datasets

A total of 100 households participated in the GR pilot. The first intervention period lasted between January 2022 and March 2022 with the participation of n = 47 households. The second intervention took place between December 2022 and January 2023 with n = 100 households and, immediately afterwards, the third one was carried out between February and March 2023, also with n = 100 households. The three post-intervention surveys were filled out by 39, 80, 73 household representatives, respectively. Mobile app data for the GR pilot have been made available for the second and third intervention periods (we could not obtain data from the first intervention period due to technical reasons).

2.2 Portuguese pilot on electricity consumption

2.2.1 Mobile app and nudging interventions

The mobile app developed for the PT pilot is called "nudge.it" (Fig. 2(b)). It was first released in March 2022, and it has since been available through the Android and iOS app stores.

The first nudge involved a dashboard with bars and a circular graph representing energy consumption of the user during selected time periods. The second nudge targeted the indoor air quality (IAQ) of each household. Users were exposed to information about IAQ indicators, e.g., CO2 levels, and push notifications when concentrations of CO2 exceeded a health-alarming threshold. Finally, as part of the third nudge, users with a thermostat received a notification to reduce the space heating temperature and all users, including those without a thermostat, were exposed to a dashboard containing information about their energy consumption.

2.2.2 Participation and datasets

101 households were monitored throughout the experimentation period, from June 2022 till March 2023. Participants were randomly assigned into two equal-size groups (group 0: n= 51, group 1: n= 50) and were alternately exposed to nudges during each intervention period. The first intervention period lasted from 3 June 2022 to 9 September 2022, with an intervention-free two-week period from 16 to 28 July 2022. After a two-month wash-out period, the second intervention took place from mid-November 2022 till end January 2023, with an intervention-free two-week period from 15 to 26 December 2022. The third intervention was launched on January 25th, 2023, and lasted till the end of March 2023, with an intervention-free week 20-27 February 2023. Mobile app data for the PT pilot have been made available for all intervention periods except for the second half of the 3rd intervention period[3]. The post-intervention surveys were filled out by 71, 70, and 82 participants, respectively. 89, 86 and 78 households interacted at least once with the app during the three intervention periods, respectively.

2.3 German pilot on self-consumption

2.3.1 Web portal and nudging interventions

The web portal (Fig. 2(c)) provides an overview on the electricity flows within the household, especially tracking the level of self-consumption. For the first feedback-type nudge, a new dashboard was created with simple colour-enhanced indicators categorizing the participant's

[3] Indeed, mobile app data for the PT pilot is missing for the interval Feb 19th-end March, which means that we have data for the first 25 days of the 3rd intervention period.

current self-consumption level into acceptable (green) or unacceptable (red). As second nudge, a bar chart compared the participants' current self-consumption level to the one in previous months. Last, for the third nudge, a new energy-friendly charging mode was recommended as the default option for participants with controllable electric vehicles (EVs, n = 39). Once the setting is initially activated, before the first usage, the EV is charged with excess self-generated electricity. The participants can overrule the default charging mode by specifying a target state of charge by a specific departure time. Moreover, all users obtain aggregate information about the two previous nudges in the form of an energy report.

2.3.2 Participation and datasets

For the DE pilot, 111 households with photovoltaic panels monitored their simultaneous consumption and generation of electricity in a web portal. With the help of the web portal and its supporting information, the goal was to increase the share of consumption covered by self-generated electricity (i.e., self-consumption). The three nudges were implemented sequentially for alternating control and treatment groups, i.e., each nudge is first provided to group 1 (n =54), during the first half of the nudging period, and it is then removed from group 1 and provided to group 2 (n = 57) during the second half of the intervention period. Nudge 1 was implemented from April to mid-July 2022, nudge 2 from mid-July till mid-February 2023 and nudge 3 mid-February till mid-June 2023. Unfortunately, information on the interaction with the app/web portal is only available for nudges 2 and 3, with 105 and 106 participants, respectively, interacting at least once with it. The three post-intervention surveys were filled out by 86, 91 and 88 unique participants, respectively.

2.4 Summary of survey and mobile app/web portal data

Table 1 summarizes the availability of survey responses and data from the interaction of participants with the mobile app (GR, PT pilots) and the web portal (DE pilot). Mobile apps are used by more than 76% of the GR and PT pilot participants, with a higher average participation across the three interventions in the second case (in the order of 84%). Even higher (almost 95%) is the percentage of DE pilot participants who access the web portal.

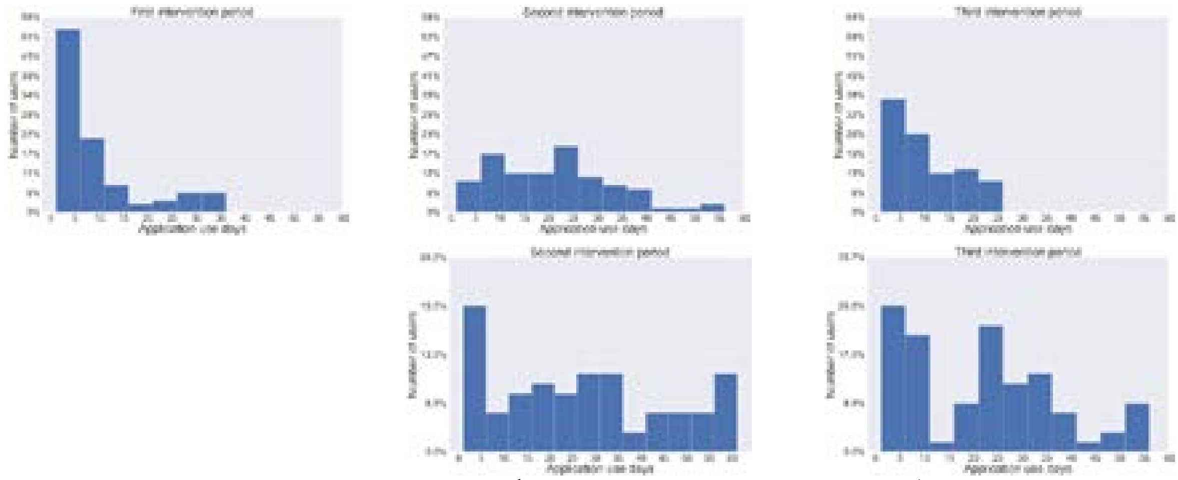
Table 1. Number of participants per pilot during the different intervention periods (n: represents the total population).

	1st Intervention		**2nd Intervention**		**3rd Intervention**	
Pilot	**Survey**	**App/portal**	**Survey**	**App/portal**	**Survey**	**App/portal**
GR (n=100)	39 (n = 47)	-	80	77	73	76
PT (n=101)	71	89	70	86	82	76
DE (n=111)	86	-	91	105	88	99

3. RESULTS

3.1 Use of digital nudging tools by pilot participants

A first question of interest is: 'How frequently do the pilot participants interact with the mobile apps and the web portal?' For the GR pilot (Fig. 3), in both intervention periods, we witnessed one out of three users interacting with the mobile app 20-40 days (or 2-4 days weekly) and one



(a) 1st intervention (b) 2nd intervention period (c) 3rd intervention period

Figure 3. Days during which PT pilot users (top) and GR pilot users (bottom) interacted with the mobile apps.

out of five doing so only rarely (less than once per week).

On the contrary, in the third intervention period, we clearly evidence fewer “devoted” users than in the second intervention period, namely users who interact with the app daily. A Kolmogorov-Smirnov (K-S) test for the app usage in the two periods does not reject the hypothesis that the two datasets are from the same continuous distribution ($p = 0.49$).

In the PT pilot, the engagement of users with the app and its evolution over time have different characteristics (Fig. 3(a)). More than 3 out of 4 app users use the app only occasionally during the first intervention period. The user engagement with the app gets better in subsequent periods. During the second intervention period is overall higher and more uniformly spread in the interval 1-5 days per week. Moreover, we identify a 10% of users that interact daily with the app during the third intervention (for the period we have data available). Finally, the DE pilot’s participants interact on average one hour per day with the app/portal (to be precise, 1.079 hours) and they are active during one third of the days.

On average, in the three pilots, the pilot participants can be grouped into three groups of low (app access once per week), medium (app access 2-5 times per week) and high (daily access) engagement. For the GR pilot, the partition of participants into the three groups is (51, 33, 16), for the PT pilot it is (45, 26, 24), and for the DE pilot (75, 20, 5).

To get a closer look into the characteristics of the users’ interaction with the mobile apps (duration, frequency) in the GR and PT pilots, we define sessions as intervals of continuous user activity, namely sequences of logged events that are not separated in time by more than a seconds. We have experimented with threshold a values of 3, 5, 10, 15, 20, 40 mins and we have found that the session characteristics are practically the same when $5 < \alpha < 40$ mins. For these values, we log 1-7 sessions per user on a weekly basis lasting less than one minute.

3.2 User exposure to nudges

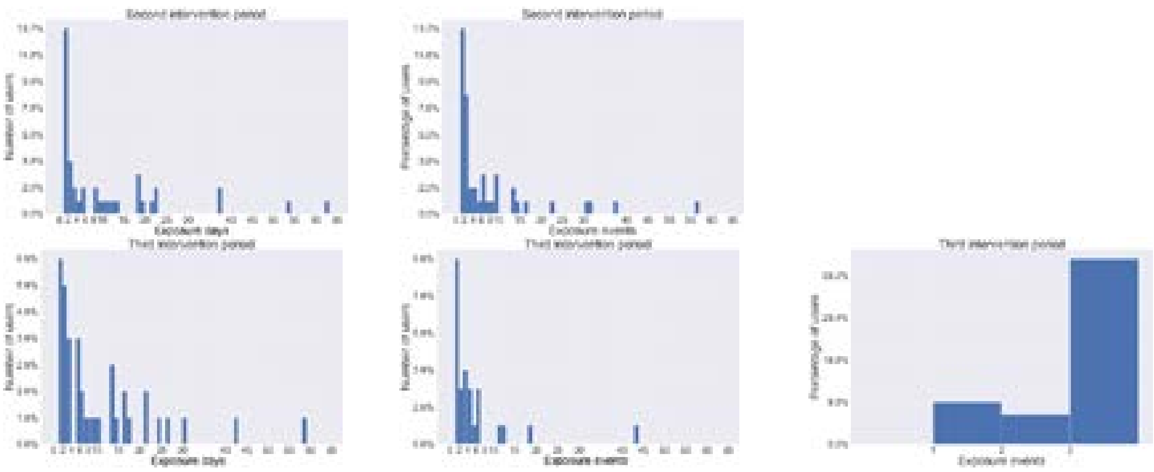
Besides the overall interaction of users with the digital tools, we want to know how much of this interaction relates to their nudging features. Notably, the nudges in the DE and GR pilots are accumulated over time*, i.e.*, the k^{th} nudge, k=2,3, is superimposed to nudges {1,..,k-1} in the k^{th} intervention period, whereas the PT pilot participants are exposed to a single nudge.

The measure of exposure varies with the nudge type. Hence, for feedback and awareness-type or nudges (1^{st} nudge in all pilots, 2^{nd} and 3^{rd} nudge in the PT pilot) that can be accessed anytime, we count the distinct days that the feedback screens/pages were accessed. For the event-based just-in-time prompts (nudge 2 in the GR pilot), we measure distinct events, whereas for push notifications (nudge 3 in the GR and nudge 2 in the PT pilots) we count the notification events that were viewed (consumed) by the participants.

In the GR pilot (Fig. 4), 65% of participants are exposed to (one of the) nudges for 1-11 days per 8-week intervention cycle, corresponding to less than twice per week. When looking into each nudge separately, approximately 40% of the pilot participants are exposed to 1-11 events for nudge 2 and 3 events for nudge 3, during the 2^{nd} and 3^{rd} intervention periods, respectively. It is important to mention that nudge 3 notifications/ messages were mostly sent 3 specific days during the third intervention period. In terms of nudge popularity, 75% of nudging events in the 2^{nd} period and 85% in the third period are related to nudge 1. For nudge 3, users rarely interact with the received notifications, as 92% were ignored. On the other hand, users were more responsive to in-app received messages, as they opened 63% of them.

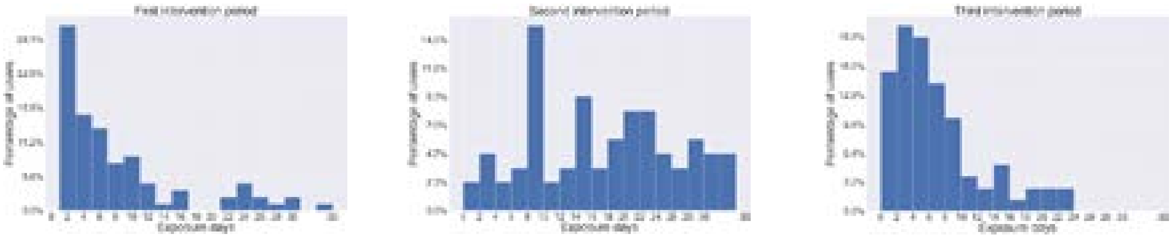
For the PT pilot, increased exposure is recorded for nudge 2 (Fig. 5), most of the users being exposed to it from 6 up to 26 days. However, the exposure level decreases during the other two intervention periods to 1-11 days, but with 39% of the users exposed 2-6 days during nudge 3.

Compared to the GR pilot, in the PT pilot the exposure to nudges is slightly increased, as users are directly exposed to nudges through the main screen. Furthermore, 60% of the users are exposed at least once per week to a nudge during the second and third intervention periods. Similarly to the GR pilot, notifications did not enjoy much attraction since participants interacted with 9% of the 894 received notifications during the 3^{rd} intervention.



(a) nudge 1 (b) nudge 2 (c) nudge 3

Figure 4. Days/occasions during which GR pilot participants were exposed to the app’s nudging features



(a) nudge 1 (b) nudge 2 (c) nudge 3

Figure 5. Days during which PT pilot participants were exposed to the app's nudging features

In the DE pilot, out of the 111 participants, 98 interacted with the relevant nudge pages at least once during nudge 2 and 88 did so during nudge 3. Notably, the nudge exposure was increased for nudge 3, more than 83% of users being active per group. For nudge 3 and the first half of nudge 2, most of the participants interacted with the nudge pages for 1 to 10 days (in particular, 59.6% for the first half of nudge 2, 86.7% for the first and 75.9% for the second half of nudge 3). This low number of activity days for the vast majority during nudge 3 is expected, since these nudges do not require much interaction.

For the second half of nudge 2, 42.9 % of the participants were active for 11 to 30 days, which is expected the specific intervention lasted longer. A minority of participants was also active beyond 30 days, which corresponds almost to every nudge day (e.g., 14.6% for the first half of nudge 2, 4.4% for the first half of nudge 3, 5.6% for the second half of nudge 3).

3.3 Correlation between application use and user exposure to nudges

To detect potential correlations between application use and nudge exposure, we cluster users based on the number of days they were exposed to nudges (*nudging exposure*) and the number of days they used the app (*engagement*). The typical clustering structure consists of four clusters and is shown in Fig. 6 for the GR pilot participants.

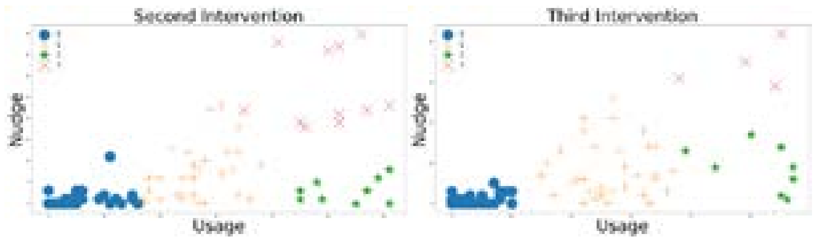


Figure 6. Clustering structuring emerging from grouping the GR pilot application according to their engagement with the DOMX app (in days) and their overall exposure to its nudging features (in days).

In all pilots, the highest portion of users is placed in the (low engagement, low nudging exposure) group (cluster 0 in Fig. 6). The highest percentage of participants in this group is recorded for the DE pilot, as users spend a maximum of 10 hours per week interacting with the Web portal. On the other side, the DE pilot seems to also feature the fewest users in the (high engagement, high nudging exposure) group (cluster 3 in Fig. 6). The other two clusters lying in between the two extreme ones, combine low exposure to nudging with either medium (cluster 1) or high (cluster 2) engagement with the app.

3.4 Correlation between application data and survey data

As a final task, we compared our findings about the engagement of pilot participants with the two mobile apps against their statements in the surveys that succeeded the nudging interventions. One set of statements related to their overall view of the application (Fig. 7), rating it from 1 (most positive) to 9 (most negative). The clear majority of pilot participants rate both apps positively and their ratings improve substantially from the 1st to the 2nd intervention, pointing to learning and training effects. With regard to individual aspects, they appreciate its time-saving features (mean rating=2.3), its comprehensibility (mean rating=2), and user-friendliness (mean rating=1.9).

In another survey question, the participants were requested to report the number of times they use the application per week. Interestingly, the provided answers by most participants stand at odds with their actual application usage. Hence, 58% of participants overestimate the frequency of app usage and another 35% underestimate it, with only 21.5% of the GR pilot and 39% of the PT pilot participants having a precise perception of how frequently they use the app. This is evidence that one needs to be cautious when analysing survey statements rather than a symptom of the social desirability bias.

Finally, a third set of questions in the three post-intervention surveys assessed the motivation and intention of users to reduce energy consumption on a scale from 1 (least likely) to 5 (most likely). The analysis of those ratings showed that, on average, there are no major rating deviations between intervention periods, but also among the pilots (Table 3). Specifically, the users' motivation to save energy is neutral (average rating is 3) and the intention of saving energy is a bit higher than the one of motivation (average score is 4). We computed the average intention and motivation scores within each of the clusters we derived in section 3.2.3 to figure out whether the two constructs differentiate from cluster to cluster, thus correlating with the usage app and/or exposure to their nudging features. The results per cluster are similar with the reported score of the total population, for both motivation and intention, as shown in Table 2.

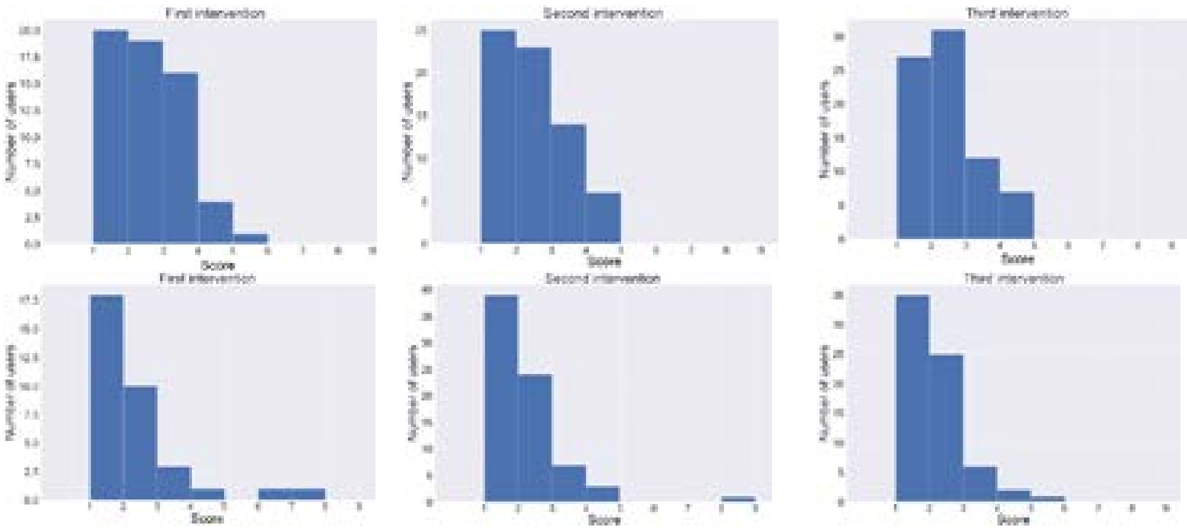


Figure 7. Distribution of app ratings at 1-9 scale according to the responses of PT (top) and GR (bottom) pilot participants in the three post-intervention surveys

Table 2. Energy saving intention and motivation ratings for the clusters of GR and PT pilot participants in section 3.3

	Total population	First Cluster	Second Cluster	Third Cluster	Fourth Cluster
GR pilot Second Intervention/ Third Intervention					
Intention	3.83/3.74	3.72/3.45	3.89/4.03	3.82/4	4/3.47
Motivation	2.79/2.99	2.9/3.05	2.89/3.03	2.62/2.84	2.48/2.45
PT pilot First Intervention/ Second Intervention/ Third Intervention					
Intention	3.77/3.96/3.97	3.75/3.87/3.93	3.8/4.1/4.1	3.8/3.99/3.91	-/4/3.91
Motivation	2.77/2.43/2.26	2.79/2.59/2.32	2.73/2.34/2.19	2.77/2.31/2.24	-/2.45/2.23

4. CONCLUSIONS

The analysis of data from three pilots provided useful insights for mobile app engagement and usage in the context of digital nudging. Over 76% of the participants interacted at least once with the digital tools that deliver the nudges, with an average frequency of 11 days per intervention period. Furthermore, the average user's nudge exposure was twice per week, but more than half of the users are not exposed to nudges on a weekly basis. The exposure rate of participants depended heavily on the type of nudge (e.g., feedback, push-notification etc.). Feedback nudges were most popular as a means of informing users about energy consumption (approximately 70% of nudging events). On the other hand, push-notifications nudges had low responsiveness, since users interacted only with 8.5% of them, on average. For the GR and PT pilots, in particular, their participants can be grouped into four clusters depending on the level of engagement with the app and their exposure to the nudging features of the app. Disappointingly, more than half the pilot participants belong to the cluster combining low engagement with low exposure to nudging.

Small details matter when trying to deliver nudges via digital means. Making the nudge integral part of the app homepage, as in the PT pilot, facilitates its delivery to the app user, when compared to embedding it in a separate page the user needs to explicitly access, as the case was with the GR pilot. Yet, the correlation of the nudging frequency with the (self-stated) intentions to save energy is rather weak. As future work, our goal is to understand the impact of nudging exposure on the actual users' energy consumption behaviour and explore whether it is possible to predict it based on their nudging exposure through statistical learning models.

5. REFERENCES

Fan, X., Qiu, B., Liu, Y., Zhu, H., & Han, B. (2017). Energy visualization for smart home. *Energy Procedia*, vol. 105, pp. 2545-2548.

Frederiks, E. R., Stenner, K., & Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable And Sustainable Energy Reviews*, vol. 41, pp. 1385-1394.

International Energy Agency (IEA) (2022), Empowering people to act: How awareness and behaviour campaigns can enable citizens to save energy during and beyond today's energy crisis, IEA commentary, July 2022

Kesselring, A., Pelka, S., Svetec, E., Nad, L., Seebauer, S., Skardelly, S., Preuß, S. (2023). Slashing the surplus – how prosumers with smart metering respond to regulatory restrictions on self-consumption in Croatia. BEHAVE Conference 2023, Maastricht, Holland.

Kroll, T., Paukstadt, U., Kreidermann, K., & Mirbabaie, M. (2019). Nudging people to save energy in smart homes with social norms and self-commitment. European Conference on Information Systems (ECIS), Stockholm, Sweden.

Maier, M., Bartoš, F., Stanley, T. D., Shanks, D. R., Harris, A. J. L., & Wagenmakers, E. J. (2022). No evidence for nudging after adjusting for publication bias. Proceedings of the National Academy of Sciences of the United States of America, 119(31), e2200300119

McAndrew, R., Mulcahy, R., Gordon, R., & Russell-Bennett, R. (2021). Household energy efficiency interventions: A systematic literature review. Energy Policy, 150, 112136.

Mertens, S., Herberz, M., Hahnel, U. J., & Brosch, T. (2022). The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains. Proceedings of the National Academy of Sciences, 119(1), e2107346118.

Mirsch, T., Lehrer, C., & Jung, R. (2018). Making digital nudging applicable: The digital nudge design method.

Rafsanjani, H. N., Ghahramani, A., & Nabizadeh, A. H. (2020). Isea: IoT-based smartphone energy assistant for prompting energy-aware behaviours in commercial buildings. Applied Energy, 266, 114892.

Schleich, J., Klobasa, M., Gölz, S., & Brunner, M. (2013). Effects of feedback on residential electricity demand—findings from a field trial in Austria. Energy Policy, vol. 61, pp. 1097-1106.

Thaler, R. H., & Sunstein, C. R. (2008). Nudge: Improving decisions about health, wealth, and happiness. Yale University Press.

Weinmann, M., Schneider, C., & Brocke, J. V. (2016). Digital Nudging. Business & Information Systems Engineering, 58, 433-436.

Collect your Retrofits: Parametric modelling to support homeowner energy retrofits in heritage buildings at the early design stage

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Keywords: Energy efficiency retrofit, Performance design, Heritage buildings, Renovation participation, Group decision-making 2a

Abstract

The joint deployment of energy reduction actions across multiple buildings at once is much needed to reach climate targets, but collective decision-making with shared ownership is a complex process. Each homeowner is accountable for their own energy use, while being constrained by their personal financial capacity and will to act with other co-owners. At the same time, decision-making for energy retrofits involves multiple constraints and criteria, relating to divergent and sometimes conflicting technical, environmental, economic, and social issues, leading to a fragmented response to the retrofitting challenge. This article presents a community-led approach to energy retrofit based on parametric modelling and design space exploration. The approach was tested under the conditions of a homeowner association residing in a heritage building in Amsterdam. Cards displaying each retrofit option and its associated impacts in terms of costs, operational carbon emissions, and energy performance were designed to facilitate negotiation between the participants and their interaction with the computational model. The intention was to empower the group by enabling the exploration of various design alternatives and to nourish conversations about sustainable retrofitting that would normally not take place. Participant feedback shows that the approach effectively improved the quality of the discussion and increased their understanding on the pathways to make their building more sustainable. This article presents the Collect your Retrofits project and describes the potentials and limitations of using parametric modelling to facilitate group decisions made at early stages of retrofit design.

1. INTRODUCTION

The energy transition is a highly complex technical and societal challenge, coping with existing ownership situations, intrusive retrofit measures, slow decision-making processes, and uneven value distribution. Large scale retrofitting activities insulating multiple buildings at once is much needed to reach the climate targets of reaching a reduction of 3.4 million metric tons of carbon dioxide (CO_2) emissions for the built environment by 2030 (RVO, 2020). Current insulation practices of such scale are only executed by single owner buildings, such as housing corporations and large private investors. About 70% of the Dutch housing stock is composed of owner-occupied houses and 1.5 million homes are part of an association of co-owners (in Dutch: Vereniging van Eigenaren or VvE) (CBS, 2018). Each dweller is accountable for their own energy use, while being constrained with their own financial capacity and a shared will to act with other buildings co-owners. There is an existing and ever growing split between individualized responsibilities and the collective energy transition, which has led to fragmented scale and scope responses to the energy retrofitting challenges. Aggregating the design process on a building level would allow more systemic decisions to happen and offer the access to alternative types of funding for co-owners.

By 2050, the municipality of Amsterdam wants to reduce CO_2 emissions by 95% compared to 1990 and be natural gas free by 2040. The Heat Transition Vision describes the ambitions for different districts and the pathways to phase out natural gas for heating the existing building stock (Gemeente Amsterdam, 2020). For Amsterdam city centre, the goal is to achieve a 70% natural gas reduction by 2040. However, there is currently no clear roadmap for reaching this target. Retrofitting monumental areas is a challenge, due to various restrictions, and that there is a lack of standardised methods for conducting energy retrofit on heritage buildings. Most toolkits do not provide tailored retrofit solutions specifically designed for building built before 1945 (Seddiki, et al. 2021). Heritage buildings have usually poor insulation and thermal comfort, which can lead to increased energy usage. Obstacles are the affordability and feasibility of implementing energy saving measures while preserving the monumental character of these buildings. Evaluating the impacts of energy retrofits of heritage buildings with poor documentation and fragmented data is difficult, in addition to the complex calibration of the models. There is lack of knowledge on how to upgrade heritage buildings to a lower temperature heat level. Typically, solutions are tailor-made, resulting in long and expensive procedures. Building owners are in need of affordable expert guidance and upfront insights on technical, financial and legal feasibility.

Collect Your Retrofits (CYR) is a research project prototyping new methods to support VvEs of heritage buildings in collectively planning energy retrofits during the initial design phase. Unlike the current system, where each owner is individually incentivized, the goal is to empower VvEs in making collective and informed multi-criteria decisions for energy retrofits while considering monumental restrictions. In the first section, the article gives an overview of the context of the research in the Netherlands. In the second section, we propose a replicable approach for flexibly exploring collective retrofit design solutions. In the last section, we demonstrate the prototypical implementation of this approach on a VvE in Amsterdam city centre.

1.1. Retrofitting owner-occupied housing in Amsterdam

The municipality of Amsterdam counts over 21.140 VvEs, including 74% small size VvEs (up to 5 units), 20% of medium size VvEs (from 6 to 50 units) and 5% of large size VvEs (more than 51 units) (Baas, 2019). The presented approach addresses the energy retrofitting process of small to medium size VvEs. Stages for implementing energy saving measures can be described as follows:

1. When one or more co-owners want to reduce their energy costs or enhance their comfort by making changes to the building, they may independently seek information or consult an expert to write an energy advice report. Often this process coincides with building maintenance, described in a multi-year maintenance plan (in Dutch: Meerjarenonderhoudsplan or MJOP). Non-profit organizations and the municipality of Amsterdam also offer this service, providing free advice and assistance.
2. The energy advice report provides an overview of the state of the building and suggests potential energy-saving solutions. Usually, it comprises a set of multiple options grouped into 3 to 4 packages, ranging from light to deep retrofit. These packages include technical modifications, implementation costs, the estimated impact on the energy bill and subsidies.
3. It is then up to the VvE to debate and vote for or against the predefined packages. The legal deed of division describes the elements within the buildings that belong to the co-propriety, usually the envelope and shared spaces. The minimum vote required for approval is generally a majority of two thirds.

Packages are formed as a combination of expert proposals together with preferences of few representatives of the VvE, who are in charge of the sustainability agenda or in the board of co-owners. VvEs are presented with predefined retrofit packages, which they then either approve or reject. The municipality of Amsterdam, in its role of assisting VvEs with energy advice, offers trainings and courses for VvEs interested in making their building more sustainable (Gemeente Amsterdam, 2023). However, there hasn't been a focus on redesigning the conversation process itself and the necessary information required to facilitate more effective communication among VvE members. In a multi-stakeholder context, it is often challenging to agree on long-term energy saving investments like deep energy retrofits. Building owners may perceive investment in energy retrofitting as too uncertain, due the high costs and vague saving predictions. Split incentive problems may also arise when some owners do not fully get the rewards of their investment, either in terms of costs or comfort. Providing information on the effects of measures plays a central role on the adoption of the solutions and on correcting potential misconceptions (Ossokina et al., 2021). Engaging owners through co-creation approaches, may potentially result in a greater acceptance for retrofit (De Feijter et al., 2019). Research highlighted the importance of integrating the opinions of owners on evaluation criteria when choosing the most suitable retrofit solutions (Medineckiene, 2011).

1.2. Using parametric modelling tools to support group decision-making

Current practices use parametric modelling combined with building energy simulation to evaluate, compare and define best-performing solutions. Parametric tools such as Grasshopper

and Ladybug Tools are able to condense in a single workflow the design logic, the simulation engines and the optimization indicators. Using parametric models help reducing designer's repetitive tasks and allows more integrated process between different disciplines. Instead of creating individual static solution, the modeller captures the logic of the design problem and reproduces it into Grasshopper environment. Rules define the relationships between the geometric elements and their related attributes (Lee et al., 1996). Additionally, rules can integrate design considerations like user preferences, requirements and limitations (Jones, 1992). When looking at energy retrofitting, parametric models can iterate all possible combinations, allowing the user for simultaneous consideration of all solutions and to quicky compare and sort retrofit scenarios that are most interesting. Giving insights on multiple criteria at once increases the negotiation space, which is often primarily focused on budget and payback period. Thanks to this multi-criteria approach, the preferences and motives of co-owners, which are usually not considered in refurbishment software and design tools (Kaltenegger et al., 2022), can be efficiently utilized. The parametric nature of such models allows replication while keeping a high degree of detailing and customization which is key for heritage buildings.
5 typical stages of the decision-making process for energy retrofitting can be identified: "Considering", "Planning", Decision", "Executing" and "Experiencing" (Ebrahimigharehbaghi et al., 2019). The present research addresses the first stage "Considering" of the decision-making process, where co-owners recognise and identify specific problems in their homes and search for information on how to best solve them (Blackwell et al. 2006, Solomon et al. 2014). The present project is putting in place the scaffolding for a scalable model of simulation-based retrofit measures through so-called "augmented negotiations". In the playful form of a physical card game, complex multi-criteria modelling was translated into an inclusive medium, accessible not only to experts in retrofitting, but every citizen. The intention was to empower the group by enabling the exploration of various design alternatives and to nourish conversations about sustainable retrofitting that would normally not take place. By using this approach, the process of retrofitting evolves into a collective problem-solving challenge, where each individual preference is considered. The focus was therefore on shaping a process for energy retrofitting as a non-zero-sum game, where one's win does not necessarily mean another's loss. The approach was developed under real conditions of a VvE in the historic centre of Amsterdam.

2. MATERIALS AND METHODS

2.1. The CYR approach

The CYR approach focuses on structuring a process that integrates both technical information related to retrofitting using energy modelling tools and the individual preferences within a VvE at the early stage of design exploration. The approach is composed of 3 distinct steps, as illustrated on Figure 1.

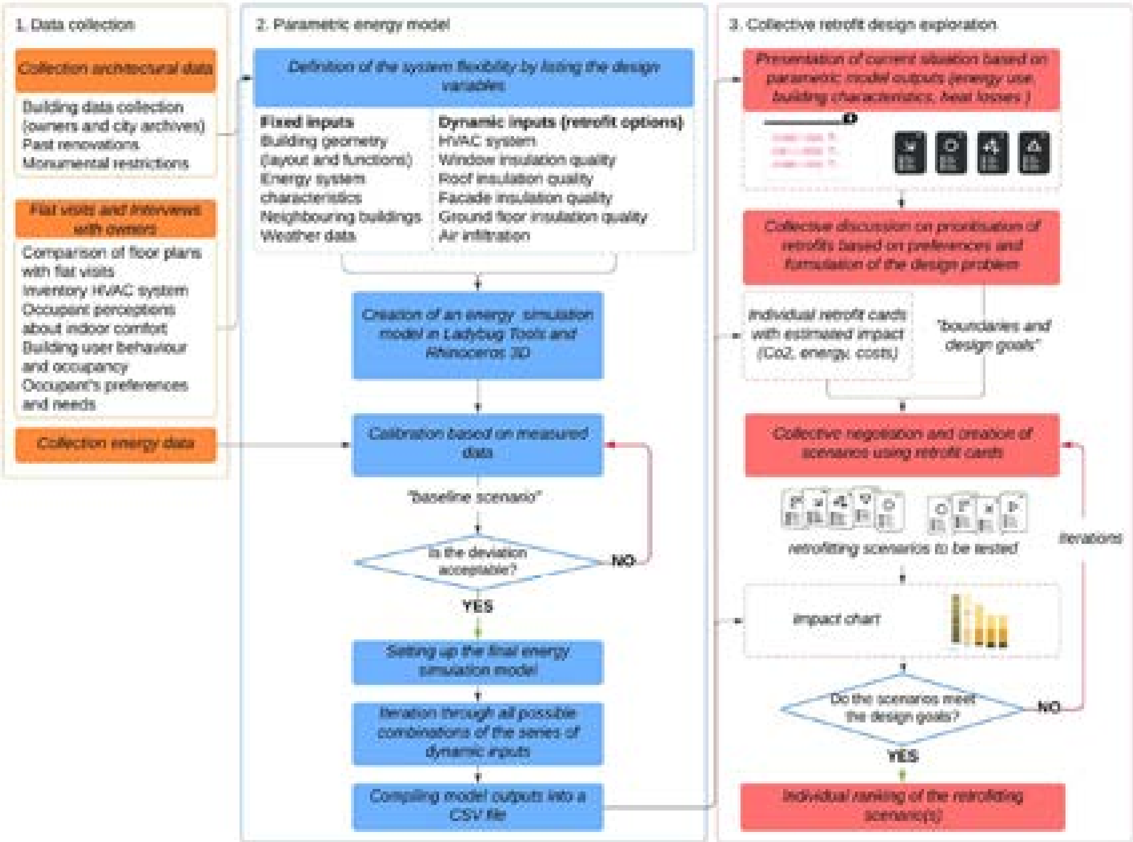

Figure 1. The CYR approach

1. *Data collection:* architectural data such as floor plans, building materials and past renovations were collected from the residents and the city archives. Interviews of the residents were conducted on potential building improvements, indoor comfort and typical use of the building (e.g., ventilation, heating set point temperatures and occupancy). Monthly energy data were collected per unit to calibrate the model.
2. *Constructing a parametric energy model:* by combining geometry of the building, the results of the interviews and simulation engines (OpenStudio and EnergyPlus), the consortium developed a parametric energy model, which calculates all potential energy retrofitting scenarios. For each individual or combination of measures (e.g., post-insulation, equipment upgrade), the model provided insights on the potential impacts on cost savings, energy savings and reduction of operational CO_2 emissions. The model also assessed if the building was ready for lower temperature heat based on annual space heating demand and the peak heating demand in living rooms. Retrofit options, defined as design variables, were subsequently filtered based on technical feasibility and monumental restrictions.
3. *Collective retrofit design exploration:* A workshop with a VvE was organised to allow

the group to interact with the model. Based on the data collected and generated from steps 1 and 2, the research consortium presented the current status of the building, the energy use and discomforts formulated during the interviews. VvE members shared their preferences and motivations for retrofitting and had the opportunity to ask questions to a retrofit expert present in the room on the available options and how the technology functions (e.g., heat pump, ventilation, radiative panels). The VvE collectively defined the design problem, establishing boundaries and goals, such as enhancing thermal comfort on the top, reducing energy expenses, or maximizing return on investment. They could select retrofit options from a set of cards and discuss upgrades to different parts of the building envelope and on the heating and ventilation system. When the group was ready to evaluate a retrofit package, they had collectively assembled, an impact chart displayed the combined outcomes (e.g. savings on costs, energy and operational CO_2 emissions, along with the investment and subsidies). Finally, they could refine their scenarios until they sufficiently aligned with their design goals. Following this iterative process, they gradually narrowed down the solution space. At the end of the workshop, each VvE member individually rated the final scenarios. Few weeks after the workshop, the VvE received a summary of the session and an expert advice with best-performing concepts to get the building off-natural gas.

2.2. Strategic design of the communication media

Two communication media were used to translate the results of the energy model and to support the VvE in creating the retrofitting scenarios: physical cards representing individual energy saving measures and an impact chart indicating the financial and environmental performances and costs of the scenarios. Designing these media followed successive iterations:

1. Beta testing: a preliminary prototype was developed based on literature review (scientific publications and best-practices) and tested with a group of researchers, leading to revisions and improved visuals.
2. Expert workshop: input was provided by behavioural economists, energy advisors, and strategic designers to further refine the prototype.
3. Real-world testing with a community in Amsterdam Centrum: suggestions included the hierarchisation of redundant information like operational CO_2 emissions, or the ability to be able to compare different scenarios outputs.
4. Final application in a VvE in Amsterdam Centrum.

The final design of the communication media is shown on Figures 2 and 3.

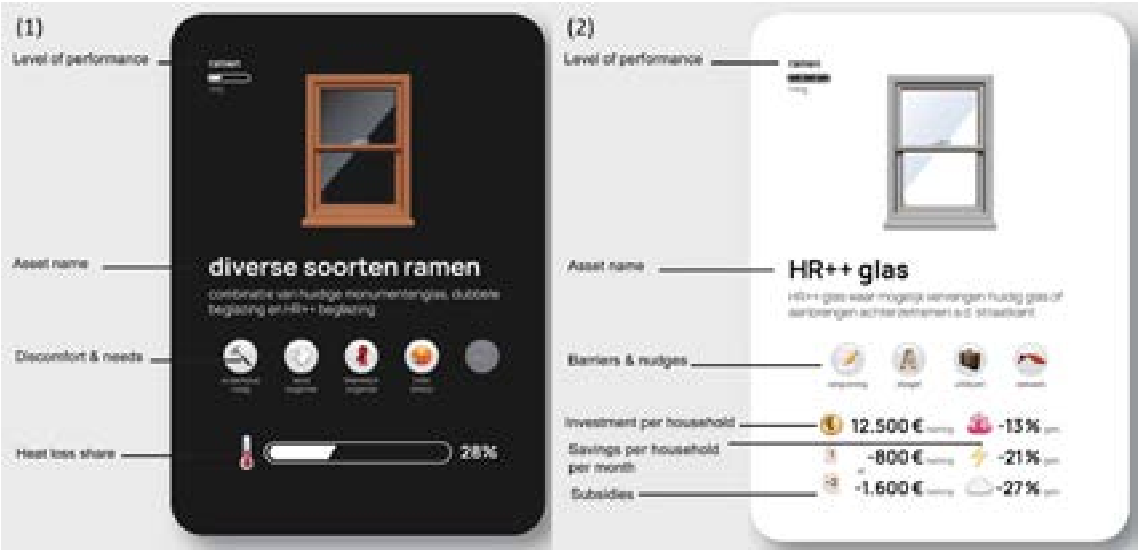

Figure 2. Design of (1) the “black cards” display the current status of the building per element and (2) the “white cards” display the retrofit option and related impacts.

“Black cards” reflect the current situation of the building. An illustration is presented for every building element, ensuring that all participants have a clear understanding of the card. The level of performance indicates the level of performance of the asset. Based on the wishes and complaints collected during the interviews, discomfort and needs are identified to the specific building element (e.g., the need for maintenance, causing wind drafts, causing thermal discomfort, causing overheat, causing noise complaints). This helps co-owners to transform specific concerns into actionable measures. Based on the energy model results, an assessment is made on the share of heat loss attributed to this specific component, which helps to understand the importance of an element over another.

“White cards” represent the individual energy retrofit option. To put in place the measures, some retrofits require more specific actions or specific invasive aspects, which includes permitting, external scaffolding, moving out for a specific time period and roof work. Barriers and nudges show to VvE members that some actions can be combined in time to reduce these barriers. The cost of the retrofit option includes value added tax and installation and is divided per household. Available subsides are shown separately from the investment costs. This is made to act as a visual discount that is an oftentimes compelling argument in behavioural economics. Finally, there is an estimation of operational savings, like utility bill, energy, and operational CO_2 emissions savings based on the energy model. VvE members are told beforehand that these savings can be simply added between cards as it is not linear. This acts as an indication of the importance of impact of a measure.

An impact chart summarizes the impacts of the generated scenarios compared to the current status (Figure 3).

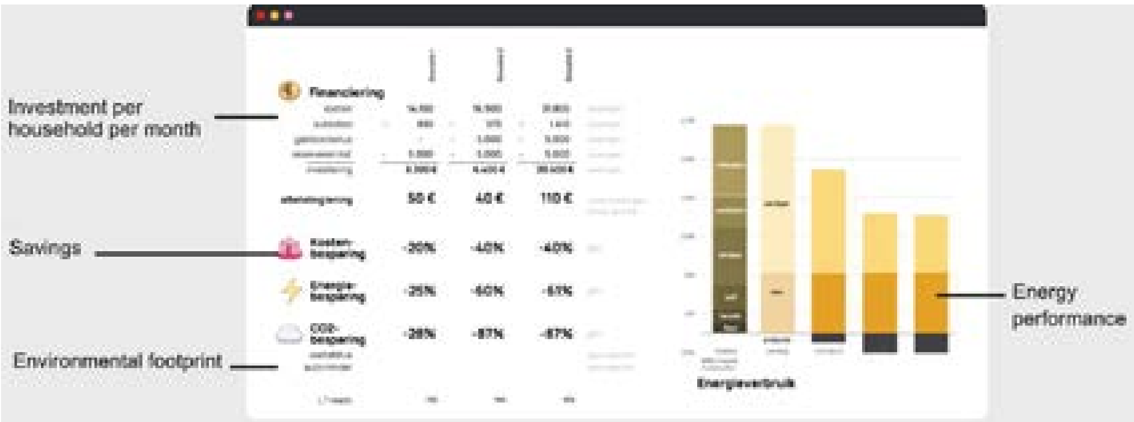

Figure 3. Impact chart comparing the base scenario and three different retrofitting scenarios

A set of costs is presented: investment costs as the sum of the costs written on the cards, the available subsidies and additional natural gas-free bonus (separated to act as a nudge), capital reserves of the VvE and total resulting costs per unit. As the previous number is rarely paid upfront in cash, breaking down the number into what it would mean for a monthly repayment per unit is a more graspable number, closer to the reality of owners. Also, it allows them to compare with the estimated savings on their energy bill. The indicated savings are average of the overall, which do not represent the differences of energy savings between the floors and do not reflect the shares in the deed of division (e.g., big apartments have larger shares, so greater investment are required). A chart is added as a visual indication of the energy savings: it showcases the energy demand in kilowatt hours (kWh) of the existing situation compared to the tested scenarios. This allows VvE members to appraise current versus projected situation and to assess different scenarios visually.

3. RESULTS

3.1. End designs

The VvE that tested the approach consisted of four units in one building: three owner-occupiers and one social housing unit from a housing corporation. The workshop counted four participants: including two owner-occupiers, a representant of the housing corporation, and the tenant of the social housing unit. One owner-occupier was not present. Following the introduction of the current building status and the retrofit cards, the group asked several technical questions on the implications of implementing certain measures (e.g., heat pump, balanced ventilation with heat recovery). Generally, there were concerns about the preservation of the building's historic windows and frames and the feasibility to use vacuum glass or a rear window system with HR++ glazing. Two owner-occupiers wanted to replace their ageing natural gas boilers and steered the discussion towards a collective investment in a shared heat source. Since purchasing a collective heat pump requires all units to be sufficiently insulated, upgrading glazing, roof insulation and reducing air infiltration were interesting options. In general, discussions focused on costs and the monetary benefits of implementing measures and little attention was paid on energy and operational CO_2 emissions savings. One complexity for participants was to consider and accept that certain measures imply requirements, like for instance installing a heat pump without adequate insulation of the building, or extensive insulation would require installing mechanical ventilation. At the end of the session, three scenarios were kept: (1) HR++ glass and 15 photovoltaic (PV) panels, (2) seams and crack sealing, 50 PV panels, mechanical ventilation with heat recovery, collective air-source heat pump, and (3) same as (2) plus roof insulation combined with greenery (Figure 4).

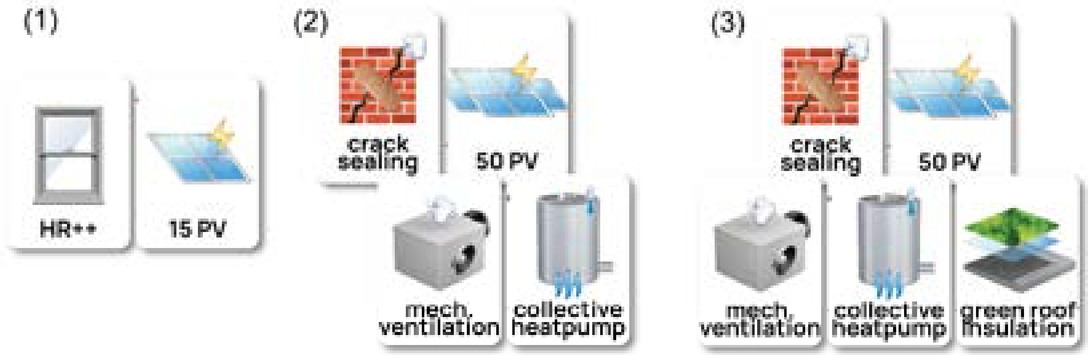

Figure 4. The three end scenarios formed by the VvE

The end scenarios were more ambitions than the results of the interviews, during which members of the VvE were most interested in installing PV panels or green roofing. Based on individual ranking, scenario 2 was most preferred with 55% of the votes against 24% for scenario 3 and 21% for scenario 1. This scenario results in 60% energy saving potential compared to the current energy demand. Using one interface with physical cards and the impact chart accelerated the group discussion and made retrofitting measures more tangible for the VvE members. However, the current setup which starts with the selection of the retrofit options led the participants to create scenarios without a clear understanding of the potential outcomes. This process lacks a systematic approach, with participants essentially hoping for favourable results. A two-ways approach: starting from the retrofits or from the design objectives would be a more effective approach to create optimal scenarios in a short amount of time.

3.2. Participant feedback

At the end of the workshop, the four participants answered a questionnaire, evaluating different aspects of the CYR approach. Participants found the workshop informative, fun and not effortful. They felt that the design of the cards was inviting and that the objectives of the session were clear. One person reported that “the cards make the situation tangible”. They were satisfied with the final scenarios and would recommend the process to other VvEs. Although one participant reported conflict, they agreed that it was easy to interact with other VvE members, and that it generally helped them to understand each other better. In general, they found that there was enough information and that the impact chart could be more simplified in monetary terms with, for instance, a preliminary overview of the most optimal scenarios. Further results are summarised on Figure 5.

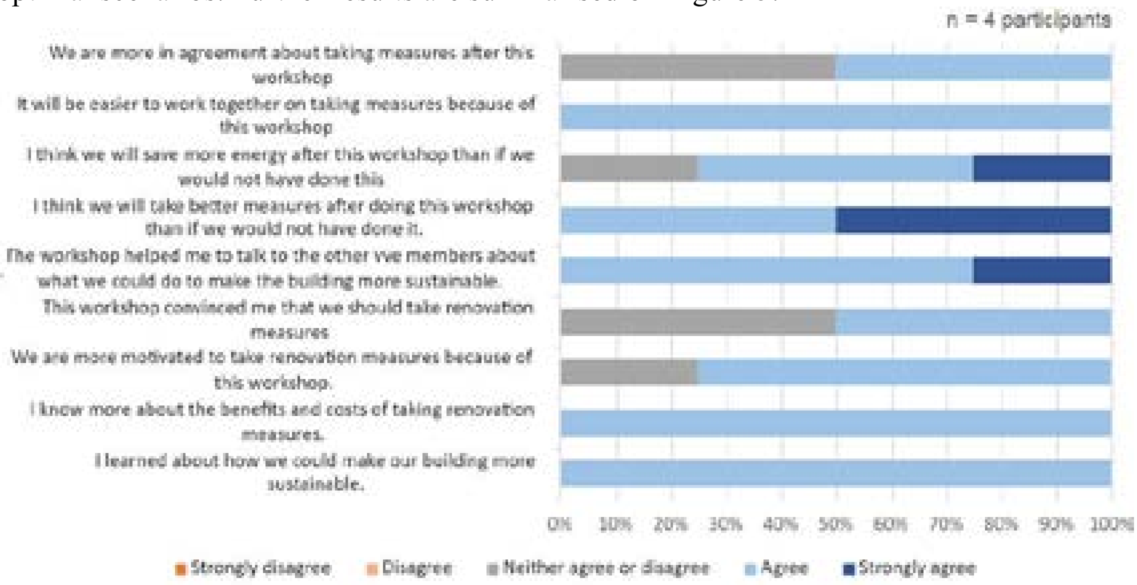

Figure 5. Participant feedback on the CYR approach

All participants said that they would use the results to take future decisions for making their building more sustainable. As improvement note for future sessions, they recommended to take into account all potential obstacles such as policy of housing corporations and to invite a subsidy expert.

4. CONCLUSIONS

Key learnings: The CYR approach proved to be versatile for the fast generation of scenarios and provided quick feedback to the VvE participants. This is an important result, when considering the complexity and time required for VvEs to collect and compare data from different construction companies. The project revealed that real-life experiences and personal preferences can be efficiently integrated when utilizing parametric modelling methods. Additionally, the approach can be used to generate staged retrofitting plans, making propositions actionable by providing insights into the timeline for implementation (e.g., what investments will be needed and when). Despite the multi-dimensional nature of the approach, the VvE primarily prioritized cost optimisation in their designs. Overall, the approach received positive feedback, with participants agreeing that they learnt more about how to make their building more sustainable and that they will take better measures after doing the workshop than if they would not have done it.

Limitations and scalability of the approach: To overcome conflicts arising from split incentives, it is essential to build capacities for collective reflection and action. Forming scenarios is a very complex process, requiring the active participation of all co-owners. In the current form, the proposed design exploration process relies on some parts on the knowledge of a retrofit expert present in the room, making difficult for VvEs to run the experiment independently. The CYR approach is tailored to the specific building situation, enabling the generation of precise results when compared to the standard archetype-based approach. While the parametric logic can be easily adapted to other VvE cases, recreating building's geometry is time-consuming. Information on past renovations in heritage buildings, including building materials and existing equipment is fragmented with often only scans from city archives available. This means that data is shared partially, requiring validation with flat visits and interviews of the VvE members. It would be interesting to integrate Historic Building Information Modelling (H-BIM) technologies using point cloud to generate geometry more efficiently. Collective interventions, as not the norm, lag in terms of reliable technical information, available subsidy, or market supply and installation. The entire 'ecosystem' is not ready for approaching retrofit collectively.

Recommendations for future research: The retrofit scenarios should directly relate to the MJOP of the VvE to make the end proposal actionable. Savings of the general maintenance plan are not integrated while it is one of the aspects that is currently the most cost savings. The desirability of the solutions and their impact on heritage significance could be more detailed: looking at different scales of impact; from area to ensemble, to building, to building elements. Retrofit costs are a limited value of the approach, since this indicator is very uncertain and dependent on the implementation of the measures, material availability, installation capacity and energy prices. Future research should also incorporate embodied carbon of insulation and energy payback time as a performance metric. Last but not least, it would be interesting to analyse how the CYR approach influences changes in behaviour, and to what degree the early involvement of co-owners in co-designing retrofitting plans is key in encouraging more ambitious energy retrofit decisions.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Baas, J. (2019). *Een analyse van verschillende typen VvE's voor duurzame woningverbetering*. Focusaanpak Klimaatneutraal Wonen. Gemeente Amsterdam. Personal communication November 4, 2022.

Blackwell, Roger D., Miniard, Paul W.; Engel, James F. (2006). Consumer behavior. 10th ed., Mason, OH: Thomson South-Western.

CBS (2018). Statistics of Building Sector. Retrieved September 18, 2023, from https://www.cbs.nl/nl-nl/cijfers#theme=bouwen-en-wonen.

De Feijter, F.J., Van Vliet, B.J.M., & Spaargaren, G. (2019). Energy efficient housing through organised interactions? Conceptualising the roles of householders and providers in housing retrofitting in the Netherlands and China. *Housing, Theory and Society.* https://doi.org/10.1080/14036096.2019.1658623.

Gemeente Amsterdam (2020, September 30). *Transitievisie Warmte Amsterdam*. Policy document. Retrieved April 2, 2023, from www.amsterdam.nl/bestuur-organisatie/volg-beleid/duurzaamheid/aardgasvrij/.

Gemeente Amsterdam (2023). *Advies en begeleiding plan van aanpak kleine vve's*. Retrieved September, 2023, www.amsterdam.nl/wonen-leefomgeving/wonen/verduurzaam-uw-vve/.

Jones, J.C. (1992). Design methods. Van Nostrand Reinhold, New York.

Kaltenegger, J K., Ossokina, I.V., Röck M., Pauwels P. (2022). ROTUNDORO: A web-based decision support prototype for housing refurbishments considering consumer preferences. *IOP Conference Series: Earth and Environmental Science,* 1085.

Lee, J.Y., Kim, K. (1996). Geometric reasoning for knowledge-based parametric design using graph representation. *Computer-Aided Design,* 28.

Medineckienė, M., Björk, F (2011). Owner preferences regarding renovation measures—The demonstration of using multi-criteria decision making. *J. Civ. Eng. Manag*, 17, 284–295. https://doi.org/10.3846/13923730.2011.582380.

Ossokina, I. V., Kerperien, S., & Arentze, T. A. (2021). Does information encourage or discourage tenants to accept energy retrofitting of homes? *Energy Economics*, 103, https://doi.org/10.1016/j.eneco.2021.105534.

RVO (2020, March 6). *Long-Term Renovation Strategy: En Route to a low-CO2 Built Environment.* Netherlands Enterprise Agency. Retrieved September 18, 2023, from https://energy.ec.europa.eu/system/files/2020-04/nl_2020_ltrs_en_0.pdf.

Seddiki, M., Bennadji, A., Laing, R., Gray, D., Alabid, J.M. (2021). Review of Existing Energy Retrofit Decision Tools for Homeowners. *Sustainability* 2021. https://doi.org/10.3390/su131810189.

Shima Ebrahimigharehbaghi, Queena K. Qian, Frits M. Meijer, Henk J. Visscher, (2019). Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making?, *Energy Policy*, 129.

Solomon, Michael R., Marshall, Greg W., Stuart, Elnora W. (2014). Marketing. Real people, real choices. 7. ed., Pearson new International ed. Harlow: Pearson

USING COLLECTIVE ENGAGEMENT APPROACHES TO SUPPORT BEHAVIOUR CHANGE AND COLLECTIVE IDENTITY FORMATION VIA ENERGY MANAGEMENT APPLICATIONS

A Gender-Aware Online Experiment

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Abstract

Achieving the energy transition is critical for moving towards a more sustainable future and end-users play an important role in this. But sustained, intrinsically motivated engagement still proves to be a challenge and approaches that successfully support sustained engagement and engage people more equally are needed. The use of collective perspectives in engagement to promote the development of shared green identities and the building of intrinsic motivation seems a promising approach. To facilitate their integration in behaviour change tools, a collective engagement framework was developed and used as conceptual base for the definition of collective identity amplifiers as interaction design elements to be integrated into digital support systems for behaviour change. In an online experiment aimed to explore the impact of collective amplification, interaction screens for both individually-focused and collectively-framed engagement approaches were developed for six persuasive strategies, and tested with regards to their respective behaviour change potential and potential interactions with gender identity. Results indicated no statistically significant effect of collective framing on behaviour change potential, communication preferences regarding benefits, or social identity perception in this setting. Statistically significant, gender-specific engagement effects were observed around responsiveness to altruistic vs. egocentric benefit communication, with results showing a decreased response to egocentric framings for women and an increased response to altruistic framings for men in the collective condition. We recommend the application of the framework in a field study to truly test its potential and validate the observed gender-related impact of collective engagement on benefit communication preferences.

1 INTRODUCTION

Successful, sustained, and large-scale engagement of end-users to actively participate in the energy transition remains a challenge. Although a multitude of measures has been developed and explored (Chatzigeorgiou & Andreou, 2021; Schrammel et al., 2023), most fall short in one form or another. Although it can be assumed that there are no cookie-cutter solutions and tailoring will always be necessary to achieve an intervention's full potential, some aspects that hold particular promise have been underexplored to this date. One of these is the fact that climate change is a collective problem and can only be solved collectively – both in its approach towards motivation and communication to get people on board and to avoid a "tragedy of the commons" situation (Vreja et al., 2017). Collective approaches seem promising regarding both the desired scale and durability. They offer increased potential of intrinsic motivation development or solidification through a shared green identity in combination with implied social intervention approaches (Jans & Fielding, 2018). Users of a technology form a natural "group" that has the potential to serve as base for collective engagement approaches, but the application of targeted measures to support group identity formation to facilitate and amplify the effect of engagement strategies has only been explored to a very limited degree to date (Duke, 2010; Jans et al., 2018).

Further, the communication of benefits to end-users (benefit communication) is of great importance for sustained engagement to support feelings of self-efficacy and create a positive feedback loop. Depending on personal motivation but also other factors such as educational or cultural background, different types of framing appeal to different groups of consumers, and message tailoring and alignment with consumer motives is important for activation and engagement of end-users (Steg et al., 2014; Wolsko et al., 2016). Viewed through a gender-lens, women show a stronger orientation towards pro-environmental values and are more inclined towards pro-environmental behaviour (Bulut et al., 2017; Zelezny et al., 2000) – indeed, pro-environmental attitudes and many pro-environmental behaviours are themselves seen as more feminine (Brough et al., 2016). However, when social identity was manipulated to be salient, male participants showed an increase in intention to consume sustainably that matched female ratings (Costa Pinto et al., 2014). Considering these insights, we think that collective engagement approaches might have the potential to increase the appeal of self-transcendence value-oriented framings in general, but in particular for male consumers, therefore helping to overcome gender-related psychological barriers to energy conservation. Our 3 research questions are as follows:

1. Are collective engagement strategies more successful in engaging end-users towards energy conservation and energy efficiency?
2. Can collective engagement approaches lead to the activation of a shared social identity?
3. Do engagement conditions impact the appeal of different types of benefit framings and is there an interaction with gender identity?

We will review the relevant literature as groundwork for the *collective engagement framework*, introduce the framework, study design and design material developed for it, and present and discuss the study results, below.

2 BACKGROUND

First, we will discuss commonly-employed behaviour change strategies in digital support systems, behaviour change models, and conceptualization of social identity as the theoretical and practical knowledge the work presented here is building on.

2.1 Engagement Strategies

Within digital support systems, *feedback* is one of the most popular approaches to engage end-users by providing insight into behavioural patterns in an accessible form (Byerly et al., 2018; Clayton et al., 2015). *Feedback* has been recognized as a powerful tool that does, however, lack engagement quality on its own and needs to be paired with other measures (Chatzigeorgiou & Andreou, 2021). Such measures include engagement strategies like *goal-setting* and *commitments* as users are more likely to follow through with a particular behaviour if there is a personal promise involved (McKenzie-Mohr & Schultz, 2014), as well as *choice architecture* and *default options* that encourage the desired behaviour (Clayton et al., 2015).
Prompts work best if consumers are already motivated to carry out the behaviour. The issue lies with thinking of it at the right time, a particular challenge in the context of energy consumption where habits and routines dominate (McKenzie-Mohr & Schultz, 2014). Actionable information in the form of *tips and training* are an important aspect of engagement as they raise perceived self-efficacy and empower consumers to act. As for *incentives*, positive feedback can help to counteract the human tendency to align with the social norm if such an alignment is undesirable (Griskevicius et al., 2012). Financial incentives, though together with social comparison among the most effective (Bergquist et al. 2023), should be employed with care since they have a number of disadvantages (Abrahamse et al., 2005; McKenzie-Mohr & Schultz, 2014). They tend to prevent internalization of the motivation, thus achieving no spill-over effects, and harming long-term impact as behaviour change reversal often occurs once the financial incentive is removed.

2.2 Behaviour Change Models

Within models explaining behavioural decisions, behavioural intention is typically at the centre, accompanied by habits and facilitating or aggravating circumstances (conditions). Commonly included as further factors or antecedents are aspects such as problem awareness, perception of responsibility, self-efficacy expectations, personal values, and social norms (See e.g. Theory of Planned Behaviour, Comprehensive Action Determination Model, Norm-Activation-Model, Theory of Interpersonal Behaviour; Ajzen, 1985; Klöckner & Blöbaum, 2010; Schwartz, 1977; Triandis, 1977, respectively). Accordingly, it is important to avoid neglecting the core factors of habits and conditions in persuasive engagement approaches to behaviour change as is often done by overestimating the relevance of intention and underestimating the influence of circumstantial and routine-related aspects of behaviour (see also Darnton et al, 2011).
The behaviour change reference model chosen for the development of the *collective engagement framework* was the Comprehensive Action Determination Model (CADM) (Klöckner & Blöbaum, 2010), as it forms an integration of multiple prominent models that

reflected the core aspects of behaviour change (behavioural intention, habits and conditions) we wanted to address.

1.1 Collective Identity

Collective, social or group identity has been operationalized with a varying number of dimensions such as unidimensional (Kelly, 1988), two-dimensional with a cognitive and an affective factor (Van Zomeren et al., 2008), three-dimensional (Cameron, 2004; Ellemers et al., 1999), and four-dimensional (Jackson & Smith, 1999). A three-factor model representing cognitive, evaluative, and affective social identity aspects, has been shown to be superior towards models with more or fewer dimensions (Cameron, 2004), and is one most commonly used. The descriptors *cognitive, evaluative*, and *affective* have been coined by Ellemers et al. (1999) but naming has varied between different authors. The definitions used in the *collective engagement framework* (see 3.1) stem from Cameron (2004) and were selected as the authors consider them to provide a better fit to the core ideas of each dimension.

2.3 Gender and Sustainable Behaviour

Many pro-environmental behaviours are perceived as more feminine (Brough et al, 2016). This is partly due to the type of activities like domestic chores which are usually associated with women due to traditional gender roles (Bloodhart & Swim, 2020). In addition, female stereotypes are typically framed as caring and nurturing (Ellemers, 2018). Pro-environmental behaviour is often seen as sending low status signals when connected with saving, reducing, reusing, walking instead of driving, etc., making it particularly unappealing for men. This is only reversed with costly financial behaviours such as buying e-cars, investing in renovation or prosumer technologies, or buying high quality and durable products (Bloodhart & Swim, 2020). These insights indicate an important link between gender and motivation for pro-environmental behaviour, as well as between inclination to carry out specific behaviours and gender identity.

3 METHODS

This section describes the *collective engagement framework*, the development of the collective amplifiers (interaction design elements that encourage the user to take a collective perspective) and associated designs, and the subsequent evaluation study carried out.

3.1 Collective Engagement Framework

The *collective engagement framework* (Fig. 1) was developed to incorporate the elements of engagement, factors of behaviour change, and the amplifying effect of social identity dimensions components into one comprehensive frame. The framework builds on the literature presented in the related work section, most strongly on the Comprehensive Action Determination Model by Klöckner & Blöbaum (2010), and the Social Identity Model by Cameron (2004). It aims to describe the impact paths different types of engagement strategies can take towards prompting behaviour change by targeting different behavioural action determination factors – namely, *behavioural intention* (directly or through affecting attitudes on a cognitive and/or emotional level), *habits*, or *conditions* (objective and subjective constraints that impact behavioural control over carrying out the behaviour). It further expresses the application of the three social identity dimensions of *cognitive centrality*, *ingroup affect*, and *ingroup ties* in the design of selected engagement strategies in order to amplify their behaviour change potential and therefore succeed in changing behaviour not only to a higher degree but also in a more intrinsically-motivated and more durable manner.

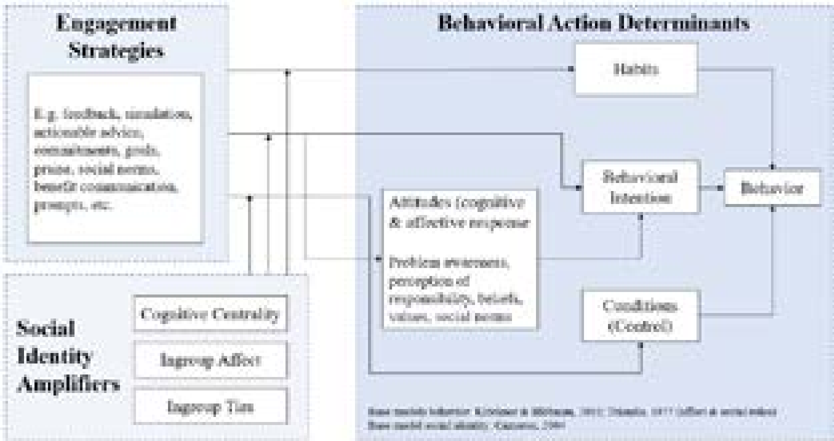

Fig. 1. Collective engagement framework

3.2 Collective Identity Amplifier Development and Design

Selection of engagement strategies. Strategies were chosen under consideration of behaviour change models and the three core components of *attitude, situational factors* and *habits* in order to provide a broad range of approaches that can also be applied individually if particular aspects are lacking (e.g., participants are willing and able but need help with breaking habits). The strategies chosen are based on traditional persuasion techniques (Cialdini & Goldstein, 2004; Oinas-Kukkonen & Harjumaa, 2008), as they are typically employed in the context of encouraging pro-environmental behaviour in general, and have been tested in the energy context (Bartram, 2009; Byerly et al., 2018; McKenzie-Mohr & Schultz, 2014). We excluded social intervention strategies as social aspects were integrated into all strategies. Selected strategies can be found in Table 1.

Selection of collective amplifiers. An expert survey with six Human-Computer Interaction experts with backgrounds varying from informatics to psychology was carried out. Participants were introduced to the three dimensions of social identity according to Cameron (2004), received a contextual framing that focused on sustainable behaviour support systems, and asked to brainstorm on interface features that would encourage the perception of each social identity aspect:

- *Cognitive Centrality*. Awareness of group membership and identification with group
- *Ingroup Affect*. Positive perception of group membership
- *Ingroup Ties*. Similarities and interdependency with other group members

The results were evaluated by the authors, and core approaches that seemed most appropriate for the context were identified and considered together with approaches from the literature. The final collective identity amplifiers were selected after careful consideration, and avenues for integration into traditional persuasive interfaces were discussed.

Development of engagement screen designs. Based on the six selected engagement approaches, interface screenshots were drafted for single user engagement approaches and then enriched with the identified community features, resulting in 12 engagement screens. Designs were developed iteratively with review processes within the team to ensure systematic integration of collective identity amplifiers and a clear differentiation from the individual engagement frames. Core aspects of engagement strategy realization and specific collective amplifiers integrated with the collective engagement screens are presented in Table 1 below.

The chosen use case was a home energy management system with a web-based interface. Provided engagement strategies were designed to help the user save energy in their home or shift their energy use according to demand-side requirements.

Table 1. Engagement strategies and selected collective identity amplification design elements; CC – Cognitive Centrality; IT – Ingroup Ties; IA – Ingroup Affect

Strategy	Description	Collective identity amplifiers within collective engagement screen designs
Facts	Process and Challenge of the Energy transition are explained, as well as the role of the participant in it and the benefits of behaviour change	● CC: Community logo; inclusive wording stressing community-membership ● IT: Display of geographically-close members ● IA: Display of past successes
Commitment	Commitment to a specific number of points to collect; selection of project to donate points to (community or environmental focus; to be realized once a specific number of points has been collected); badge to be won if a particular number of points has been collected (“future power hero award”)	● CC: Community logo; inclusive wording stressing community-membership ● IT: Display of geographically-close members; number of other community members donating their points to the same project as selected by the participant ● IA: Points collected and badges won on community level
Actionable Advice	Personalized as well as general actionable advice for energy saving and shifting possibilities	● CC: Community logo; inclusive wording stressing community-membership ● IT: Display of geographically-close members; possibility to react and comment on tips and add your own tip ● IA: Community tips
Feedback	Energy consumption curve for the last 3 days with option to change displayed period, feedback on specific successes and failures, option to have feedback regularly sent rather than only provided within the portal	● CC: Community logo; inclusive wording stressing community-membership ● IA: Feedback on community savings ● IT: Feedback on community consumption
Prompts	Notification display of a reminder for an upcoming peak event, information on points that can be collected, points that	● CC: Community logo; inclusive wording stressing community-membership

	were collected the previous time, the possibility to set a new reminder and the option to display tips for peak shaving	• IT: Display of geographically-close members; potential collective point collection achievement • IA: Communication of communal success during last peak event
Improved Control / Automation	A number of possibilities to activate automation within specific time frames for different processes such as e-car charging, running of the dishwasher, etc., as well as optimized consumption for specific devices (fridge)	• CC: Community logo; inclusive wording stressing community-membership • IT: Display of geographically-close members; percentage of other users that use a particular automation feature • IA: Achieved community savings through automation

4 QUESTIONNAIRE STUDY

As a use case, a home energy management system was chosen.

Study Design - Individual and Collective Engagement Condition. The online experiment included an individual and a collective engagement condition. Participants were split into 2 groups (see below for more details) and presented with the six associated individual or collective engagement screens. For each screen, participants were asked if the display/feature would (1) motivate them to optimize their energy consumption (impacting intent); (2) improve their control over their energy consumption (impacting conditions); (3) remind them to optimize their energy consumption (impacting habit); (4) be likely to lead to them optimizing their energy consumption (achieving behaviour change). Rating was carried out on a 5-point Likert scale ranging from 1="disagree completely" to 5="agree completely".

Benefit framings. The study included four benefit communication framings: Two egocentric ones (financial benefits; status) and two altruistic ones (environmental benefits; community benefits). Framings were chosen based on the three most-commonly considered values (Steg et al., 2014), and extended with "status" as second egocentric value. Screens for the four framings were drafted again with individual vs. collective perspective and participants were asked to rate on a 5-point Likert scale from 1=[I would] "not care at all" to 5="care very much" [about this].

Accompanying Scales. Further scales included to answer our research questions were:

Cameron's (2004) Social Identity Scale adjusted to "energy community" as the referenced group to measure the potential of each engagement condition to create a collective identity as user of the energy management system (collective identity potential). We used the 12-items scale including the item "I would be proud to be a member of an energy community" (Luhtanen & Crocker, 1992) with a 7-point Likert scale (1="agree completely" to 7="disagree completely"). This scale was applied to test if participants of the collective engagement condition were more likely to identify with the "community" of application users.

The traditional femininity and masculinity scale TFM (Kachel et al., 2016) was included to test if participants with female gender find transcendence value framings more appealing than egocentric framings, and if this difference is reduced for participants from the collective condition (Costa Pinto et al., 2014). The scale was presented in a split manner, measuring femininity and masculinity separately in order to measure gender identity in a multi-dimensional manner, with two 7-point Likert scales ranging from “1=not at all feminine/masculine” to “7=very feminine/masculine”.

Data Collection. Via a panel, 407 Austrian participants were recruited to participate in the survey with a distribution representative for Austria regarding age, gender, parenthood status and degree of urbanization, as well as an even distribution regarding educational level. Participants were split within these categories into 2 sub-samples forming the individual vs collective engagement groups: Condition *individual engagement* consisted of 199 participants (55% female; mean age 46y, ranging between 18 and 83, sd=2.49); condition *collective engagement* of 208 participants (45% female; mean age 45y, ranging between 18 and 79, sd=2.15).

5 RESULTS

Comparing overall scores between the groups, using non-parametrical Mann-Whitney U-tests, no statistically-significant differences were observed for any of the overall scores. This includes the overall behaviour change potential with a mean of 3.5 out of 5 for both the individual (i), and the collective (c) condition ($U(N_i=199, N_c=208)=20456$, $z=-0.2$, $p=.839$, two-tailed), and the social identity potential with means of 3.59 in the individual and 3.65 in the collective condition ($U(N_i=199, N_c=208)=19428.5$, $z=-1.07$, $p=.285$, two-tailed). Overall, participants did express only a limited likelihood to change their behaviour to optimize their energy consumption based on the presented strategies, and a small preference for egocentric benefit communication was observed.

As for benefit communication preferences, the scores show a marked preference for a financial benefit framing with environmental benefit framing coming in second, community benefit framing third and status benefit framing forth in both conditions (Table 1).

Table 1. Benefit communication preferences per benefit framing and engagement condition

Benefit Communication	Framing Type	Individual Condition		Collective Condition	
		mean	sd	mean	sd
Financial Benefits	egocentric	4.14	1.01	3.98	1.17
Environmental Benefits	altruistic	3.1	1.19	3.06	1.16
Community Benefits	altruistic	2.9	1.17	2.93	1.15
Status Benefits	egocentric	2.22	1.18	2.21	1.23

Differences in the scores between the 2 engagement conditions were minimal and non-significant, averaging to 3.18 (ind.) vs. 3.10 (coll.) for egocentric framings ($U(N_i=199, N_c=208)=20013$, $z=-0.59$, $p=.557$, two-tailed), and means of 3.00 (ind.) and 3.00 (coll.) for altruistic benefit framings ($U(N_i=199, N_c=208)=10683.5$, $z=-0.01$, $p=.991$, two-tailed).

Looking at TFM scores, we sorted participants into 4 categories (feminine, masculine, intergender, gender-neutral) according to their femininity (f) and masculinity (m) scores, resulting in 4 quadrants with 37% feminine (f-score ≥4 and m-score <4), 40% masculine (m-score ≥4 and f-score <4), 6% intergender (m- and f-scores ≥4) and 11% gender-neutral participants (m- and f-scores <4). Fig. 4 below shows the average benefit framing preference scores for all genders in both conditions. Intergender and gender-neutral participants were excluded from further gender-specific analysis due to their small number.

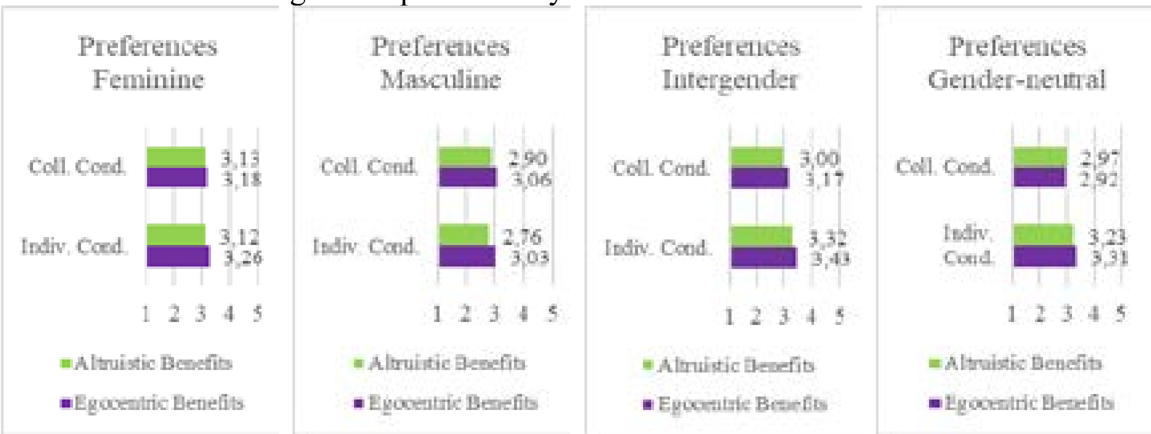

Fig. 4. Benefit Communication preferences per gender and engagement condition

Tested for significant gender differences regarding responsiveness to egocentric vs. altruistic benefit framings between the individual and the collective condition, results show a significant difference for both egocentric (m_m=3.03 and m_f=3.26 with U(N_m=84, N_f=75)=2525.5, z=-2.20, p=.028) and altruistic (m_m =2.76 and m_f =3.12 with U(N_m=84, N_f=75)=2577, z=-2, p=.045) benefit communication preferences in the individual condition, that becomes non-significant in the collective condition for both types of benefit communication (egocentric benefit communication preference in the collective condition: m_m =3.06 and m_f =3.18 with U(N_m=104, N_f=74)=3664.5, z=-0.55, p=.581; altruistic in the collective condition: m_m =2.90 and m_f =3.13 with U(N_m=104, N_f=74)=3377, z=-1.41, p=.160).
Lastly, looking at the strategies, *commitment* and *actionable advice* received comparatively higher scores for impacting intent, *facts* and *prompts* for impacting habits, and *feedback* and *improved control* for impacting conditions (see Fig. 5). Overall, *feedback* and *improved control* received the best scores for behaviour change potential.

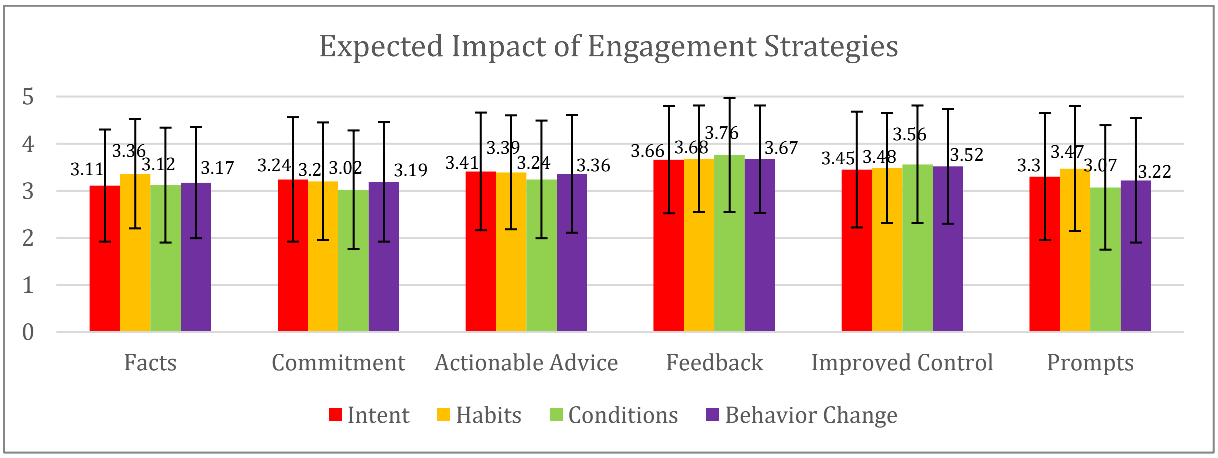

Fig. 5. Expected impact on intent, habits, conditions, and overall behaviour change of engagement strategies

6 DISCUSSION AND CONCLUSIONS

The study reported here aimed to explore if persuasive strategies that are enriched with design elements to further the building of a collective identity are more successful in encouraging sustainable energy consumption than ones that focus exclusively on the individual. We carried out an online experiment with six different engagement screens designed as either focusing on the individual alone (*individual engagement* condition) or engaging the individual as part of a community through theory-based collective amplification elements within the screen designs of each strategy (*collective engagement* condition). Within the experiment, participants within the collective condition indicated neither a greater likelihood to optimize their energy consumption, nor a greater likelihood to develop a collective identity with regards to a community of people using the fictional home energy management system.

We further designed four screens for benefit communication, two of which were based on egocentric values (financial and status-related benefit framings) and two on altruistic values (environmental and community benefit framings). The results showed us only negligible differences between the responsiveness to egocentric vs. altruistic benefit communication between the engagement conditions.

Finally, we explored if potential gender-related differences in responsiveness to egocentric over altruistic benefit communication would decrease in the collective condition due to participants with a male gender identity specifically showing an increase in preference of altruistic framings closer to the preference of participants with a female gender identity. This proved to be the case as we saw statistically-significant differences between participants presenting with male and female genders for both responsiveness to egocentric and altruistic benefit communication in the *individual engagement* condition turn non-significant in the *collective engagement* condition.

Our study was limited by its form as an online experiment as it likely did not allow for the forming of an actual shared social identity to impact engagement. Further, “engagement” was measured solely through self-reported assumptions rather than actual behaviour change, limiting the validity of the results. We suspect these limitations to be the reason why we were unable to see the expected results despite indicators from prior work (Duke, 2010; Jans et al., 2018; Jans & Fielding, 2018) that this approach is valid. We therefore suggest that future research should test these different engagement conditions in the field to collect data with true criterion validity. Additionally, the result that collective amplifiers do indeed lead to a statistically-significant alignment of responsiveness to different benefit framings between people with male and female gender identity is a promising one. It hints at the potential of collective approaches to engage people with different gender identities more equally towards sustainable behaviour and should be explored further with larger sample sizes for non-binary identities to allow for full inclusion in the data analysis.

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REFERENCES

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *Journal of environmental psychology*, *25*(3), 273–291.

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In *Action control* (S. 11–39). Springer.

Bartram, A. (2009). Behaviour change intervention tools. *Department for transport, energy & infrastructure. Government of south Australia*.

Bergquist, M., Thiel, M., Goldberg, M. H., & Van Der Linden, S. (2023). Field interventions for climate change mitigation behaviors: A second-order meta-analysis. Proceedings of the National Academy of Sciences, 120(13). https://doi.org/10.1073/pnas.2214851120

Bloodhart, B., & Swim, J. K. (2020). Sustainability and consumption: What's gender got to do with it? *Journal of Social Issues*, *76*(1), 101–113.

Brough, A. R., Wilkie, J. E., Ma, J., Isaac, M. S., & Gal, D. (2016). Is eco-friendly unmanly? The green-feminine stereotype and its effect on sustainable consumption. *Journal of Consumer Research*, *43*(4), 567–582.

Bulut, Z. A., Kökalan Çımrin, F., & Doğan, O. (2017). Gender, generation and sustainable consumption: Exploring the behaviour of consumers from Izmir, Turkey. *International Journal of Consumer Studies*, *41*(6), 597–604.

Byerly, H., Balmford, A., Ferraro, P. J., Hammond Wagner, C., Palchak, E., Polasky, S., Ricketts, T. H., Schwartz, A. J., & Fisher, B. (2018). Nudging pro-environmental behavior: Evidence and opportunities. *Frontiers in Ecology and the Environment*, *16*(3), 159–168.

Cameron, J. (2004). A three-component model of social identification. *Self and identity*, *3*(3), 239–262.

Chatzigeorgiou, I. M., & Andreou, G. T. (2021). A systematic review on feedback research for residential energy behavior change through mobile and web interfaces. *Renewable and Sustainable Energy Reviews*, *135*, 110187.

Cialdini, R. B., & Goldstein, N. J. (2004). Social influence: Compliance and conformity. *Annu. Rev. Psychol.*, *55*, 591–621.

Clayton, S., Devine-Wright, P., Stern, P. C., Whitmarsh, L., Carrico, A., Steg, L., Swim, J., & Bonnes, M. (2015). Psychological research and global climate change. *Nature Climate Change*, *5*(7), 640–646.

Costa Pinto, D., Herter, M. M., Rossi, P., & Borges, A. (2014). Going green for self or for others? Gender and identity salience effects on sustainable consumption. *International Journal of Consumer Studies*, *38*(5), 540–549.

Darnton, A., Verplanken, B., White, P., & Whitmarsh, L. (2011). Habits, Routines and Sustainable Lifestyles: A summary report to the Department for Environment, Food and Rural Affairs. AD Research & Analysis for Defra.

Duke, C. C. (2010). Social identity and the environment: The influence of group processes on environmentally sustainable behaviour [Dissertation]. University of Exeter.

Ellemers, N. (2018). Gender Stereotypes. *Annual Review of Psychology*, *69*(1), 275–298. https://doi.org/10.1146/annurev-psych-122216-011719

Ellemers, N., Kortekaas, P., & Ouwerkerk, J. W. (1999). Self-categorisation, commitment to the group and group self-esteem as related but distinct aspects of social identity. *European journal of social psychology*, *29*(2–3), 371–389.

Griskevicius, V., Cantú, S. M., & Van Vugt, M. (2012). The evolutionary bases for sustainable behavior: Implications for marketing, policy, and social entrepreneurship. *Journal of Public Policy & Marketing*, *31*(1), 115–128.

Jackson, J. W., & Smith, E. R. (1999). Conceptualizing social identity: A new framework and evidence for the impact of different dimensions. *Personality and Social Psychology Bulletin*, *25*(1), 120–135.

Jans, L., Bouman, T., & Fielding, K. (2018). A Part of the Energy „In Crowd": Changing People's Energy Behavior via Group-Based Approaches. *IEEE Power and Energy Magazine*, *16*(1), 35–41.

Jans, L., & Fielding, K. (2018). The Role of Group Processes in Environmental Issues, Attitudes, and Behaviours. *Environmental psychology: An introduction*, 228–237.

Kachel, S., Steffens, M. C., & Niedlich, C. (2016). Traditional masculinity and femininity: Validation of a new scale assessing gender roles. *Frontiers in psychology*, *7*, 956.

Klöckner, C. A., & Blöbaum, A. (2010). A comprehensive action determination model: Toward a broader understanding of ecological behaviour using the example of travel mode choice. *Journal of Environmental Psychology*, *30*(4), 574–586.

Luhtanen, R., & Crocker, J. (1992). A collective self-esteem scale: Self-evaluation of one's social identity. *Personality and social psychology bulletin*, *18*(3), 302–318.

McKenzie-Mohr, D., & Schultz, P. W. (2014). Choosing effective behavior change tools. *Social Marketing Quarterly*, *20*(1), 35–46.

Oinas-Kukkonen, H., & Harjumaa, M. (2008). A Systematic Framework for Designing and Evaluating Persuasive Systems. In H. Oinas-Kukkonen, P. Hasle, M. Harjumaa, K. Segerståhl, & P. Øhrstrøm (Hrsg.), *Persuasive Technology* (S. 164–176). Springer Berlin Heidelberg. http://link.springer.com/chapter/10.1007/978-3-540-68504-3_15

Schrammel, J., Diamond, L. M., Fröhlich, P., Mor, G., & Cipriano, J. (2023). Influencing residential electricity consumption with tailored messages: Long-term usage patterns and effects on user experience. *Energy, Sustainability and Society*, *13*(1), 1–14.

Schwartz, S. H. (1977). Normative Influences on Altruism. In L. Berkowitz (Hrsg.), *Advances in Experimental Social Psychology* (Bd. 10, S. 221–279). Academic Press. https://doi.org/10.1016/S0065-2601(08)60358-5

Steg, L., Bolderdijk, J. W., Keizer, K., & Perlaviciute, G. (2014). An integrated framework for encouraging pro-environmental behaviour: The role of values, situational factors and goals. *Journal of Environmental psychology*, *38*, 104–115.

Triandis, H. C. (1977). *Interpersonal behavior*. Brooks/Cole Publishing Company.

Van Zomeren, M., Postmes, T., & Spears, R. (2008). Toward an integrative social identity model of collective action: A quantitative research synthesis of three socio-psychological perspectives. *Psychological bulletin*, *134*(4), 504.

Vreja, L. O., Bălan, S., & Mavrodin, C. (2017). Sustainability and the Tragedy of the Commons. A New Perspective. *Competitiveness of Agro-Food and Environmental Economy*, 176–188.

Wolsko, C., Ariceaga, H., & Seiden, J. (2016). Red, white, and blue enough to be green: Effects of moral framing on climate change attitudes and conservation behaviors. *Journal of Experimental Social Psychology*, *65*, 7–19.

Zelezny, L. C., Chua, P.-P., & Aldrich, C. (2000). Elaborating on gender differences in environmentalism. *Journal of Social issues*, *56*(3), 443–458.

Navigating Public Perception: Understanding Acceptance and Implementation Conditions of CCS and DACCS

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Abstract

The public perception and acceptance of innovative technologies are critical elements for successful deployment. For complex and (for the public yet unknown) infrastructure technologies, such as Direct Air Capture (DAC) and Storage (DACCS), it is therefore crucial to investigate acceptance influencing factors such as perceived benefits and barriers as well as conditions formulated by the public towards the implementation of CCS and DACCS. Empirical data on laypersons' public perceptions was used (collected in two surveys with n = 177 and n = 135 German laypeople).

The results from Study I indicate that predictors of acceptance are predominately perceived benefits for general CCS acceptance and perceived risks in case of local acceptance. It was also found that the most pressing conditions perceived by the public for the implementation of CCS are linked to the requirement of an actual environmental impact of the technology.

A direct comparison in Study II revealed that for DACCS benefit perceptions are lower, while condition perception is higher than is the case for CO_2 capture from industrial point sources. Finally, several relationships with user factors such as environmental awareness and knowledge point towards a connection between technology perception and technology awareness. This research provides an empirical basis for DACCS perceptions that can be continued in further research in this realm. Findings also allow for the deduction of initial policy recommendations that in the future should focus on transparent and comprehensible communication – with an emphasis on the actual climate impact of the technology – that can foster a successful realization of (local) DACCS infrastructure projects.

1. INTRODUCTION

Climate change remains a major threat to life, ecosystems, and resources, with the 1.5 °C temperature increase limit likely to be reached before 2040, even under low greenhouse gas emission scenarios (IPCC, 2022). Climate change mitigating technologies provide the option to work towards meeting climate targets and slowing down the process of anthropogenic climate change. One technological approach is carbon removal through Direct Air Capture (DAC) or CO_2 capture from industrial point sources, followed by long-term underground storage of CO_2. In addition to other regulatory, economic, or technical prerequisites, public perception and acceptance of technological innovations are essential factors to consider, as they may promote or hinder technology diffusion or implementation of local projects (Deutscher Bundestag, 2018). Therefore, this study aims to analyse public perception and acceptance of Carbon Capture and Storage (CCS) and Direct Air Capture and Carbon Storage (DACCS), as well as perceived conditions for the implementation of these approaches.

2. RELATED WORK

Long-term underground storage by means of CCS is considered as one option of CO_2 sequestration to prevent further increase of emissions (Markewitz et al., 2012). The CO_2 can be separated from industrial gas streams, e.g., at iron, cement, or steel production plants or chemical plants (von der Assen et al., 2016). Separation methods – depending on flow rate and composition – are physical or chemical absorption, adsorption, or use of membranes (Hasan et al., 2015). An alternative to point sources is CO_2 capture via DAC, which is not dependent on a source of CO_2 emissions and can be located at sites with a high availability of renewable energy. This process chemically binds CO_2 from the ambient air to a filter and can then be collected as concentrated CO_2 (Sodiq et al., 2023). DACCS represents the combination of the separation of CO_2 by DAC and the subsequent geological storage (Terlouw et al., 2021).
As with other technological innovations aimed at reducing emissions, CO_2 capture and storage may be subject to public evaluation. Public perception and acceptance are potential factors of successful or futile technology implementation efforts, in general but also for local scenarios. *Technology acceptance* is defined as the active or passive approval, the object of which can be the development, implementation, or use of a technology or process (Dethloff, 2004). Wüstenhagen et al. (2007) define three dimensions: *Socio-political acceptance* is the general acceptance of technologies and policies, e.g., by the public, as it is relevant to this study. The same applies to *community acceptance*, regarding local acceptance, e.g., of siting decisions. Finally, *market acceptance* represents the adoption of a technology, e.g., by consumers or investors, but is of lesser relevance for the purpose of this study (Wüstenhagen et al., 2007).
Previous research identified several factors that influence general and local CCS acceptance. *Perceived benefits* (e.g., Braun, 2017), such as emission reduction (Oltra et al., 2010) or local economic benefits (Krause et al., 2014), *barriers*, such as the perceived delay of increasing emissions (Arning et al., 2019), and *risks* (e.g., Braun, 2017), such as steady or explosive CO_2 leakage (Arning et al., 2019) have been identified to be part of the public's assessment of the CCS approach. In addition, user-related factors such as demographics and individual attitudes (e.g., Arning et al., 2019) and technology-related aspects such as previous awareness (e.g.,

Braun, 2017) have been included in previous studies.
Research on perception and acceptance of DACCS is still underexplored. Jobin (2019) found that public support for DACCS research and deployment was moderate, while a study by Wenger et al. (2021) revealed that the affective evaluation of DACCS after informational input was also moderate. Satterfield et al. (2023) identify risk perceptions related to physical and moral hazard risks as negatively predictive factors, while benefit perceptions positively influenced community support for a specific DACCS project. However, these findings are isolated and further research is needed to gain a deeper understanding of perceptions of DACCS that help to form public and policy information and communication strategies.

3. METHOD

Research approach

As there is a wider body of research on the topic on CCS acceptance, but little knowledge on the topic of perception and acceptance of DACCS, a two-step research approach was followed: In *Study I* quantitative survey data is used to investigate whether user factors – in addition to technology perceptions such as perceived barriers and benefits, and singular user related factors, like demographics – predict CCS acceptance: *RQ1 – Which factors significantly predict local and general acceptance of CCS?* In addition, to gain a deeper understanding of the conditions for CCS implementation, which were identified through a preliminary interview study with laypeople, it was asked: *RQ2 – Which conditions for the implementation of CCS are linked to acceptance of CCS? Study II* focused on the perception of DACCS by directly comparing it to the capture (and subsequent storage) of CO_2 from industrial point sources: *RQ3 – Does technology perception differ between DACCS and CO_2 capture from point sources?* Finally, to explore the relationship between the two technology approaches and public perception, it was asked: *RQ4 – Which user factors are linked to the perception of DACCS and CO_2 capture from point sources?*

Measurement instruments

At the start of the surveys, participants in Studies I and II were informed about the length of the survey, that they could stop participating at any time, and about how data would be handled in accordance with German GDPR. They gave their informed consent to participate before starting the rest of the survey. Both questionnaires included questions on demographic information (i.e., age, gender, education, net monthly income, and place of residence). After providing this information, participants in *Study I* indicated their (dis)agreement with several groups of items used to measure their affinity for technology interaction (ATI) (Franke et al., 2019), personal innovativeness regarding technologies (PIT) (Arning et al., 2019), citizen trust in government organizations (CTGO) (Grimmelikhuijsen & Knies, 2017), and risk tolerance (Arning et al., 2019; Kramer et al., 2020). Next, in connection to climate change as the general context of CCS as an emissions-reducing technology, participants answered questions about perceived climate change consequences and perceived affectedness by climate change (van Valkengoed et al., 2021), as well as on pro-environmental self-identity (Whitmarsh & O'Neill, 2010). The next part of the survey introduced participants to the topic of CCS by briefly explaining the concept of CO_2 capture and subsequent long-term storage, followed by another block of items asking about people's perceptions of the CCS approach (Arning et al., 2019, Salak et al., 2021), their affective evaluation of CCS (Linzenich et al., 2019, 2022), and their risk perception of CCS (Arning et al., 2019). Finally, local acceptance of CCS was surveyed (Arning et al., 2019), as were perceived conditions for the implementation of CCS[i] and general acceptance of CCS (Arning et al., 2019). Respondents in *Study II* were introduced to the topic of CO_2 capture by DAC or CO_2 capture from point sources and subsequent long-term storage, after answering demographic questions. They were then asked about their knowledge of DACCS and CO_2 capture from point sources. Subsequently, technology perception for DACCS and point sources was queried. In the last survey part, respondents indicated their environmental awareness (Geiger & Holzhauer, 2020), technology commitment (Neyer et al., 2012), and personal innovativeness regarding technologies (PIT) (Arning et al., 2019).

Data collection and analysis

In both surveys, all items were evaluated on six-point Likert scales (1 = do not agree at all – 6 = strongly agree). Only the *affective evaluation of CCS* in Study I was measured using seven-point bipolar opposite pairs, allowing people to indicate indecisiveness in their affective assessment. If necessary for construct formation, items were inverted. For each construct, Cronbach's alpha was calculated to ensure internal consistency. Data was analyzed by using descriptive as well as inferential statistics, i.e., factor analyses to identify underlying constructs, repeated measures ANOVAs, *t*-tests, correlation analyses, and stepwise multiple linear regression analyses. The level of significance was set at 5%. After data collection, the data sets were screened for incomplete cases, speeders, and straight-lining, which resulted in $n = 177$ for *Study I* and $n = 135$ for *Study II*.

Samples

Table 1: Descriptive statistics of sociodemographic criteria of samples in Studies I and II.

	Age [*M*, (*SD*)]	*Gender* [%] female male diverse	*Education* [%] low medium high	*Net income per month and household* [%]* < 1.000 € 1.000 - 3.000 € < 3.000 €	*Place of residence* [%] rural area city suburb
Study I (n = 177)	33.63 (13.22)	55.4 43.5 1.1	3.5 26.5 70.1	21.3 45.6 33.1	16.9 18.6 64.4
Study II (n = 135)	36.80 (18.31)	49.6 49.6 0.7	1.5 36.3 62.2	29.1 30.6 40.3	14.8 25.2 60.0

* Voluntary indication, Study I: $n = 169$, Study II: $n = 134$

[i] Items stemmed from the qualitative interview pre-study (not published).

The two surveys resulted in two distinct samples (see Table 1). The average age in Study I (M = 33.63, SD = 13.22) was slightly lower than in Study II (M = 36.80, SD = 18.31). Gender was more equally distributed in Sample II, while Sample I consisted of 55.4% women, 43.5 % men, and 1.1 % people indicating a non-binary gender. In both samples there was a surplus of highly educated people (i.e., people with a university degree). In Sample I the largest share of people indicated to have access to a monthly net income of between 1.000 € and 3.000 €, while it was above 3.000 € per month in Sample II. When it comes to respondents' place of residence, in both samples most of the people lived in suburban areas.

4. RESULTS

Acceptance of and perceived conditions towards the implementation of CCS

In *Study I*, the *general acceptance of CCS* was rather high (M = 4.19, SD = 1.04) and significantly higher than *local acceptance* (M = 3.76, SD = 1.12, $F_{1,\,174}$ = 37.85, p < .001, η^2 = .18). However, the mean *local acceptance of CCS* still significantly differed from the mid-point of the scale (3.5) (t_{176} = 3.26, p = .001, d = .25) and can therefore be interpreted as rather high.
Exploratory factor analysis with all items included to investigate perceptions of CCS revealed two underlying factors: *perceived benefits* (M = 3.75, SD = 0.88) and *perceived barriers of CCS* (M = 3.69, SD = 0.83). Respondents' mean agreement for the two constructs did not differ ($F_{1,\,176}$ = 0.27, *n.s.*). *Risk perception of CCS* (M = 3.41, SD = 0.82), however, was found to be significantly lower than both *benefit* ($F_{1,\,176}$ = 9.99, p = .001, η^2 = .05) and *barrier perceptions of CCS* ($F_{1,\,176}$ = 18.05, p < .001, η^2 = .09).
To analyse which factors influence local and general acceptance (*RQ1*), stepwise multiple linear regressions were performed with the constructs measuring CCS perception and user factors. For the model used to predict *general CCS acceptance*, the Durbin-Watson statistic was 2.108, indicating that the assumption of independent errors was met. The final model explained 64.1% of variance (*adj.* R^2; $F_{5,\,168}$ = 62.70, p < .001). Interpretation of standardized beta coefficients (see Table 2) shows that *perceived benefits of CCS* (β = .411, p < .001) is the strongest predictor of *general acceptance of CCS*, followed by respondents' *local acceptance* (β = .242, p < .001). Individuals with higher levels of agreement with benefits and higher levels of acceptance for CCS being implemented near their home express higher levels of general acceptance of CCS. In contrast, *perceived barriers of CCS* (β = -.154, p = .013) negatively affect *acceptance of CCS*, i.e., the higher the impression that CCS poses barriers, the lower acceptance (and vice versa). Finally, *affective evaluation of CCS* (β = .148, p = .05) has a significant positive impact on *general acceptance of CCS*. The only user factor that was identified in the model to be influential is respondents' *perception of climate change consequences* (β = .125, p = .007), i.e., the more aware a person is of potentially negative consequences of climate change, the more likely they are to accept CCS. Factors that were excluded from the final model were *ATI, PIT, CTGO, risk tolerance, perceived affectedness by climate change, pro-environmental self-identity, perceived risks of CCS, age, gender,* and *education.*
For *local acceptance of CCS*, a model with 61.0 % of explained variance (*adj.* R^2) was revealed by stepwise linear regression ($F_{3,\,173}$ = 91.07, p < .001). The Durbin-Watson statistic was 1.638. However, in case of *local acceptance of CCS* only three predictors were included

in the final model, of which the one with the highest predictive was *perceived risks of CCS* (β = -.354, p < .001), indicating that the higher a person's risk perception of CCS, the lower their acceptance of local implementation of CCS (and vice versa). In addition, the factors *affective evaluation of CCS* (β = .273, p = .001) and *general acceptance of CCS* (β = .277, p < .001) significantly predict local acceptance of CCS. Factors excluded from the final model were *ATI, PIT, CTGO, risk tolerance, perceived climate change consequences, perceived affectedness by climate change, pro-environmental self-identity, perceived benefits of CCS, perceived barriers of CCS, age, gender,* and *education.*

Table 2: Stepwise multiple linear regression models for *general* and *local acceptance of CCS*.

						95% CI for B			
	B	*SEB*	*β*	*t*	*p*	Lower	Upper	*T*	*VIF*
General acceptance CCS									
(Constant)	.753	.633		1.191	.235	-.496	2.002		
Perceived benefits	.495	.079	.411	6.234	<.001	.338	.651	.477	2.095
Local acceptance	.224	.061	.242	3.663	<.001	.103	.345	.476	2.099
Perceived barriers	-.193	.077	-.154	-2.514	.013	-.345	-.041	.552	1.812
Perceived climate change consequences	.169	.062	.125	2.724	.007	.046	.291	.982	1.018
Affective evaluation	.121	.061	.148	1.976	.050	.000	.243	.371	2.693
Local acceptance CCS									
(Constant)	3.066	.587		5.221	<.001	1.906	4.225		
Affective evaluation	.242	.071	.273	3.394	.001	.101	.382	.349	2.865
Perceived risks	-.491	.096	-.354	-5.124	<.001	-.680	-.302	.473	2.116
General acceptance	.299	.069	.277	4.333	<.001	.163	.435	.552	1.811

Respondents were also asked to rate the importance to a series of statements containing conditions for the implementation of CCS (*RQ2*) that originated from a preliminary interview study with laypeople. Table 3 lists the descriptives and correlations with *local* and *general acceptance of CCS*. Perceived importance for the conditions was generally quite high. Respondents indicated *Definition of a limited* CO_2 *storage period* (M = 3.71, SD = 1.37) as least important and *Assurance of positive effect on the environment & climate* (M = 5.61, SD = 0.71) as most important. The former is still significantly different from the mean of the scale (3.5) (t_{175} = 2.15, p = .033, d = .16), indicating that all listed conditions are rather of relevance. Interestingly, the conditions with highest mean values – apart from the assurance of actual impacts of the technology with the highest mean agreement – are on the one hand safety-related, e.g., the *Assurance of low-risk and hazard-free operation* (M = 5.49, SD = 0.75), and on the other hand also relate to aspects such as public communication (*Transparent information and education* (M = 5.47, SD = 0.75)). Pearson correlations were used to explore the relation between conditions for CCS implementation and *local* and *general acceptance of CCS*. For *general acceptance of CCS*, there are several weak positive associations with perceived importance of conditions. The higher a person's general acceptance, the more they perceive

Transparent information & education, *Assurance of low-risk & hazard-free operation*, *EU-wide introduction*, and *Assurance of positive effect on the environment & climate* to be of importance. The perceived importance of the *Continuous development of CCS technology* correlated moderately. In case of *local acceptance of CCS*, interestingly only negative significant relationships were identified. The lower a person's local acceptance, the more important they perceive *Minimal impact of CCS plants on landscape, Allocation of plants across all federal states*, and *Rewards for citizens (e.g., tax savings) if plant/ storage facility is built and operated near place of residence* to be (and vice versa). Perceived importance of a *Definition of a limited CO_2 storage period* was moderately negatively correlated with local CCS acceptance.

Table 3: Descriptives of conditions for CCS implementation and correlations with *general* and *local acceptance.*

	M	*SD*	*General acc. CCS (r (p))*	*Local acc. CCS (r (p))*
Transparent information & education	5.47	0.75	.152 (.045)	-.043 (.568)
On-site information events	4.61	1.14	.079 (.300)	-.041 (.590)
Assurance of low-risk & hazard-free operation	5.49	0.75	.176 (.020)	.009 (.908)
Use of renewable energies throughout entire process	5.21	0.87	.087 (.254)	.001 (.990)
Minimal impact of CCS plants on landscape	4.18	1.26	.003 (.971)	-.224 (.003)
Assurance of an effective & efficient process	5.38	0.74	.088 (.247)	.041 (.587)
Continuous development of CCS technology	5.14	0.89	.350 (< .001)	.121 (.111)
Definition of a limited CO_2 storage period	3.72	1.37	-.128 (.092)	-.338 (< .001)
Assurance of low-noise operation	4.68	1.05	.134 (.077)	-.032 (.669)
Definition of EU-wide guidelines for plant operation	5.05	1.06	.075 (.324)	-.069 (.362)
Allocation of plants across all federal states	4.68	1.21	.057 (.457)	-.149 (.048)
EU-wide introduction	4.79	1.12	.227 (.003)	.062 (.417)
Rewards for citizens if plant/storage facility is built & operated near place of residence	3.76	1.30	.004 (.962)	-.168 (.026)
Assurance of positive effect on environment & climate	5.61	0.71	.158 (.037)	.041 (.585)

Public perception of DACCS and CO_2 capture and storage from point sources

In a next step, it was analysed if perceptions of different CO_2-capture-methods (referred to as technology contexts: DACCS vs. point sources) differed. An exploratory factor analysis with DACCS and point source perception items in *Study II* revealed three constructs per technology context: perceived benefits, conditions, and risks. For the constructs of *perceived benefits of DACCS* and *point sources*, the item with the highest mean agreement was "The technology can make a significant contribution to CO_2 reduction." ($M_{DACCS} = 4.26$, $SD = 1.15$; $M_{point\ source} = 4.40$, $SD = 1.12$). In case of *perceived conditions*, the highest mean agreement was found for "Energy costs play a major role in assessing how useful the technology is." ($M_{DACCS} = 4.46$, $SD = 1.19$; $M_{point\ source} = 4.36$, $SD = 1.18$). Finally, for *risk perception*, for both contexts, people agreed the most to the item stating, "I am concerned that this will weaken the motivation of the population and industry to save CO_2 on their own". ($M_{DACCS} = 3.86$,

$SD = 1.43$; $M_{point\ source} = 3.84$, $SD = 1.46$).

Repeated measures ANOVAs showed that there were significant differences between the two technology contexts (*RQ3*): *Benefit perception* of DACCS ($M = 3.97$, $SD = 0.81$) was significantly lower than for point sources ($M = 4.11$, $SD = 0.77$, $F_{1,\ 104} = 8.66$, $p = .004$, $\eta^2 = .08$). The *perceived conditions* were significantly more pronounced in case of DACCS ($M = 3.83$, $SD = 0.94$) than for CO_2 capture from point sources ($M = 3.69$, $SD = 0.91$, $F_{1,\ 134} = 7.43$, $p = .007$, $\eta^2 = .05$). However, for the third construct, *perceived risks*, the analysis showed no differences in means between DACCS ($M = 3.24$, $SD = 0.88$) and point sources ($M = 3.17$, $SD = 0.94$, $F_{1,\ 134} = 3.08$, *n.s.*).

Finally, the connection between the perception of the two investigated CO_2 capture specifications and respondents' characteristics was studied (*RQ4*). Interestingly, only a limited number of correlations were identified for respondents' demographics (see Table 4). For both DACCS ($r = -.29$, $p = .003$) and point sources ($r = -.26$, $p = .007$), the younger a person, the more they perceived the two types of CO_2 capture to be beneficial. As for gender, women were associating more conditions to DACCS than men ($r = .21$, $p = .013$). Environmental awareness for consumption was weakly correlated with *perceived risks* of DACCS ($r = .22$, $p = .010$) and moderately correlated in case of *point sources* ($r = .31$, $p < .001$). Furthermore, the higher a person's *technology commitment*, the lower their *risk perception* for both DACCS ($r = -.28$, $p = .001$) and point sources ($r = -.29$, $p = .001$), and the higher their *benefit perception* for point sources ($r = .25$, $p = .012$). While *PIT* was positively linked to *perceived conditions* in case of DACCS ($r = .19$, $p = .031$), the lower a respondent's *PIT*, the more they perceived point sources to pose risks (and vice versa) ($r = -.18$, $p = .041$). Finally, pre-existing knowledge of the two investigated CO_2 capture options was examined for relationships with technology perceptions. It turns out that *knowledge on DACCS* was positively linked to *perceived conditions* of the DACCS ($r = .25$, $p = .003$) and point sources context ($r = .20$, $p = .019$), as was *knowledge on point sources* ($r_{DACCS} = .29$, $p = .001$; $r_{point\ sources} = .26$, $p = .003$). Also, the more a person rated their knowledge of DACCS to be high, the less they reported perceiving risks linked to point sources ($r = -.18$, $p = .037$).

Table 4: Pearson and Kendall's tau[a] correlations of DACCS and point source perceptions with user factors.

	DACCS			*Point sources*		
Perceived…	*benefits*	*conditions*	*risks*	*benefits*	*conditions*	*risks*
Age	-.291	-.047	.124	-.261	-.035	.156
	(.003)	(.589)	(.151)	(.007)	(.691)	(.070)
Gender	-.104	.213	-.070	.045	.134	-.164
(0 = male, 1 = female)	(.292)	(.013)	(.422)	(.651)	(.121)	(.058)
Education[a]	.065	-.019	-.108	.095	-.016	-.123
	(.427)	(.797)	(.142)	(.248)	(.829)	(0.92)
Environmental awareness: social sustainability	.097	-.023	.101	.143	-.030	.155
	(.327)	(.790)	(.242)	(.145)	(.730)	(.074)
Environmental awareness: consumption	.085	-.150	.220	.028	-.101	.307
	(.386)	(.081)	(.010)	(.779)	(.243)	(< .001)

Technology commitment	.131	.089	-.281	.245	.137	-.285
	(.183)	(.306)	(.001)	(.012)	(.114)	(.001)
PIT	.094	.186	-.168	.154	.164	-.177
	(.341)	(.031)	(.051)	(.116)	(.057)	(.041)
DACCS knowledge	-.053	.250	-.070	.070	.201	-.180
	(.588)	(.003)	(.418)	(.477)	(.019)	(.037)
Point source knowledge	.034	.294	.049	.168	.255	-.053
	(.731)	(.001)	(.572)	(.087)	(.003)	(.543)

5. DISCUSSION

The first aim was to identify factors that predict local and general acceptance of CCS (*RQ1*). The analysis revealed that predictors differed depending on the technology context. While for general acceptance, perceived barriers held the most predictive values, it was risk perception towards CCS in case of the local scenario. Interestingly, affective evaluation acted as a predictor in both cases. Demographics and attitudes of respondents – except for the impact of perceived climate change consequences on general CCS acceptance – were of no relevance. These findings are in line with previous research (Arning et al., 2019; Braun, 2017).

The findings furthermore highlighted a) which requirements laypeople perceive to be of most importance for the implementation of CCS and b) which conditions are linked to CCS acceptance (*RQ2*). It is striking that, in addition to the points of safety and transparency, the aspect of sustainability plays a fundamental role among the conditions perceived as most important, which is reflected in the aspects of renewable energies for the *entire* process and ensuring effectiveness and a real impact of the technology. Interestingly, the CO_2 storage time limit is the least relevant, as well as rewards for residents, which is an interesting result given that local acceptance in this and other studies (Arning et al., 2019; Oltra et al., 2022) is lower than general acceptance of CCS. In the future, this condition should be studied separately for plant and storage sites. In addition, the results can be used to identify condition profiles: While for the general acceptance of CCS transparent information, actual sustainability, safety, and a push for development as well as a Europe-wide distribution are relevant, local acceptance depends on the conditions of temporary storage, landscape impacts, and equal deployment perceived as equally distributed at federal state level. It is also interesting that the generally less important condition of compensation for residents is negatively related to local acceptance.

For the previously under-researched perception of DACCS, it was found that the approach was associated with lower benefit and higher condition perception in direct comparison to point sources with subsequent storage (*RQ3*). The item that weighed most heavily in the benefits construct was again the actual impact of the technology. It is possible that the laypersons' assessment is linked to the comparison with high-emitting industrial sources and the possibility of preventing larger amounts of emissions than the capture of atmospheric CO_2 already emitted. This may also explain the higher condition perception, as spatial decoupling may appear to be an elaborate option, which could lead to a questioning of the impact, and thus conditions such as costs may come to the fore.

Finally, regarding the final research question on user factors in relation to DACCS and perception of point source capture (*RQ4*), it can be observed that there is no evidence of distinct demographic profiles based on the results, as correlations with perceived benefits, conditions, and risks were equally (not) observed. A regression with a larger and more evenly distributed sample in terms of demographic characteristics (e.g., education) would need to verify this finding. It was also found that the more a person is accustomed to dealing with new technologies, the lower their risk perception (and the more they perceive benefits of point source CO_2 capture). In connection with higher domain knowledge on both technology CCS approaches it can be assumed that increased information exposure can impact laypeople's evaluation and (indirectly their) acceptance of technologies such as DACCS.

Future research needs to validate these initial findings and to analyse the connection of technology perception of DACCS with its acceptance by the public, but also other involved stakeholder groups. Furthermore, it should be investigated whether and how the perception of the DAC step affects the perception of storage, i.e., analyse in more detail how lay perceptions of CO_2 capture options affect the acceptance of long-term CO_2 storage – or possibly further processing and utilization of CO_2.

6. CONCLUSION

This study delved into several aspects surrounding the acceptance of CCS technologies, shedding light on critical factors and conditions influencing both local and general acceptance. It highlighted the importance of sustainability perceived by the public as a paramount condition for the implementation of CCS. Additionally, initial results were gathered on the perception of DACCS in direct comparison with CO_2 capture (and storage) from point sources. For the future, it is necessary to validate these findings by exploring the relationship between DACCS perception and technology acceptance as well as by checking for underlying groups with varying requirement profiles. Policymakers could benefit from further research to develop information strategies that may counteract perceived barriers during implementation of CCS technologies, aligning their development and roll-out with public values and sustainability aims. Additionally, further research should encompass a broader demographic sample to confirm these trends and consider the perspectives of various stakeholder groups involved in CCS initiatives.

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8. REFERENCES

Arning, K., Offermann-van Heek, J., Linzenich, A., Kaetelhoen, A., Sternberg, A., Bardow, A., & Ziefle, M. (2019). Same or different? Insights on public perception and acceptance of carbon capture and storage or utilization in Germany. *Energy Policy*, 125, 235–249. doi:10.1016/j.enpol.2018.10.039

Braun, C. (2017). Not in My Backyard: CCS Sites and Public Perception of CCS. *Risk Analysis*, 37(12), 2264–2275. doi:10.1111/risa.12793

Dethloff, C. (2004). *Akzeptanz und Nicht-Akzeptanz von technischen Produktinnovationen* [Acceptance and Non-Acceptance of Technical Product Innovations]. Pabst Science Publ.

Deutscher Bundestag (2018), Evaluierungsbericht der Bundesregierung über die Anwendung des Kohlendioxid Speicherungsgesetzes sowie die Erfahrungen zur CCS-Technologie, [Evaluation Report of the Federal Government on the Application of the Carbon Dioxide Storage Act and the Experience with CCS Technology], 19, https://dserver.bundestag.de/btd/19/068/1906891.pdf

Franke, T., Attig, C., & Wessel, D. (2019). A Personal Resource for Technology Interaction: Development and Validation of the Affinity for Technology Interaction (ATI) Scale. *International Journal of Human–Computer Interaction*, 35(6), 456–467. doi:10.1080/10447318.2018.1456150

Geiger, S., & Holzhauer, B. (2020). *Weiterentwicklung einer Skala zur Messung von zentralen Kenngrößen des Umweltbewusstseins*. [*Further development of a scale to measure key indicators of environmental awareness*.] Umweltbundesamt. https://www.umweltbundesamt.de/en/publikationen/weiterentwicklung-skala-umweltbewusstsein

Grimmelikhuijsen, S., & Knies, E. (2017). Validating a scale for citizen trust in government organizations. *International Review of Administrative Sciences*, 83(3), 583–601. doi:10.1177/0020852315585950

Hasan, M. M. F., First, E. L., Boukouvala, F., & Floudas, C. A. (2015). A multi-scale framework for CO_2 capture, utilization, and sequestration: CCUS and CCU. *Computers & Chemical Engineering*, 81, 2–21. doi:10.1016/j.compchemeng.2015.04.034

IPCC (2022). Summary for Policymakers In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, doi:10.1017/9781009325844.001

Jobin, M. (2019). *Public acceptance of technologies to tackle climate change* [Doctoral dissertation, ETH Zurich]. doi:10.3929/ethz-b-000365225

Kramer, M. D., Patrick, C. J., Hettema, J. M., Moore, A. A., Sawyers, C. K., & Yancey, J. R. (2020). Quantifying Dispositional Fear as Threat Sensitivity: Development and Initial Validation of a Model-Based Scale Measure. *Assessment*, 27(3), 533–546. doi:10.1177/1073191119837613

Krause, R. M., Carley, S. R., Warren, D. C., Rupp, J. A., & Graham, J. D. (2014). "Not in (or Under) My Backyard": Geographic Proximity and Public Acceptance of Carbon Capture and Storage Facilities: Not in (or Under) My Backyard. *Risk Analysis*, 34(3), 529–540. doi:10.1111/risa.12119

Linzenich, A., Arning, K., Offermann-van Heek, J., & Ziefle, M. (2019). Uncovering attitudes towards carbon capture storage and utilization technologies in Germany: Insights into affective-cognitive evaluations of Benefits and risks. *Energy Research & Social Science*, 48, 205–218. doi:10.1016/j.erss.2018.09.017

Linzenich, A., Engelmann, L., Arning, K., Du, M., Heger, S., Roß-Nickoll, M. & Ziefle, M. (2022). Harmful or Beneficial to Humans and the Environment? An Empirical Study on the Social Acceptance and Risk Perception of CO_2-Based Fuels. *Frontiers in Environmental Science*, 10, 737070. doi:10.3389/fenvs.2022.737070

Markewitz, P., Kuckshinrichs, W., Leitner, W., Linssen, J., Zapp, P., Bongartz, R., Schreiber, A., Müller, T.E. (2012). Worldwide innovations in the development of carbon capture technologies and the utilization of CO_2, *Energy & Environmental Science,* 5(6), 7281–7305. doi:10.1039/C2EE03403D

Neyer, F.J., Felber, J., & Gebhardt, C. (2012). Entwicklung und Validierung einer Kurzskala zur Erfassung von Technikbereitschaft [Development and validation of a brief measure of technology commitment]. *Diagnostica,* 58(2), 87–99. doi:10.1026/0012 1924/a000067

Oltra, C., Sala, R., Solà, R., Di Masso, M., & Rowe, G. (2010). Lay perceptions of carbon capture and storage technology. *International Journal of Greenhouse Gas Control,* 4(4), 698–706. doi:10.1016/j.ijggc.2010.02.001

Oltra, C., Dütschke, E., Preuß, S., Gonçalves, L., & Germán, S. (2022). What influences public attitudes and acceptance of CCUS technologies on the national and regional level? Results from a survey study in France and Spain. *Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16) 23-24 Oct 2022*. doi:10.24406/publica-502

Satterfield, T., Nawaz, S., & Peterson St-Laurent, G. (2023). Exploring public acceptability of direct air carbon capture with storage: climate urgency, moral hazards and perceptions of the 'whole versus the parts'. *Climatic Change,* 176(2), 14. doi:10.1007/s10584-023-03483-7

Sodiq, A., Abdullatif, Y., Aissa, B., Ostovar, A., Nassar, N., El-Naas, M., & Amhamed, A. (2023). A review on progress made in direct air capture of CO_2. *Environmental Technology & Innovation*, 29, 102991. doi:10.1016/j.eti.2022.102991

Terlouw, T., Bauer, C., Rosa, L., & Mazzotti. M. (2021). Life cycle assessment of carbon dioxide removal technologies: A critical review. *Energy & Environmental Science,* 14(4), 1701–1721. doi:10.1039/D0EE03757E

von der Assen, N., Müller, L.J., Steingrube, A., Voll, P., & Bardow, A. (2016). Selecting CO_2 sources for CO_2 utilization by environmental-merit-order curves. *Environmental Science & Technology,* 50(3), 1093–1101. doi:10.1021/acs.est.5b03474

van Valkengoed, A.M., Steg, L., & Perlaviciute, G. (2021). Development and validation of a climate change perceptions scale. *Journal of Environmental Psychology,* 76, 101652. doi:10.1016/j.jenvp.2021.101652

Wenger, A., Stauffacher, M. & Dallo, I. (2021). Public perception and acceptance of negative emission technologies – framing effects in Switzerland. *Climatic Change,* 167(3), 53. doi:10.1007/s10584-021-03150-9

Whitmarsh, L. & O'Neill, S. (2010). Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology,* 30(3), 305–314. doi:10.1016/j.jenvp.2010.01.003

WILL OUR ENERGY COMMUNITY BE FAIR?

Perspectives of Austrian Households on Choices in the Genesis of an Energy Community.

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Abstract

This contribution aims at determining the perspective of Energy Community (EC) members towards fairness mechanisms within their community. Given the various facets of inclusiveness, openness and fairness, we analyse three choices, which any member of an EC will be confronted with during the foundation process. These analyses are grounded in data from two survey samples conducted among Austrian citizens encompassing 537 and 655 respondents. At first, a household needs to decide whether to join an EC. We analyse the decision-making power within the household versus the responsibilities of household energy-consuming activities through the gender lens. We identify a discrepancy of responsibility within these tasks. This may hamper the exploitation of the full potential, that ECs can bring to a household. Once integrated into an EC, members collectively determine the communties' tariff structure. With this agreement, the savings distribution among community members is set – which impacts not only the profitability for each member and the community as a whole but also distributional justice within the EC. Even though all members of an EC benefit from cost reduction, more affluent households mainly do not agree to shorten their benefits to increase savings for low-income households. The third choice within our analysis is the revenue sharing of surplus energy sales. Our results show that distribution methods based on social gradients receive low ratings. This contribution expands the discourse on the complexities of a just energy transition by delving deeper into the inequalities that can arise during the formative processes of ECs.

1. INTRODUCTION

Energy Communities (ECs), as defined in the Renewables Energy Directive (RED) (Directive EU 2018/2001) and the Electricity Market Directive (EMD) (Directive (EU) 2019/944) redefine the role of consumers within the energy system. Consumers are no longer passive customers but are offered opportunities to actively engage with the energy system through ECs. Beyond advancing the energy transition and reducing carbon emissions through local, efficient, and renewable energy consumption, ECs are expected to deliver not only economic but also social value.

One example of such an added social value is stipulated in the RED II, Art 22, §4, which mandates the inclusion of low-income and vulnerable households. In addition to inclusivity, there are expectations that ECs will contribute to the democratization of the energy system, fostering a just and widely accepted energy transition (Hanke et al. 2021; Dudka et al., 2023).

As the foundation of an EC is complex, many steps in its genesis have to be completed. Consequently, members are asked to make several decisions on the way of forming and subsequently managing their ECs. Initially, there needs to be a selection of eligible households and the choice on the legal form of the EC, which defines the degree of co-determination among members. Once these decisions are made, the newly formed group has to agree on details of their own EC. Such details encompass the distribution key for the energy produced, the tariff structure within the EC or revenue sharing if surplus energy is sold. These decisions finally determine how fair and inclusive – or exclusive – the emerging EC will be.

The number of ECs in Austria is rising constantly. From about 300 registered communities in early 2023 (Dvorak, 2023), four months later the number grew to nearly 900 (ebUtilities, 2023). Little is known about their size, types of members or internal operation processes and whether the operators and participants have considered their mission on equal and non-discriminatory treatment of members as well as inclusiveness and openness as claimed by the RED (Art 22 §4). First estimations set the theoretical potential for ECs in Austria at around 47.000 communities (Fina et al., 2022), which underlines the theoretical impact and importance of a just design of these communities.

Hence, our study centers on the Austrian population's perspectives on fair and inclusive ECs. We aim to determine whether future members themselves would agree to inclusive and fair mechanisms within an EC. Given the various facets of inclusiveness, openness and fairness within communities, we set our scope on the three fundamental choices that pave the way for energy justice in ECs:

- Decisional power: implications of gender roles (section 4.1)
- Intra-community benefit sharing: implications on low-income households (section 4.2)
- Surplus energy selling: household perspectives on distributional justice (section 4.3)

2. THEORETICAL BACKGROUND

2.1. Fairness and justice – what are we talking about?

Our study employs the "three-tenet approach" of energy justice. This approach distinguishes between (1) procedural, (2) distributional and (3) recognition justice, as elaborated by Sovacool and Dworkin (2015). Procedural justice refers to the processes of decision-making, encompassing accessibility to information, participation, and representation. Distributional justice focuses on the inter- and intra-generational sharing of benefits and burdens. The third dimension points towards recognition of who is included, and which parts of society are excluded.

As highlighted by Jenkins et al. (2016), the energy justice framework gives the "opportunity to explore where injustices occur, developing new processes of avoidance and remediation and recognizing new sections of society" (Jenkins et al., 2016, p.174). For example, Walker and Day (2012) analyse energy poverty through the lens of justice. In line with the argument of Jenkins et al. (2016), the analysis of justice of a certain matter starts with the questions of distribution of burdens of benefits (second tenet) and the recognition of those affected (third tenet). Accordingly, we discuss dimensions of justice as recognition and procedural justice in the context of shared energy household activities and the distribution of responsibility among household members of two-person households (see section 4.1). Thereby, we examine who is involved in ECs, and how existing biases may affect this involvement. We scrutinize situations where only members holding the current contract to DSO or grid operator are officially addressed to become EC members. Principles of intra-generational equity (Sovacool & Dworkin, 2015) towards diversity are considered. Secondly, distributional justice is scrutinized in the question of intra-community benefit sharing (section 4.2) and surplus energy selling (section 4.3). In the present study, the principles of equality (all receive the same share of benefits), equity (benefits shared according to needs), capital/ ownership (benefits shared in favor of those who bring in capital) and performance (benefits are shared according to input and effort given to community) are applied.

2.2. Energy Communities and the claim for energy justice

RED stipulates that ECs should prioritize "(…) environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits" (Directive EU 2018/2001, Art 2, par. 16c). However, the specific social impact that ECs may provide and how their impact shall be measured remain undefined. Several studies investigating the potential impacts on communities and society refer to other community energy initiatives when assessing social impacts, such as energy cooperatives (Karakislak et al., 2023) or peer-to-peer trading (Georgarakis et al., 2021). Bielig et al. (2022) provide a comprehensive framework of the social impacts of community energy initiatives utilizing a systematic literature review. They distinguish four main categories of social impact: (1) Energy Justice, (2) Social Capital, (3) Energy Democracy, and (4) Community Empowerment, including aspects like the reduction of energy poverty or change in power structures. Despite the broad variety of social impacts associated with ECs, there is a lack of evaluation of their real-life impact. In cases, where communities' social impacts are reviewed, evaluation reveals that those are not sufficiently provided (Bielig et al., 2022).

Hanke et al. (2021) link the Renewable Energy Community (REC) concept with the energy justice framework, based on an empirical analysis of 71 European case studies. They identify and assess potential elements in which threats to justices emerge across all three justice tenets:

(1) procedural barriers in access to information, memberships and decision-making; (2) distributional barriers regarding benefits and services, as well (3) threats to recognition justice through the lack of acknowledgement of member diversity and awareness of vulnerabilities. As Hanke et al. (2021) point out, there is a need to further analyse how REC legislation affects the accessibility towards memberships or the responsibilities towards vulnerable households. Their results (ibid.) point towards the opportunity of investing in social energy tariffing in REC, as a measure to address distributional justice within them.

In addition, Radtke and Ohlhorst's (2021) empirical results on German energy communities question the fulfilment of inter-generational equity in energy communities. Their data show low levels of diversity in community participation. They criticise that women and younger people are currently underrepresented, and communities seem to be catered to the needs of more affluent and academic households. In their reflection, they question a central aspect: the general assumption of community projects being more democratic or equitable by default does not hold.

3. METHODOLOGY

3.1. Research Framework

In our study, our primary focus lies on aspects of energy justice regarding access to ECs and the provision of distributional justice, as outlined in chapter 2.1.

An EC is a multi-stage process, and, in each stage, several aspects must be decided upon. We have chosen to concentrate on the foundational phase of ECs. We believe that during this phase, the central alignments regarding justice, diversity and inclusion are determined. From these decisions, we have selected three pivotal steps for analysis, assessing the justice dimension within these three decisions as follows:

- *Selection of members:* households can decide whether to join an EC or not. We analyse the decision-making power among household members versus their responsibilities for energy-consuming activities, with a particular focus on gender perspectives.
- *Tariff design*: the agreement on tariffs settles the intra-community benefit sharing and carry significant implications not only for the profitability and the overall distributional justice within the EC. Therefore, we reflect upon benefit sharing from the perspective of low-income and affluent households.
- *Revenue allocation*: we evaluate decisions related to the revenue sharing of surplus energy sales among EC members, as well as its implication on distributional justice thereof.

3.2. Survey design and data sampling

Our analysis is based on two survey samples conducted in Austria in 2021 and 2022. These surveys were implemented in the course of research projects[i] on Energy Communities by means of a professional online sample provider. All data was collected anonymously with the informed consent of respondents. The following sections describe both sampling processes, including

[i] *SocialLowCostFlex, FFG grant No.873524 (https://projekte.ffg.at/projekt/3307427) and DigitalEnergy4All, FFG grant No.873847 (https://www.ffg.at/laura-bassi-4.0-digitalisierung-und-chancengerechtigkeit-digitalenergy4all)*

explanatory notes on those parts of the questionnaire used for the present analyses. Both surveys aimed for a representative distribution of respondents across various age groups, genders, and educational backgrounds. Due to the online-only sampling strategy, the samples are not truly representative in terms of a reliable extrapolation on the total population. Nonetheless, the good distribution of and diversity in the above-mentioned variables provides valuable insights into the viewpoints of Austrian inhabitants, which we deemed sufficient to answer our research questions and derive recommendations.

Sample A comprises 537 respondents after data cleansing and serves as the basis for sections 4.1. and 4.3. The survey design has shown to be quite complex, as especially revenue sharing in an EC cannot be properly explained to uninformed people in a quantitative online survey. Results in section 4.1. (implications of gender roles on EC membership) comprise a sample size ranging from 331 to 352 responses, since one-person households (141), single parents (17) and multifamily households (20) were excluded. Results of section 4.1 show two limitations: the sample did not consist of male and female respondents from the same households, and our analysis assumes heterosexual relationships thereby neglecting potential diversity in two-person household relationships. Survey data did not include questions regarding relationship status in households for ethical reasons.

For section 4.3. all household types were considered, and results are based on the use of an everyday-life metaphor for a simple illustration of different revenue-sharing mechanisms, posing a limitation to our study. The example used in the survey was of a (hypothetical) neighbourhood sharing a collective vegetable patch. While each neighbour will receive a share of vegetables for their use, the community will sell the surplus vegetables. To assess the perception of fairness of revenue sharing, respondents had to rate different revenue-sharing options on a 5-point Likert scale ranging from "1 = unfair" to "5 = fair".

Sample B consists of 655 respondents living in rented apartments in Vienna and serves as the basis for our analysis in section 4.2. As ECs at the time (and still to the present date) are widely unknown to the public, there was a need for an easily understandable description of what ECs are. First, a short explanation of the concept was given within the survey, followed by introductory questions on their intent to join and general impression of the joint generation plant. To assess the perception of fair tariff designs, respondents had to rate different tariff options on a 5-point Likert scale ranging from "1 = I would reject this option" to "5 = I would support this option". To deepen the understanding of respondents' views on fairness, we included an open-ended question about their thoughts on the possibility of a social tariff, which 573 people answered.

Data collection occurred from January 26th to January 31st, 2023 (Sample A), and November 2nd to November 12th, 2022 (Sample B). Data was analysed using IBM SPSS Statistics 29.0, employing various statistical tests, including Pearson's chi-squared test (with α=0.05) and univariate ANOVA, both with and without repeated measurements (with α=0.05). The analysis of open-ended questions in Sample B was performed using MAXQDA 2020.

4. RESULTS

4.1. Decisional Power: Implications of Gender Roles

Initially, a household must decide whether to become a member of an EC. In our analysis, we explored the dynamics of decision-making within households versus the responsibilities of household energy-consuming activities under the viewpoint of gender perspectives. We consider four activities and assess whether men, women, or all household members (including children) primarily undertake these tasks.

- *Choosing supplier:* Who is (mainly) responsible for the decision on the households' electricity supplier? This task is akin to joining an EC since an EC can be interpreted as a secondary electricity supplier.
- *Purchase of new household appliances:* Who is (mainly) responsible for the decision on which new large household appliances to buy? In the context of ECs, this choice is relevant, as the number and type of large devices not only influence electricity consumption but also the flexibility of a household.
- *Set-up of new household appliances*: Who is (mainly) responsible for installing, setting up and deciding on the settings of household appliances? In the context of ECs, this task is crucial for the efficient use of appliances, especially for energy-saving and smart devices, which require knowledge of device functionalities proper settings.
- *Operation of household appliances:* Who is (mainly) responsible for the everyday use of household appliances? In the context of ECs, this role is significant for achieving general electricity savings and for optimizing self-consumption within the EC through load shifting.

1The results highlight that decision-making power is not evenly distributed among households. In all four tasks given, most households share responsibilities. Men predominantly execute two tasks: choosing electricity suppliers and setting up new household appliances. For the former, only 15.4 % of respondents state, that women are responsible, and for the latter, only 4.8 % of households entrust this to women. Conversely, when it comes to operating household appliances, only 4.8 % of respondents believe that men are responsible, while 36.1% stated that women primarily handle this task. While these results are irrespective of the survey respondent's gender, figure 1 illustrates the varying viewpoints of men and women on shared household responsibilities.

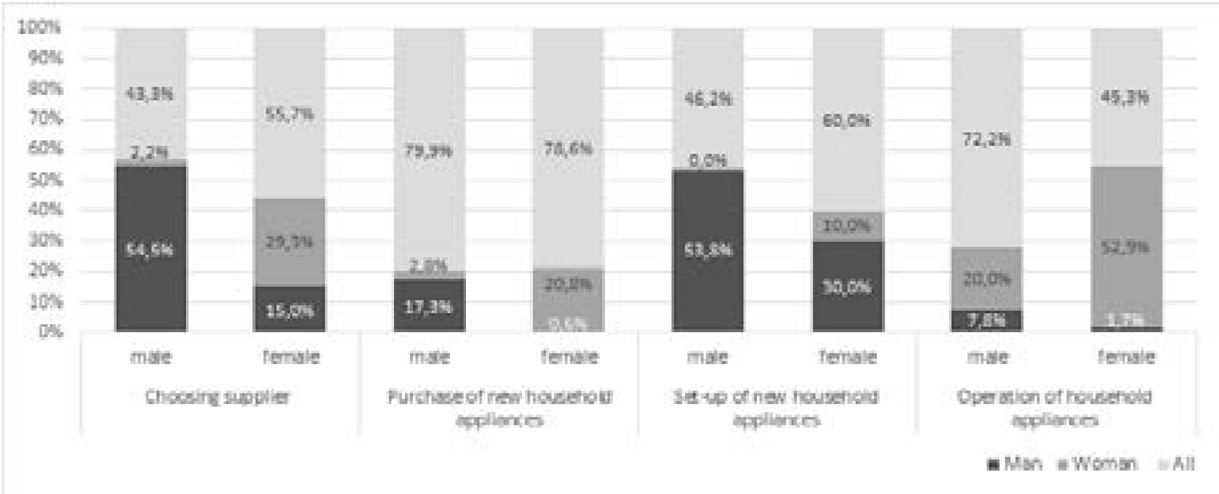

Figure 1: Agreement to intra-community tariff options (Sample B, n=655)

Examining answers based on gender reveals a clear discrepancy in the perception of household responsibilities. For instance, regarding the choice of supplier, 54.4 % of male respondents feel that they make the decision, while only 15 % of female respondents assign this task to their partners. However, 29.3% of female respondents assert responsibility for this task. This discrepancy also shows statistical significance (with $Chi^2(2)=50.069$, $p<.000$, $n=343$). Another important discrepancy shows the operation of household appliances. This is especially important when it comes to manual demand response (load shifting) to increase the possible financial benefit of an EC. Here, with 52.9%, the majority of women believe, that they are responsible themselves. Only 20.0% of men assign this task solely to their partner but more often have the feeling of shared responsibility. These findings reveal that the decision regarding the supplier (and consequently EC membership) is generally not aligned with the responsibilities for household activities, and therefore the power to implement (manual) load shifting. Our results show a discrepancy between those activities, which may lead to reduced accessibility of ECs and may cause inefficiency in the use of community-produced electricity.

4.2. Inclusiveness: Implications on low-income households

Once participants of an EC are determined, this newly formed group must reach a consensus on the mechanisms of intra-community benefit sharing – which has a severe impact not only on the profitability for each member and the community but also on distributional justice within the EC. Figure 2 presents respondents' agreement with four tariff options within the EC:

- *Social Tariff:* depending on income, some households are entitled to a reduced electricity price. No details on the income threshold were given.
- *Same Tariff for Everyone:* every member pays the same price (which is the default in ECs in Austria).
- *Free Base Amount*: members receive a certain amount of kWh for free, and any consumption beyond this limit incurs the same tariff as everyone else.
- *Progressive Tariff*: electricity price increases progressively with higher consumption.

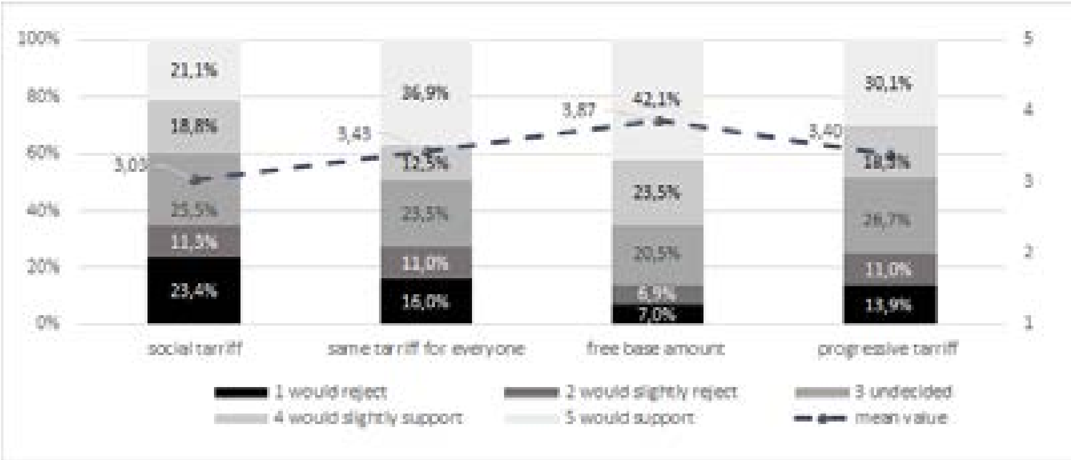

Figure 2: Agreement with intra-community tariff options (Sample B, n=655)

Across the entire sample, the results indicate that the free base amount is the most favoured option among respondents, with the social tariff option being the least favoured one. Nevertheless, for all given options, a notable percentage of respondents, ranging from 18 % to 26 %, remain undecided.

Figure 3 further demonstrates the agreement with a social tariff among different income levels, categorized into income quartiles (Q1 – Q4). The results reveal a significant decrease in approval of a social tariff as income rises. Conversely, the social tariff is most preferred among lower-income quartiles and least favoured among higher-income quartiles.

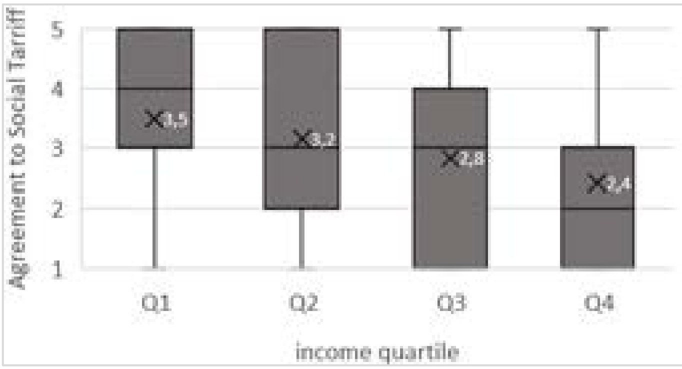

Figure 3: Agreement with a social tariff among different income levels (Sample B, n=655)

In addition to this quantitative assessment, respondents were invited to express their opinion on a social tariff through an open-ended question, to which 573 people responded. These responses provide deeper insights into the concerns of individuals disapproving of the social tariff. Out of 573 answers, one-third expressed negative sentiments. A common concern among both disapproving and approving respondents is the definition of entitlement for any social tariff and the need for continuous review. Among the negative responses, the main reason for the rejection of a social tariff is the perceived unequal treatment, cited by 61 % of those who expressed

negative comments.
While the above-presented results highlight preferences for intra-community electricity prices, we also assessed approval of the same tariff options in conventional power supply. Interestingly, agreement to a social tariff rises significantly (from a mean of 3.03 to 3.30), resulting in higher acceptance of a social tariff within conventional power supply than within the respondents' own EC.

4.3. Distributional Justice: Household Perspectives

The third choice in our analysis pertain to the revenue sharing of surplus energy sales among EC members. Figure 4 displays the respondents' ratings for all options provided. Distribution mechanisms along social gradients (that favour EC members with lower household incomes or families with many children, for example) were rated poorly in the survey. Concerning the option of preferential treatment for lower-income households, 36.5 % rated this as (rather) unfair, while 40.8 % remained undecided. Only 22.7 % regarded this option as (rather) fair. This assessment shows a relation with income levels: with rising income, this option is perceived as more unfair.

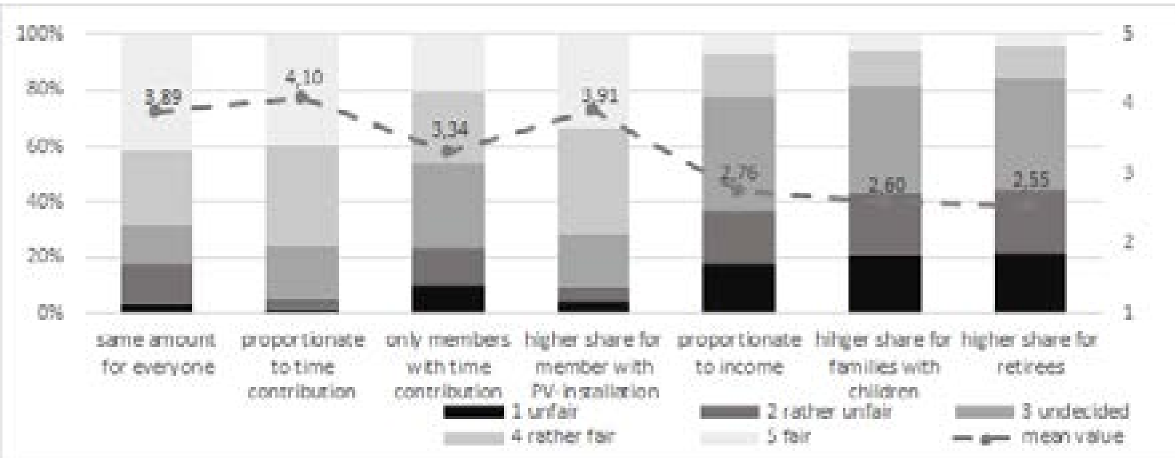

Figure 4: Perceived fairness to revenue-sharing options (Sample A, n=537)

Besides the rating of all options regarding the perceived fairness, respondents were asked to state, which option they considered the fairest. Results indicate that Austrian households primarily prefer an equal distribution of benefits (38.9 %). Secondly, they favour prosumers in distribution (25.5 %) due to their greater contribution to the community (i.e., generation technology). The third-most preferred option involves members with high commitment (e.g., contributing time to the community project) receiving a higher share (23.6 %). Within this assessment, it becomes evident, that revenue-sharing mechanisms based on social criteria are generally unwelcome among respondents. For instance, revenue sharing proportionate to income was favoured by only 4.1%. However, these results only offer a first insight into revenue-sharing preferences, as the survey was based on an everyday metaphor and not explicitly linked to ECs (see chapter 3.2.).

5. DISCUSSION

This study adds to the discussion of social aspects in accessibility and decision-making within ECs that emphasize the importance of a closer look at how societal inequalities might play into the organisation and individual versus collective decisions within ECs.

We aimed to investigate the opinion of Austrian citizens towards these choices. Our results support the findings of Radtke and Ohlhorst (2021) and Hanke et al. (2021) and show that the requirements towards an inclusive design of ECs may be set too ambitious. Our analyses reveal that unguided and narrow-focused engagement processes will hardly achieve inclusiveness.

Additionally, we emphasize this argument by highlighting potential disparities in opportunities for households to engage in ECs if community participation is officially addressed solely through contract holders. Particularly for RECs aiming to provide services like demand-side management and load shifting, which require households to adjust their behaviour patterns, understanding the impact of ECs should extend beyond the perspective of households as a whole. It should also consider dynamics within households and their members. Therefore, we identify a need for further research and adjustment in engagement practices regarding justice as recognition in ECs.

Currently, the Austrian legislative framework lacks incentives or concise mechanisms to include low-income households. Moreover, low-income households encounter the same hurdles when it comes to joining or founding an EC. Our results reveal a significant gap between the legislator's expectations regarding fairness and equality and the Austrian people's attitude towards fairness and equality within their own (hypothetical) EC. We have identified the following implications for energy justice stemming from the reviewed choices:

(1) *Selection of members*: Based on our results, men generally decide on membership in an EC and the set-up of household appliances. Conversely, women have to face the burden of operating energy-consuming household activities and optimize community self-consumption to increase savings. The discrepancy of responsibility within these tasks may hamper the exploitation of the full potential that energy communities can bring to a household.

(2) *Tariff design:* One important innovation within ECs is that members are allowed to decide on electricity prices. This poses a chance to defuse the precarious situation of many low-income or impoverished people by a preferred treatment such as through a social tariff. While such a model would still bring financial benefit to all EC members, entitled members would even benefit more. However, our results show that most ECs will very likely not seize this opportunity, as especially affluent households would not support a social tariff. Even though all members of an EC benefit from cost reduction, households that are more affluent mainly not agree to shorten their benefits to increase savings for low-income households. One finding suggests that a social tariff is not per se disagreed: if these (perceived) cuts in savings are decided upon by an external entity, the agreement rises significantly.

(3) *Revenue allocation*: A similar situation is shown with the revenue allocation of surplus energy selling. Again, ECs may decide on the use of these financial resources themselves without regulatory restrictions. This could serve as an opportunity to share revenues among social gradients. Unfortunately, these options are rated as (rather) unfair by most respondents, and especially by wealthy households. The preferred option is – as with the intra-community

benefit sharing – to share equally among all members. Interestingly, even preferential treatment for prosumers would be more welcome as a priority for low-income households. On the reasons for these preferences, further research is needed to better understand favourable distribution mechanisms.

6. CONCLUSIONS

Our findings show that achieving justice within ECs in Austria may not be feasible when these communities are solely responsible for determining intra-community benefit sharing and surplus energy selling. It becomes evident that specific requirements are essential to establish and uphold justice mechanisms within ECs. It is imperative that communities and their members are not left to navigate alone the complex task of integrating vulnerable or low-income households equitably, or deciding how benefit sharing can best serve those in greatest need. Inclusiveness and fairness within an EC would require a deep understanding of (social) inequalities, which poses another hurdle for EC members and founders. This is supported by our finding of rising acceptance of redistribution mechanisms through external decision-making bodies (e.g., government) rather than placing the entire burden on EC members themselves to achieve distributional justice. This is especially of importance to not further sharpen the rich-poor divide with the instrument of ECs, even more as they were initially constructed to fight this divide. As the rise of ECs in Austria is still to come, our findings provide a base for steering the further development towards socially just mechanisms: We recommend transparent ready-made solutions, which have already demonstrated a positive impact on inclusiveness and fairness, thus contributing to energy justice. These concepts should be readily adaptable and applicable, whether initiated by privately founded ECs as well as by energy service providers. Furthermore, the legal framework should incentivise not only inclusiveness but also more actively promote opportunities within ECs for vulnerable households.

REFERENCES

Bielig, M., Kacperski, C., Kutzner, F., & Klingert, S. (2022). Evidence behind the narrative: Critically reviewing the social impact of energy communities in Europe. *Energy Research & Social Science*, *94*, 102859. https://doi.org/10.1016/j.erss.2022.102859

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources. 2018. Retrieved September 14, 2023, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32018L2001

Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU. 2019. Retrieved September 14, 2023, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944

Dudka, A., Moratal, N., & Bauwens, T. (2023). A typology of community-based energy citizenship: An analysis of the ownership structure and institutional logics of 164 energy communities in France. *Energy Policy*, 178, 113588. https://doi.org/10.1016/j.enpol.2023.113588

Dvorak, E. (2023). Unterstützende Maßnahmen und Services für Energiegemeinschaften. In: Österreichische Koordinationsstelle für Energiegemeinschaften, Konferenz Energiegemeinschaften. Retrieved September 15, 2023, from https://www.klimafonds.gv.at/wp-content/uploads/sites/16/4_Eva-Dvorak__Koordinationsstelle-Energiegemeinschaften.pdf

EbUtilities (2023). Marktpartner-Verzeichnis. Online Request on registered RECs and CECs in Austria. Retrieved July 12, 2023, from https://www.ebutilities.at/marktpartner

Fina, B., Monsberger, C., & Auer, H. (2022). A framework to estimate the large-scale impacts of energy community roll-out. *Heliyon,* 8(7), 1-11. https://doi.org/10.1016/j.heliyon.2022.e09905

Georgarakis, E., Bauwens, T., Pronk, A.-M., & AlSkaif, T. (2021). Keep it green, simple and socially fair: A choice experiment on prosumers' preferences for peer-to-peer electricity trading in the Netherlands. *Energy Policy*, 159, 112615. https://doi.org/10.1016/j.enpol.2021.112615

Hanke, F., Guyet, R., & Feenstra, M. (2021). Do renewable energy communities deliver energy justice? Exploring insights from 71 European cases. *Energy Research & Social Science*, 80, 102244. https://doi.org/10.1016/j.erss.2021.102244

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy Research & Social Science*, 11, 174–182. https://doi.org/10.1016/j.erss.2015.10.004

Karakislak, I., Sadat-Razavi, P., & Schweizer-Ries, P. (2023). A cooperative of their own: Gender implications on renewable energy cooperatives in Germany. *Energy Research & Social Science*, 96, 102947. https://doi.org/10.1016/j.erss.2023.102947

Radtke, J., & Ohlhorst, D. (2021). Community Energy in Germany – Bowling Alone in Elite Clubs? *Utilities Policy,* 72, 101269. https://doi.org/10.1016/j.jup.2021.101269

Sovacool, B. K., & Dworkin, M. H. (2015). Energy justice: Conceptual insights and practical applications. *Applied Energy*, 142, 435–444. https://doi.org/10.1016/j.apenergy.2015.01.002

Walker, G. & Day, R. (2012). Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth. *Energy Policy*, 49, 69-75. https://doi.org/10.1016/j.enpol.2012.01.044

LIGHTNESS - ENGAGING CITIZENS COMMUNITY IN THE FUTURE OF ENERGY

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Keywords: Energy Communities, Citizen Empowerment, Local Engagement, Flexibility Services

Abstract

Citizens Energy Communities (CECs) are a powerful instrument for promoting the energy transition, putting citizens at the centre, increasing energy efficiency and tackling energy poverty. CECs are a relatively new topic and the incomplete transposition of EU provisions for CECs into national laws is putting a barrier to citizens' involvement. Beyond this, there is a lack of information and knowledge about regulation, technology and operations of CECs, urging the need for advisory centres to increase trust and raise citizens' awareness on the benefits of energy communities. In this work, an analysis of how the development of CECs can be fostered will be carried out, using as a reference the experiences gained from the EU-funded LIGHTNESS project. In the LIGHTNESS project, pilot leaders have provided the citizens involved with guidance and training to become active users within the community. In order to involve users directly, energy services can be implemented, such as demand side flexibility, to facilitate the integration of new loads and renewables, and innovative financing schemes can be set-up, such as dedicated incentives or crowdfunding, which arise as participatory tools. Furthermore, the deployment of a dashboard, that shows users relevant insights on energy monitoring, proved that digitalization is a part of the engagement process.
The aim of this paper is to fill the gap of the little attention given in energy projects to the evaluation of the impacts of citizens' engagement process, using behavioural insights and smart technologies to find innovative approaches to engage communities in a just energy transition.

1. INTRODUCTION

In the context of the energy transition towards cleaner energy production and more aware use of energy, in 2019 the European Union (EU) published the "Clean Energy for all Europeans" package (European Commission, 2019) which introduces a set of rules aimed at modifying the energy market design and the citizens energy behaviour, empowering individuals or communities to participate actively to the energy system transformation. As part of this package, the Renewable Energy Directive was revised in order to speed up the EU's clean energy transition and the Directive EU/2018/2001 (RED II) (Directive 2018/2001) entered into force in 2018. A further part of the package seeks to establish a modern design for Europe's electricity market and, through the introduction of the Electricity Market Directive EU/2019/944 (Directive 2019/944), the EU in 2019 adopted a set of common rules for the internal market for electricity, putting the consumer more at the centre of the clean energy transition and allowing more flexibility to better integrate an increasing share of renewable energy in the grid. Both Directives have among their priorities the empowerment of customers through more active involvement in the EU energy system and provide, for the first time, an enabling EU legal framework for collective citizen participation in the energy system (Caramizaru & Uihlein, 2020). Indeed both display two official definitions of Energy Communities (ECs), namely for Renewable Energy Community (REC) and Citizen Energy Community (CEC), i.e. non-commercial entities characterised by collective energy actions around open, democratic participation and governance with the primary purpose of providing environmental, economic or social benefits for its members rather than financial profits.
Regarding citizens-empowerment, ECs can play a key role for social innovation as they reflect a fundamental change in consumer behaviour. Citizens have the possibility to participate directly in the energy market, not only as "consumers" but also as "prosumers" through the promotion of self-consumption. In fact, ECs allow citizens and users to become producers and owners of plants, capable of generating economic, social and environmental value in their territory.
Despite their potential, ECs are today a minor actor in the European energy system and prosumers are not motivated enough to participate in local energy value chains due to the incomplete regulatory framework and the lack of information and knowledge about regulation, technology and operations of ECs (Rossetto, 2023; Massey et al., 2018; Steg et al., 2018).
The establishment of ECs as a pillar of the energy transition and the long term sustainability of ECs projects should primarily rely on citizens' engagement besides viable business models, innovative financing schemes, smart technologies and national regulatory support.
Citizen engagement in the energy system is a concept that is widely studied in literature, but citizens currently engaged in energy transition and specifically in local ECs are still few (Massey et al., 2018; Huttunen et al., 2022), since that recruitment of participants can still be challenging. Only in the last few years, thanks to the push of the EU, projects are being developed that collectively engage citizens in ECs, encouraging them to change their behaviour (Shortall et al., 2022). It is crucial that different projects test different engagement strategies to understand and address key challenges and hence foster citizens participation in the energy transition (European Commission, 2023).

Terras et al. (2020) proposed a market model which enables the use of the communities' flexibility; instead Martirano and Araneo (2022) and Toderean et al. (2023) explored how blockchain technology can address the problem of end-users integration in ECs and thus foster citizen engagement in two different manners, the first empowering the potentialities of a proposed power-sharing model and the latter proposing a solution that joins this technology with cooperative games. Peeren et al. (2023) investigated the potential of demand response services among local ECs in three different European countries and identified barriers and drivers that impact citizens engagement. However there is still a lack of attention in projects on social impact and specific explanation of the engagement process, as stated by Blečić et al. (2023), beyond the lack of formal assessment approaches to assess the outcomes of engagement strategies (Shortall et al., 2022).
The aim of this paper is to fill this gap, carrying out an analysis of how the development of ECs can be fostered and focusing on the description and the evaluation of the impacts of the citizens engagement process, using as a reference the experiences gained from the EU-funded LIGHTNESS project. In section 2 the project is introduced and the methodology of engagement adopted is presented; in section 3 we discuss about the role of digitalisation in the engagement process, how it enables the deployment of some innovative energy services and financing schemes that make citizen active users, and the community dashboard developed, which shows end-users insights on their energy behaviours, is presented; finally in section 4 we provide recommendations and the lessons learnt in pilots sites of the project during the training process of the citizens.

2. CITIZENS ENGAGEMENT: THE LIGHTNESS PROJECT

LIGHTNESS (market uptake of citizen energy communities enabLing a hIGH peneTratioN of renewable Energy SourceS) is a EU funded project under the Horizon 2020 Framework Programme. The LIGHTNESS project is part of those efforts for the transition from fossil fuel energy extraction towards an energy model based on renewable energy, specifically solar energy. What is special about this project is that it recognises the importance of communities. A transition of this scale will only be possible with the inclusion of all relevant actors: this means citizens, energy cooperatives, utility companies, governments of different scales, small and large businesses, etc. A diverse array of stakeholders, committed to being part of this transition, are coming together in what has come to be known as Citizen Energy Communities. It is a term that has been legally recognised by the EU, so that these different actors can form a cohesive community to advance the inclusive and just production and consumption of renewable energy. In this paragraph an overview of the project is presented, focusing specifically on the methodology of engagement of the participants.

2.1 LIGHTNESS project: an overview

LIGHTNESS main purpose is to support the various stakeholders (including residential consumers, managers/occupants in tertiary building, professionals in the smart grid sector, Energy Services Companies (ESCOs), Aggregators, Utilities, Distribution System Operators (DSOs), etc), in their efforts to become engaged in the creation and management of the CECs.

The project is based on 6 major objectives:

- Engage, motivate and educate consumers on CEC benefits
- Create a roadmap uptake of CECs in use-case countries
- Raise stakeholder acceptance via CEC impacts assessment tools
- Support the market uptake with turnkey cutting edge low-cost tech package for CEC
- Demonstrate CEC impact in real Energy Communities
- Demonstrate CEC sustainability and business models

To achieve these objectives, during the project an extensive inquiry of the regulatory and policy framework has been performed in the countries of the partners: Poland, Spain, France, Italy, Bulgaria and Netherlands (Preziosi, 2021). The methodology adopted to investigate the existing regulations for energy communities was a Regulatory Impact Assessment with a final report completed on the bases of both desk research activity and a survey performed including twelve EU countries respondents on topics related to policy and regulatory aspects of ECs, flexibility services and the use of blockchain technology. Special attention has been paid to the regulation regarding the flexibility market and the accessibility to the different actors in the energy value chain (Nikolova-Deme, 2021). Pilot sites have been deployed engaging end users and by implementing low-cost, customizable, user-friendly and secure hardware and software solutions to operate the Energy Community. For this reason a platform has been developed, resulting in a fast penetration solution with data analytics capabilities, including blockchain, Artificial Intelligence (AI) forecasting, optimization, model-predictive control and features to increase end-user engagement.

2.2 Methodology of engagement in LIGHTNESS

LIGHTNESS user engagement plans have taken into account some local requirements in its three blocks of inclusiveness (people will have a say in the decisions and system requirements that impact on them), materiality (decision makers will identify and be clear about the issues that matter) and responsiveness (organisations will act transparently on material issues). These requirements have been obtained through interviews, to implement a participatory continual improvement process, gamification services, professional workshops and roundtables. In addition, to the extent that a CEC, for its community members, fulfils various purposes – not only related to the energy transition but also related to social, social-economic and environmental goals – the engagement process will actively seek to address these as well.

The engagement in the project was based on a just recruitment plan. The objective of this plan was to organise a just process in each of the LIGHTNESS pilots that brought together a group of end-users (residents or businesses) to use and test the tool for peer-to-peer (P2P) energy trading and the tool for energy-efficiency and neighbourhoods. This group should have been as diverse as possible and preferably a good representation of the whole group from which end-users were selected in the different contexts of the LIGHTNESS pilots.

Essential for just and successful recruitment is that the 'value proposition' of the project is made fully transparent to participants right from the start.

The engagement process across the 36 months of the project, is based on eight main phases, as shown in Figure 1 (Slingerland et al., 2021a).

Figure 1 – Engagement process adopted in LIGHTNESS project

First of all, a pre-engagement analysis has been performed. In this analysis, pilot leaders established contacts with recruitment intermediaries to build small end-user co-design groups. Interviews with end-users have been performed, to define the basic characteristics of LIGHTNESS tools and create group and contextual variables of the community, to monitor the performance of the engagement process.

After the pre-engagement analysis, a recruitment phase has started. To perform the actions for this phase, some documents have been prepared, such as a recruitment plan template based on engagement principles and a participation/consent form. In this phase potential participants have been approached. They have been informed about the benefits of participating in an Energy Community and what would be expected from them during the project. After participants were found and formally involved, they received a digital web-based app to install on their mobile devices, to monitor their performance and exchange energy with their fellow community members.

During the kick-off workshop, participants shared their expectations, ambitions and worries. In addition, they have been taught how to use the app in a meaningful way. Participants were given a template to express their energy and sustainability aims.

During the midterm engagement workshop, participants shared their experiences in using the app and what were their outcomes. This feedback was very important for the final evaluation.

Then, another app has been given to the participants: the Intelligent Communities Lifecycle tool, that simulates the impact of technological interventions on energy efficiency and performance, such as installation of solar panels. This tool can help CECs to make decisions about investments into new technologies to improve their energy performance.

The final step of the engagement procedure has been the evaluation workshop, in which participants shared their experiences compared to their expectations. Information collected during the final workshop helped to formulate best practices and draw conclusions on future P2P energy trading communities.

The whole engagement process has been evaluated using the "Voicer" approach (Breukers et al., 2016), a tool previously proved useful in understanding justice issues in several local community contexts, further developed by the partner Duneworks (NL) and adapted to the context of the LIGHTNESS project. This approach is based on six main indicators: recognition, participation, distribution, capacities, responsibilities and learning (Slingerland et al., 2021b).

3. THE ROLE OF DIGITALIZATION IN THE ENGAGEMENT PROCESS

Digitalisation is considered to be an enabler for the clean energy transition (European Policy Center, 2023) and it has an enormous potential to improve the quality of life of citizens (European Commission, 2022b), since the use of data and digital solutions can improve the overall functioning of energy systems. This kind of solution can facilitate the integration of intermittent renewables by increasing flexibility in power systems, both at supply side and demand side. They can also boost energy efficiency and savings in buildings, transport and industry by enabling smart management of energy demand. Furthermore, they can contribute to the decentralisation of energy systems and empower European citizens to take active part in the energy transition by turning them into so-called prosumers.

In this new concept, in the power system of the future, the historic paradigm according to which energy production adapts to balance demand is no longer valid and the role of supply and demand will change with demand being modulated to adapt to the higher variability of renewable resources (European Commission, 2022b). At the same time the role of the citizens is changing and has gained so much attention that it is necessary to engage them as an active part of the solution. Helping consumers increase control over their energy use through new digital tools and services is included among the key actions of the EU action plan for digitalisation of energy (European Commission, 2022a).

Digital technology can help citizens make aware decisions about our energy usage: the installation of smart meters, demand-side flexibility, etc. are some of the measures that can be adopted. In particular, tracking energy consumption in homes, i.e. energy monitoring, has enormous potential for saving energy because it provides information to final domestic consumers about their actual energy consumption and the necessary changes in their habits and strategies (Etra I+D, 2023). To make this possible, citizen engagement is needed to allow the user to decide on how his energy data is used and whether they want to actively participate in the energy community (European Commission, 2022b).

3.1. The LIGHTNESS dashboard

Since digital tools, such as phone apps or platforms, can facilitate citizen engagement as well, in the LIGHTNESS project the digitalization of the community has been an important part of the engagement process and the community dashboard has had a central role. The user interface (UI) application of the LIGHTNESS platform is provided in the form of a progressive web app, which is also packaged as a mobile app available in the Apple App Store and Google Play Store, in order to further contribute to the usability, versatility and ease of access for end users. It shows EC participants relevant insights on energy production and consumption, energy price savings and energy sharing with neighbours. Providing citizens with access to data, which are collected in real time using smart meters and gathered on a central server via the internet to

make them accessible to end users, on their energy production and consumption is crucial to the success of energy communities, raising awareness about the impacts of their behaviour and highlighting the economic benefits of being part of the community (IEA, 2023).
In addition to energy monitoring, the platform includes a section to increase customer involvement and citizens co-creation in which gamification strategies are implemented, so the more the user behaves in a sustainable way the more points he will earn and thus the higher his rank will be in the community ranking in order to get rewards. The dashboard is also equipped with an interaction system via contact form. In Figure 2 an example of a view of the engagement screen of the dashboard is shown.

Figure 2 – Engagement screen with gamification widgets of the LIGHTNESS platform

3.2. Energy services to enhance flexibility

Citizens that take up the role of prosumers are able to become energy suppliers and they can provide energy to the whole EC replacing traditional energy providers, reducing energy purchase costs and employing demand-side flexibility solutions.
Demand-side flexibility is a set of energy services that allow customers or aggregators, i.e. the communities, to adapt their demand to the renewable energy generation patterns, guaranteeing the reliability and stability of the electricity system and supporting collective self-consumption while preventing costly investments. Demand response (DR) is one of the strategies included in demand-side flexibility services and it implies that end-users must have the ability to change their energy behaviour and to respond to an external signal, adapting their consumption model. So consumers are driven to shift controllable electrical loads in order to shave their load profile and match self-generation or in response to incentive payments. (Yiasoumas et al., 2023)
Energy monitoring systems and data analytics capabilities, including blockchain, smart contracts and machine-learning, enable the optimisation of DR actions and increase user engagement. But there are still barriers to the deployment of demand-side flexibility services, indeed during the LIGHTNESS project difficulties were encountered in making citizens aware of their potential role in this flexibility due to the absence of European frameworks for aggregation and the lack of incentives to participate in DR programs.

3.3. Innovative financing schemes

As already mentioned, digitalisation can contribute to the decentralisation of the energy system and to the birth of new players in the energy market. Technologies such as blockchain, which is a secure way to record transactions without the involvement of a central authority, and smart contracts, that are able to automate transactions, enable individuals to the use of innovative energy trading and financing schemes, making them participatory actors (European Commision, 2022b).

Through P2P trading schemes, prosumers can share and instantly sell excess energy produced to other EC participants, increasing trading efficiency, reducing unnecessary financial burdens and building trust among prosumers.

Regarding innovative financing tools, equity crowdfunding and lending crowdfunding are a form of collective bottom-up financing and participatory tools as well as energy community, that allow full sharing of the benefits among members. Indeed, crowdfunding platforms are not only an alternative source of funding, but also communication tools, as they allow transparency and active participation, sharing information and providing suggestions.

4. UPSKILLING CITIZENS: LESSONS LEARNT AND RECOMMENDATIONS

The establishment and development of Energy Communities in the LIGHTNESS pilot sites were not based on a pre-defined community initiative, but local ECs were facilitated by the stakeholders' community. So citizens and residents who showed willingness to join the energy project were encouraged to participate and received advice and information to upgrade their energy skills. The engagement and training process in each pilot site followed a reflexive learning approach, where feedback picked up from residents was used to improve the engagement strategy.

In the LIGHTNESS project, case studies consist of a village energy cooperative and neighbourhood energy community (ES), a multi building housing community (PL), a private multi-apartment smart condominium (IT) and two zero-energy building and renovation projects (NL). The different regulatory and policy framework allowed us to exchange best practices and provide road maps for the authorities.

In the pilot in the city of Woerden (NL) all participants are tenants in social housing, 109 households characterised by a senior age group with limited energy and digital literacy, but with a high energy awareness. During the meetings, the pilot leaders acknowledged that residents were already taking actions to reduce their energy consumption. It was during the more technical explanations of the EC features that the leaders experienced the need of speaking in a more direct and simple language in order to clearly explain energy community concepts.

A just engagement strategy departs from the recognition of different needs and aims of residents, who in the Woerden case had limited energy vocabulary. Thus, in order to achieve an adequate level of understanding to participate in the EC, pilot leaders should have the capability to adjust explanations in form (tangible) and content (comprehensible).

The growth of energy literacy, as well as digital literacy, is further supported in the shared learning process facilitated in workshops, interaction between residents straightens their bonds and sharing experiences also contributes to forging awareness raising about their individual and

community practices. Recommendation for an energy project characterised by community members with low digital and energy literacy but with high energy awareness is to deploy appropriate leaders who implement reflexive learning strategies.
Conversely, in the pilot located in the neighbourhood of Quatre Bras, in the south west of Amsterdam, 17 households, with a high level of knowledge on energy technology, actively participated in the project. There, the main barrier was the limited availability of time as their daily life is largely occupied by the family household with young children and work. So in such a case, a solution could be to have an ambassador for the group to minimise the activities needed by all members and decide the type of communication channels they prefer to use throughout the project.
A smart condominium in Cagliari (IT) was the pilot site for the Italian LIGHTNESS project, with eight households engaged in collective self-consumption from PV production. Residents had strong community ties with daily interaction and they had a varying level of prior knowledge regarding energy flows and fair distribution of energy and related costs.
Thanks to strong community ties and frequent interactions, the group facilitated a shared learning process where one resident with in depth knowledge appeared to be a successful mediator throughout the project. The resident trusted this person and therefore it helped to smooth the decision making process and energy learning of the whole group.
Condominiums represent an opportunity to form energy communities. The recommendation is to support a learning process among residents to increase their understanding of energy matters in their own household and in the whole building.
The pilot site in Alginet (ES) consisted of a local energy community of 13 single-family houses, where residents were grouped in an energy cooperative with a strong governance structure. The participants were invited to many workshops by pilot leaders where they shared examples of different existing energy communities in Spain and tried to facilitate a shared learning activity among residents to build up energy literacy. There were mixed motivations for residents to join the energy community: for some, financial drivers due to the rising of energy prices and the uncertainty caused by price fluctuations, for others, social concerns and drive innovation potential for climate mitigation. Furthermore, a clear need for information on the current regulatory framework emerged, asking know-how to implement the EC in terms of technical and legal requirements, and which organisational structure the community would be.
Learning from all engagement processes, the origin of the community is an important factor to take into account when designing engagement and upskilling strategies. While the pilot sites in Cagliari (IT) and Alginet (ES) had existing community bonds, the pilot sites in the Netherlands did not and therefore it required extra efforts to facilitate the engagement process.
An analysis on upskilling tools used in all the pilot projects found out that digital tools are good to reach broad target groups but they will not be effective in engaging residents. The importance of physical, tangible and interactive tools (including workshops and informative gatherings) lie at the core of engaging residents in energy communities. Moreover, energy literacy is the essential key to building an energy community, without the necessary knowledge people cannot be fully aware of the value proposition of an energy community, of its benefits and real impact on their use of energy in everyday life. Nevertheless, energy literacy is not a precondition to building an EC, as it emerged that a shared learning process among residents is the most

effective and nicest way for participants to build their energy skills. In some cases this learning process should have been facilitated by party leaders with strong social skills, not only to recruit participants but also to gather feedback from end users and consequently adapt communication strategies and tools, or to find the right channels to reach certain groups, such as elderly people or people with short time availability. **(**Gaglione, 2022)

5. CONCLUSIONS

In this paper, an analysis of the citizen engagement process and the innovative tools that enable end users to be active participants in the energy system was carried out by referring to the EU-funded LIGHTNESS project. A preliminary context analysis was performed, by desk research and interview with stakeholder groups, on the application and development of ECs in EU countries, where different cultural contexts and heterogeneous macroeconomic conditions are present, to tailor engagement strategies to the case studies. Then pilot sites have been deployed. Throughout the activities carried out on the pilot sites of the project, we found that:

- the origin of the community is an important factor to take into account when designing engagement and upskilling strategies: the creation of the community requires extra effort if no prior community bonds exist;
- local communities and the general public want to be informed more about ECs benefits: the knowledge gap about regulation and technology could be filled up by establishing advisory centres that can provide help in the early stage of setting up an energy project;
- physical, tangible and interactive tools, such as workshops, are the most effective way to engage residents;
- the figure of party leaders can facilitate gathering feedback from end users.

The outcome of the project reveals that citizen empowerment is a key factor to unleash ECs potential: with appropriate engagement strategies and the adequate energy literacy, citizens can be an active part of the renewable energy solution, as they can choose, produce, distribute and share their own energy. Digitalisation can be an important part of this process, as it offers powerful tools that enable the development of energy services, such as demand-side flexibility and P2P energy trading, which make end users active participants in the electricity market.
In conclusion, a just engagement process and the provision of the appropriate tools allow ECs to be accepted and to be considered a truly valid tool to make citizens active players in the energy transition.

REFERENCES

Blečić, I., Carrus, A.S., Muroni, E., Saiu, V. & Saliu, M.C. (2023). *Engagement and Inclusion Experiences for Energy Communities. An Ongoing Case Study in Cagliari, Italy*. In: Gervasi, O., et al. Computational Science and Its Applications – ICCSA 2023 Workshops. ICCSA 2023. Lecture Notes in Computer Science, vol 14109. Springer, Cham. https://doi.org/10.1007/978-3-031-37120-2_33

Breukers, S.C., Mourik, R.M., Van Summeren, L.F.M. & Verbong, G.P.J. (2016). *Giving Voice to Residents. Environmental Justice and Sustainable Transformations of Dutch Social Housing Neighbourhoods.* Eindhoven. March 2016. Can be retrieved from http://www.duneworks.nl/project-nl/stem-de-buurttransformator/.

Caramizaru, A. & Uihlein, A. (2020). *Energy communities: an overview of energy and social innovation*, EUR 30083 EN. Publications Office of the European Union, Luxembourg, ISBN 978-92-76-10713-2, doi:10.2760/180576, JRC119433.

Directive 2018/2001. *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources*. http://data.europa.eu/eli/dir/2018/2001/oj

Directive 2019/944. *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU*. http://data.europa.eu/eli/dir/2019/944/oj

Etra I+D, Marqués, A., Serrano, M. & Alacreu, L. (2023). *Landscape analysis for energy platforms/consumer applications*. FINAL STUDY REPORT, https://digital-strategy.ec.europa.eu/en/library/empowering-consumers-leveraging-digital-technology-facilitate-voluntary-energy-reductions

European Commission (2022a). *Digitalising the energy system - EU action plan*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0552&qid=1666369684560#document1

European Commission, Directorate-General for Energy, (2019). *Clean energy for all Europeans*, Publications Office. https://data.europa.eu/doi/10.2833/9937

European Commission, Directorate-General for Energy, Birch Riley, L., Kuivalainen, M. & Ktenidis, P. (2023). *Exploration of citizen engagement methodologies in European R&I projects 3.0 : consumer & citizen engagement working group*. Publications Office of the European Union. https://data.europa.eu/doi/10.2833/843591

European Commission, European Climate, Infrastructure and Environment Executive Agency, Alpagut, B., Zhang, X., Gabaldon, A. (2022b). *Digitalization in urban energy systems : outlook 2025, 2030 and 2040*. Publications Office of the European Union. https://data.europa.eu/doi/10.2926/070630

European Policy Center, Dekeyrel, S. & Fessler, M. (2023). *Digitalisation: An enabler for the clean energy transition*. Discussion Paper, Sustainable Prosperity For Europe Programme, https://www.epc.eu/en/Publications/Digitalisation-An-enabler-for-the-clean-energy-transition~4ddf8c

Gaglione, M. (2022). Policy recommendations for CECs and Flexibility uptake. Deliverable D2.6 of the Lightness Project. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5f587c3b8&appId=PPGMS

Huttunen, S., Ojanen, M., Ott, A. & Saarikoski, H. (2022). What about citizens? A literature review of citizen engagement in sustainability transitions research. *Energy Research & Social Science*, 91, 102714, https://doi.org/10.1016/j.erss.2022.102714.

IEA (2023). *Empowering people – the role of local energy communities in clean energy transitions.* IEA, Paris, https://www.iea.org/commentaries/empowering-people-the-role-of-local-energy-communities-in-clean-energy-transitions, License: CC BY 4.0

Martirano, L. & Araneo, R. (2022). *Blockchain-Based Democratic Power Sharing in Building-Scale Energy Communities*. Workshop on Blockchain for Renewables Integration (BLORIN), Palermo, Italy, 68-73, doi: 10.1109/BLORIN54731.2022.10028256.

Massey, B., Verma, P. & Khadem, S. (2018). *Citizen Engagement as a Business Model for Smart Energy Communities*. 2018 5th International Symposium on Environment-Friendly Energies and Applications (EFEA), Rome, Italy, doi: 10.1109/EFEA.2018.8617063.

Nikolova-Deme, N. (2021). *Regulatory Impact Analysis for CECs and flexibility services*, Deliverable D2.2 of the Lightness Project. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5e3d594ef&appId=PPGMS

Peeren, R., Dabhi, D. & Dalton, J. (2023). *H2020 Auto-DAN Project: Enhance the Participation of the Community to Demand Response by Providing the State-of-the-Art Technological and Policy Solution*. 2023 International Conference on Future Energy Solutions (FES), Vaasa, Finland, 1-7, doi: 10.1109/FES57669.2023.10182635.

Preziosi, M. (2021). *PESTLE Analysis & benchmarking of CEC implementations with stakeholder mapping*, Deliverable D2.1 of the Lightness Project. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5dc57e5c1&appId=PPGMS

Rossetto, N. (July-Aug. 2023). Beyond Individual Active Customers: Citizen and Renewable Energy Communities in the European Union. *IEEE Power and Energy Magazine*, 21(4), 36-44, doi: 10.1109/MPE.2023.3269541.

Shortall, R., Mengolini, A. & Gangale, F. (2022). Citizen Engagement in EU Collective Action Energy Projects. *Sustainability*, 14, 5949. https://doi.org/10.3390/su14105949

Slingerland, S., Young, J., Lutz, L., Mourik, R. (2021a). *Monitoring and Evaluation Framework*, Deliverable D5.1 of the Lightness Project. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5de23bbf8&appId=PPGMS

Slingerland, S., Young, J., Mourik, R., Lutz, L. (2021b). *Energy Communities for Just Energy Transitions on a Local Scale: Initial Lessons from the LIGHTNESS Project*. Environmental Sciences Proceedings. https://doi.org/10.3390/environsciproc2021011029

Steg, L., Shwom, R. & Dietz, T. (Jan.-Feb. 2018). What Drives Energy Consumers?: Engaging People in a Sustainable Energy Transition. *IEEE Power and Energy Magazine*, 16(1), 20-28, doi: 10.1109/MPE.2017.2762379.

Terras, J. M., Sousa, J. E., Mendes, G., Rodrigues, E., Neto, A., Annala, S., Repo, S. & Kilkki, O. (2020). *Local flexibility markets and the role of active customers and communities supporting grid system operators – DOMINOES engagement plan*. CIRED 2020 Berlin Workshop (CIRED 2020), Online Conference, 646-649, doi: 10.1049/oap-cired.2021.0181.

Toderean, L., Chifu, V. R., Cioara, T., Anghel, I. & Pop, C. B. (2023). Cooperative Games Over Blockchain and Smart Contracts for Self-Sufficient Energy Communities. *IEEE Access*, 11, 73982-73999, doi: 10.1109/ACCESS.2023.3296258.

Yiasoumas, G., Berbakov, L., Janev, V., Asmundo, A., Olabarrieta, E., Vinci, A., Baglietto, G. & Georghiou, G.E. (2023). Key Aspects and Challenges in the Implementation of Energy Communities. *Energies*, 16, 4703. https://doi.org/10.3390/en16124703

TO WHAT EXTENT ARE BEHAVIOURAL CHANGES NECESSARY TO ACHIEVE CARBON NEUTRALITY? AN ANALYSIS OF PROSPECTIVE SCENARIOS FOR THE FRENCH RESIDENTIAL SECTOR

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Abstract: *Achieving carbon neutrality requires pulling all four energy transition levers (sufficiency, energy efficiency, decarbonisation and carbon sinks). Each of these levers entails changes in behaviour, from changing individual energy-related habits to investment decisions. But how far do these lifestyle changes need to go? And to what extent are they related to sufficiency?*

This article focuses on the role of sufficiency to reduce energy demand and carbon emissions in the residential sector in France by 2050. The explanatory effects of the variation in energy demand between 2015-2050 are decomposed using a statistical LMDI-method applied to the four net-zero Transition(s) 2050 scenarios developed by ADEME (the French Ecological Transition Agency). Results show that energy efficiency is responsible for most of the energy savings in all scenarios, while decarbonisation is responsible for most of the GHG reduction in the three scenarios involving a very rapid deployment of renewable energies. Sufficiency accounts for 10-15% of the energy savings in two scenarios, thus offsetting the increase in consumption due to activity drivers (e.g. population growth) between 2015-2050. The respective impacts of different types of sufficiency (related to activity vs. use) are quantified. We conclude that sufficiency has a pivotal role in the broader energy transition as lower consumption is a necessary condition to aid widespread deployment of less carbon-intensive energies. Both types of activity-related and use-related practice changes entailed by sufficiency are needed to achieve the 2050 targets, which requires significant policy integration of sufficiency goals.

INTRODUCTION

Achieving carbon neutrality requires pulling all four transition levers (sufficiency, energy efficiency, decarbonisation and carbon sinks). Each of these entails changes in behaviour, from changing individual energy-related habits to investment decisions. But how far do these lifestyle changes need to go? And to what extent are they related to sufficiency?
These questions have been explored in ADEME's Transition(s) 2050 scenarios. This project, carried out from 2019 to 2022, illustrates the range of possible long-term options to achieve carbon neutrality in France by 2050 (Vidalenc et al., 2022), based on four coherent and contrasting scenarios inspired by the 1.5 °C scenarios of the IPCC (IPCC, 2018). A subsequent study focusing on the evolution of energy consumption and GHG emissions in the residential sector (Gaspard et. Al, 2023) provides detailed information on energy efficiency and sufficiency options in dwellings.
The present paper builds on these previous studies with a decomposition analysis of energy consumption and GHG emissions in the residential sector of the Transition(s) 2050 scenarios. The main objective of this work is to enable easy and quantified comparison of the respective importance of sufficiency, efficiency, and decarbonisation in these scenarios. After a brief presentation and explanation of the ADEME Transition(s) 2050 scenarios, the methodology used to carry out the component analyses is detailed. Results of the decomposition analysis are subsequently presented. The role of sufficiency and its behaviour-related components to reduce energy demand and carbon emissions in the residential sector in France by 2050 are then discussed.

CONTEXT: THE ADEME's TRANSITION(S) 2050 SCENARIOS

The "Transition(s) 2050" scenarios illustrate four different methods to achieve carbon neutrality in France in 2050. They share the same macroeconomic, demographic and climate change (RCP 4.5) framework. What differentiates them is the intensity with which they activate the different transition levers (sufficiency, efficiency, decarbonisation, and carbon sinks (either natural or technological); Table 1)). A Business As Usual (BAU) scenario was added to help understand the extent to which the other scenarios introduce changes compared to past trends. The BAU scenario follows an RCP 8.5 climate scenario and does not reach carbon neutrality in 2050.

	Sufficiency	Efficiency	Low carbon energy	Carbon sinks
S1	++++	++	++++	+
S2	+++	+++	++++	++
S3		++++	++++	+++
S4		++	+	++++

Table 1: Intensity of the levers of action explored in each scenario.

The storylines of the 4 scenarios are summarised as follows:

- **Frugal Generation (S1):** Major lifestyle changes allow carbon neutrality achievement without using carbon capture nor storage technologies. The growth in energy demand is coming to a halt, thanks to behavioural, organisational, and technological innovations.

- **Regional Cooperation (S2):** Society is transformed through shared governance and territorial cooperation. To achieve carbon neutrality, society is counting on a gradual but steady evolution of the economic system towards a sustainable path combining sufficiency and efficiency.
- **Green Technologies (S3):** Technological development drives the transition. Best technologies are widely accessible. Sufficiency does not fit in such a scenario.
- **Restoration Gamble (S4):** Current lifestyles are preserved with significant impacts on the environment, but society places its confidence in the ability to manage or even repair social and ecological systems with technologies. This is called a gamble, as some of the required technologies are not mature. Here again, in such a society, sufficiency is not included as a focus for transition.

Transition(s) 2050 thus enables to explore sufficiency and associated behavioural changes in S1 and S2 scenarios.

METHODOLOGY

The detailed methodology is available in the decomposition analysis of building sector Transition(s) 2050 scenarios (Ademe Enerdata, 2023).

Scope of the study

Our work focuses on the energy consumption and GHG emissions of residential buildings in their use-stage, i.e., scope 2. The analysis is done by end-use for six end-uses: heating; domestic hot water; electrical appliances (cooling, washing, cooking, IT, home automation, others); lighting; air conditioning, ventilation and auxiliaries. The study covers the period from 2015 (base year) to 2050, with intermediate time steps: 2020, 2030, 2040.

Introduction to decomposition analysis

Decomposition analysis provides a detailed understanding of the impact of various factors on energy use. It involves the decomposition of energy demand into two main components:

- **An activity effect,** that captures how changes in activity levels impact energy demand. For example, as far as heating is concerned, activity refers to the number of households and dwelling size (i.e. the surface area to be heated). For electrical appliances, activity encompasses the number of households and equipment rate. Activity thus relies on a variety of behaviour such as cohabitation patterns (i.e. number of people per household), choice of the dwelling size, or buying decisions. **Activity-related sufficiency** therefore refers to reduction in activity level.
- **A unit consumption effect**, corresponding to the amount of energy used per unit of activity. For example, for heating, the energy consumed per unit of dwelling surface in kWh/m^2. This effect can be further decomposed into an energy efficiency effect and a sufficiency effect. For instance, for an appliance such as a washing machine, use-

related efficiency will refer to improvement in the energy performance of the appliance used and the fact that households use the most energy- efficient settings, when **use-related sufficiency** will cover both changes in habits such as lowering the number of washing cycles or the washing temperature, and changes in buying practices (e.g., choosing a smaller washing machine if there is no need for a bigger one).

To capture the dynamics of carbon emissions in the scenarios, another component was added, i.e., a **decarbonisation effect**. It covers both the reduction in the carbon content of the various fuels (electricity, district heat, gas), and the electrification of heating and hot water through heat pumps.

An example of the effects analysed in the decomposition for the three main end-uses, that represent over 90% of household energy consumption and CO2 emissions, is provided in Table 2.

Effects	**Pure Activity**	**Activity-related sufficiency**	**Use-related sufficiency**	**Efficiency**
Space heating	Trend in number of households and m²/dwelling in BAU	Reduction in number of households and m²/dwelling due to sufficiency, compared to BAU	Reduction of temperature setpoint for some households	Variation of unit consumption in kWh/m² not related to sufficiency (renovation, standards, heating efficiency)
Water heating	Demography		Reduction in the hot water need (number and length of showers) and higher share of cold showers for some households	Variation in the quantity of high-efficiency equipment, progress made in improving efficiency etc.
Electrical Applicances	Trend in number of households and equipment rate in BAU	Decrease in number of households and equipment rates related to sufficiency	Reduction in the use and size of equipment	Reduction in unit consumption related to efficiency progress, greater use of ECO mode, etc.

Table 2: Example of effects included in the decomposition analysis for 3 end-uses.

Method for quantifying sufficiency factors

Sufficiency is rarely introduced in decomposition analysis in a way that makes it possible to differentiate between activity-related and use-related sufficiency. To do so, a specific method was developed as follows:

- **Activity-related sufficiency is calculated by contrast to activity levels in the BAU scenario**. Indeed, this scenario does not have any sufficiency. Therefore, any variation from that scenario that contributes to bringing activity down can be considered as sufficiency. In the calculations, this is expressed through an **activity-related sufficiency index**, calculated as the ratio between the activity index of the scenario studied and the activity index in BAU. It is equal to 1 for the scenarios without sufficiency (Table 3).
- **Use-related sufficiency is identified based on the behavioural assumptions used in the model**. This **use-related sufficiency index** is calculated in relation to the reference year (2015). For example, in a scenario in which 10% of the population voluntarily reduces the number of showers they take (20% savings) and begins taking more cold showers (30% savings) amounts to 10%*(20%+30%) = 5% savings. The value of the index is 0.95 (Table 4).

Effects			**BAU**	**S1**	**BAU**	**S1**	**BAU**	**S1**
		2015	2020	2020	2030	2030	2050	2050
Activity & Sufficiency	Millions of households	28	29.5	29.5	31.3	30.6	33.8	32.2
Pure activity	Index	1	1.05	1.05	1.12	1.12	1.21	1.21
Sufficiency of activity	Index		1	1	1	1	1	0.95

Table 3: Activity and activity related to sufficiency indices. Example for the S1 scenario.

Effects			**BAU**	**S1**	**S2**	**S3**	**S4**
		2015	2050	2050	2050	2050	2050
Efficiency & Sufficiency	Unit Cons. (kWh) (Index 2015= 1)	785 (1)	453 (0.58)	425 (0.54)	460 0.59)	474 (0.6)	354 (0.45)
Sufficiency	Index		1	0.95	0.99	1	1
Efficiency	Index	1	0.58	0.57	0.61	0.60	0.45
Share of population reducing comfort			0%	10%	10%	0%	0%
Energy savings related to the reduction in the number of showers compared to 2015			0%	20%	10%	0%	0%
Energy savings related to the share of cold showers compared to 2015			0%	30%	0%	0%	0%

Table 4: Illustration of the methodology to separate the efficiency and sufficiency effects in the variation of the

unit consumption in all scenarios.

Decomposition method

The decomposition analysis relies on the Divisia method, or Log Mean Divisia Index (LMDI) method, that was initially introduced by Ang (2000). This method was introduced to improve decomposition methods such as Laspeyres, Pasches or Laspeyres-Pasches by reducing, or even eliminating, the decomposition residual. In this paper. it was applied in annual steps or over short periods. The Divisia method considers the effect of the variation of each factor in logarithms. Using logarithms implicitly means decomposing the growth rate of the variable to be explained (e.g energy demand or emissions) in a combination of the variations in the growth rate of the explanatory variables. For example, let us consider the variation in energy consumption C expressed as:

$$C(t) = A(t) \times S(t) \times Ef(t) \#(1)$$

where t refers to the calculated year, A refers to the activity, S refers to sufficiency and Ef refers to efficiency.

The variation in consumption between $t-1$ and t, i.e., $\Delta C(t)$, is decomposed into three explanatory effects:

$$\Delta C(t) = C(t) - C(t-1) \#(2)$$

$$\Delta C(t) = Activity_{effect} + Sufficiency_{effect} + Efficiency_{effect} \# (3)$$

The various explanatory effects (activity, sufficiency and efficiency) are calculated as follows:

$$Activity\ effect = \frac{\Delta C(t)}{ln \frac{C(t)}{C(t-1)}} \times ln \frac{A(t)}{A(t-1)} \#(4)$$

$$Sufficiency\ effect = \frac{\Delta C(t)}{ln \frac{C(t)}{C(t-1)}} \times ln \frac{S(t)}{S(t-1)} \#(5)$$

$$Efficiency\ effect = \frac{\Delta C(t)}{ln \frac{C(t)}{C(t-1)}} \times ln \frac{Ef(t)}{Ef(t-1)} \#(6)$$

Periodisation

In some studies of factors driving long-term emissions trends, the decompositions have focused on the variation between the base year (e.g., 2015) and the target year (e.g., 2050) without considering any intermediate periods. As shown by Bigo (2020), this methodology may introduce some bias where some effects dominate over others, in particular in scenarios with drastic changes.

To avoid this kind of bias, we performed t he decomposition analysis on sub-periods of 10 years, and the total of the changes between the reference year and 2050 was subsequently obtained by summing up the results of the sub-periods.

RESULTS

Energy consumption

Results of the decomposition analysis for energy consumption (Figure 1) show that:

- **The efficiency effect dominates in all scenarios**, even the ones that also rely on sufficiency to reach the 2050 target. Analysis by end-uses (not shown here) shows that heating contributes most to efficiency-related energy savings.
- **In the most sufficiency-focused scenario (S1), sufficiency allows for a 15% decrease in energy consumption**, thus offsetting the increase in energy consumption due to pure activity, i.e. population growth, surface area per dwelling, equipment rates. **By contrast in S4, the sufficiency effect is negative.** This reflects the fact that, in this scenario, households have adopted behaviours that are energy intensive and go beyond BAU trends (such as a widespread use of "smart" new appliances, which drives equipment rates up).

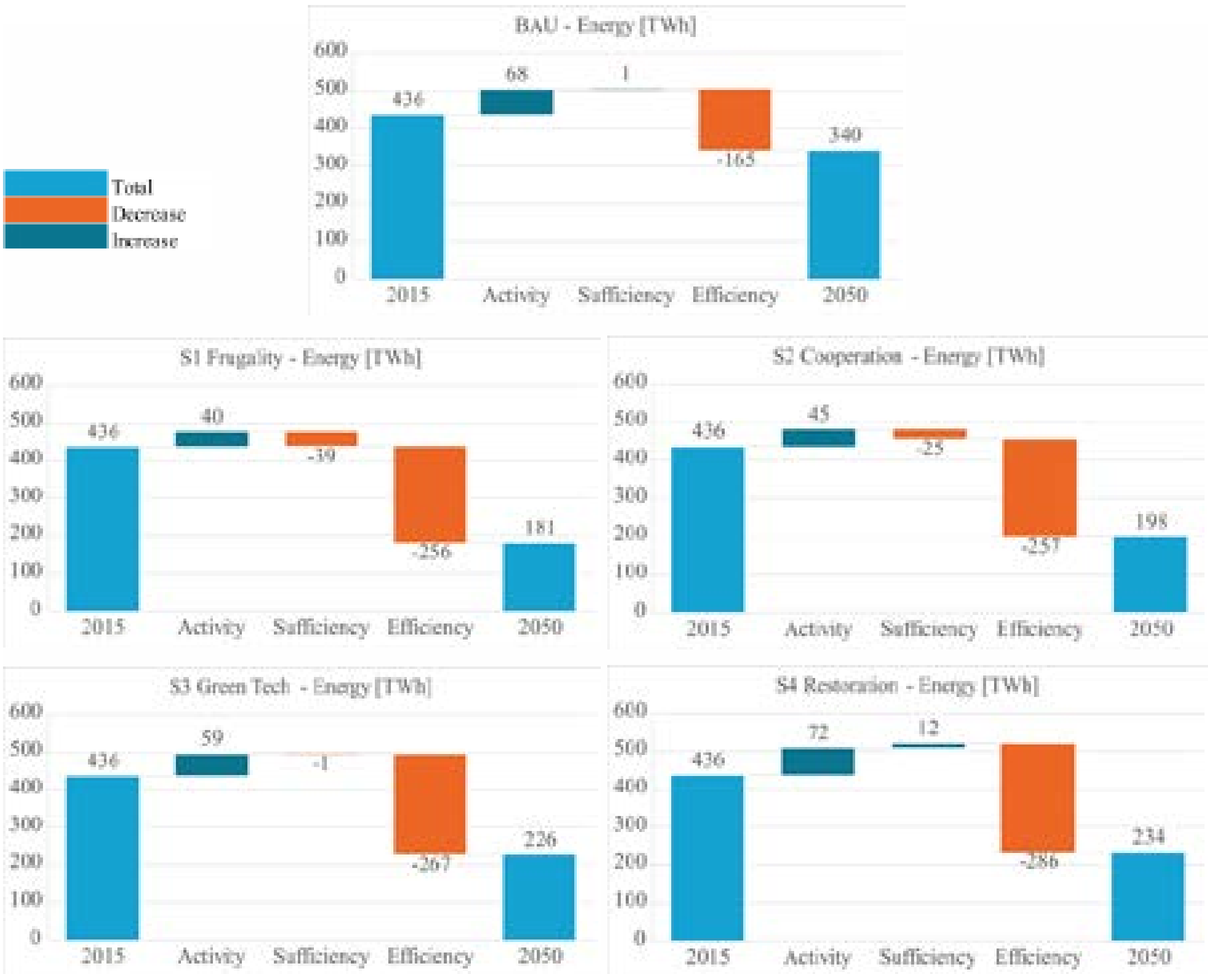

Figure 1: Results of the decomposition of energy consumption

7

GHG emissions

Results of the analysis for carbon emissions (Figure 2) show that:

- Whereas the efficiency effect came first in all scenarios as far as energy consumption was concerned, the results differ from one scenario to the next when it comes to GHG emissions. **The decarbonisation effect is the most important factor in S1, S2 and S3** (about 62% of emissions reductions between 2015 and 2050). In S4 (and BAU), efficiency and decarbonisation are of the same order of magnitude (about 53% of emissions reductions between 2015 and 2050). This reflects the fact that some dwellings using fossil fuels for heating have not been renovated in S4.
- **The effect of sufficiency on GHG emissions is weak in all scenarios**. Even in Scenario 1, which is the most sufficient one, it only accounts for 4% of emissions reductions between 2015 and 2050. This is due to a sharp decrease in energy emission factors in all scenarios: as renewable energy develops between 2015 and 2050, energy saved in 2015 saves more carbon that in 2050.

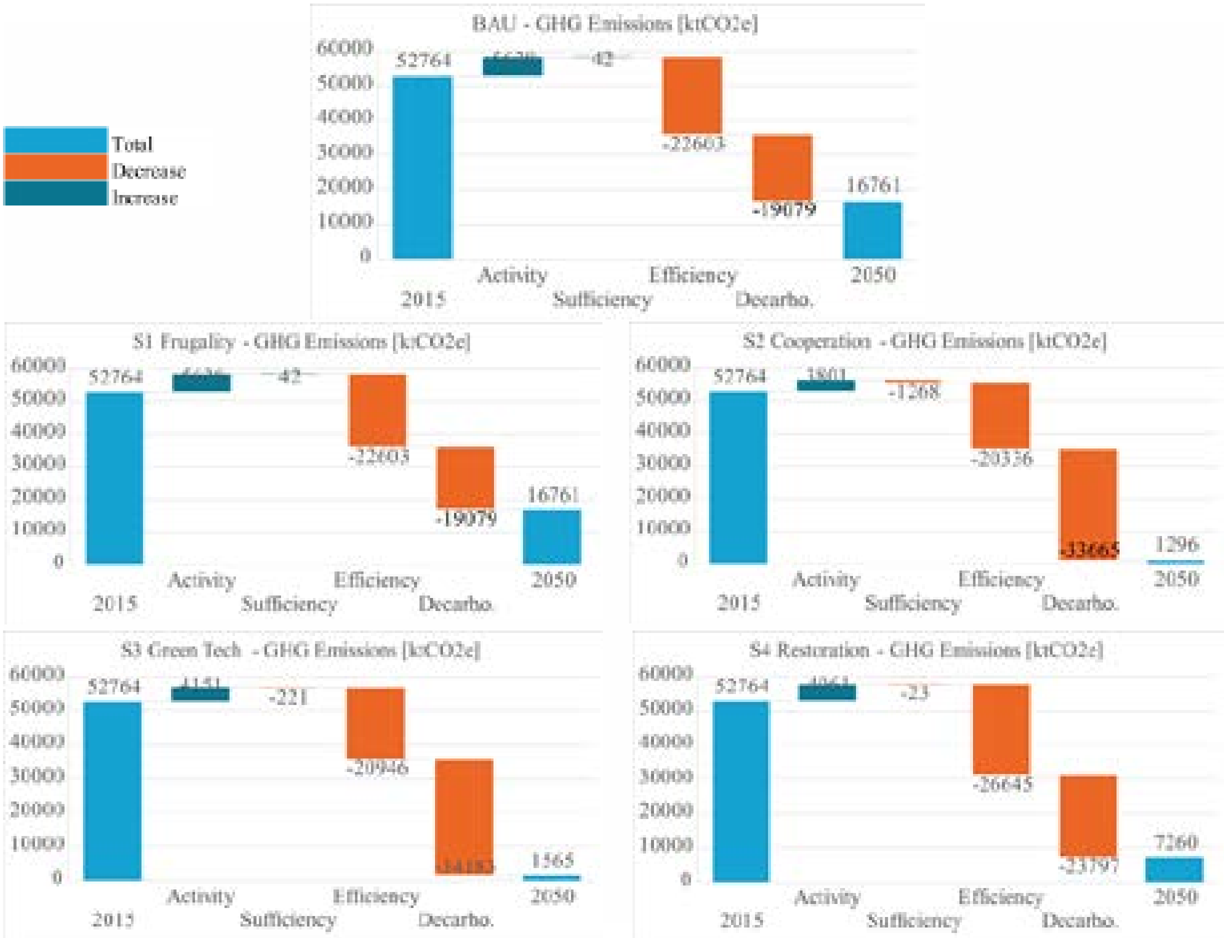

Figure 2: Results of the decomposition of GHG emissions

Focus on heating in scenarios S1 and S2

Our analysis makes it possible to compare the impact of activity-related and use-related sufficiency in the evolution of energy and carbon savings for heating in S1 and S2. It shows that (Figure 3):

- Activity-related sufficiency, i.e., greater cohabitation leading to a reduced number of dwellings, makes the greatest contribution to energy savings in both scenarios (8 TWh by 2050). Use-related sufficiency, i.e., having part of the population (up to 30% in 2030, then 10% in 2050 when all dwellings are renovated in S1) reduce their temperature setpoint, is of secondary importance in this context.
- Looking at GHG emissions in S1, results are different as use-related sufficiency is the dominating effect. This is because, in this scenario, more people adopt a lower setpoint. The energy it saves in existing buildings has a higher carbon saving impact, since new buildings have low carbon energy.

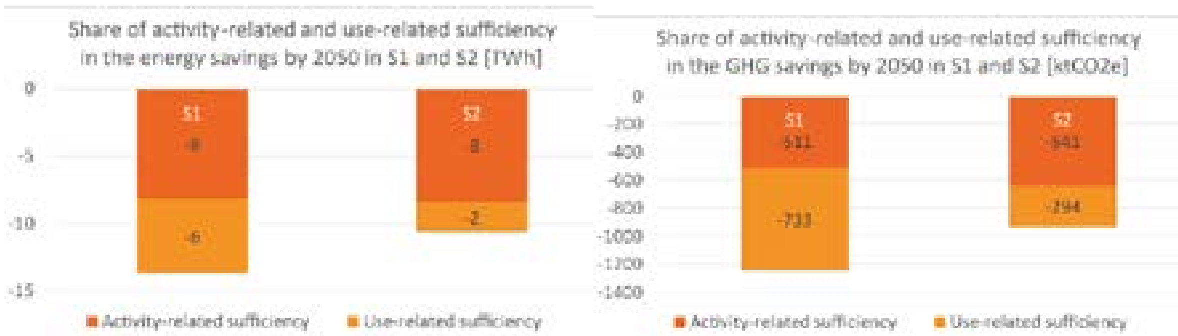

Figure 3: Share of activity-related and use-related sufficiency on heating in the (a) energy and (b) GHG savings by 2050 in S1 and S2

DISCUSSION

The results of the decomposition analysis enable the drawing of conclusions with respect to sufficiency and related practices' role in the energy transition in the French residential sector:

- **In the most sufficiency-focused scenario (S1), sufficiency represents 15% of energy savings.** Although it is not the first effect (efficiency comes first), it is nonetheless sizable. For many uses in the residential sector, sufficiency can offset the increase in consumption linked to the rise in activity (population growth). Therefore, **sufficiency-related practices need to be encouraged**.
- **Activity-related sufficiency**, i.e. greater cohabitation in housing to slow down the decline in the number of people per household and strategies to better use existing buildings to avoid new buildings, **is the first to come into play compared with used-related sufficiency.** This highlights the relevance of introducing both types of sufficiency in policies, and exploring in more detail what both types entail when it comes to behavioural change. Indeed, if use-related sufficiency has a strong bearing on everyday practices, activity-related sufficiency relies more on one-off decisions (moving when one's dwelling becomes too big, investing in the refurbishment of a

vacant home instead of building a new house…). The policy instruments needed to trigger such changes will thus differ.

- **Efficiency remains the prime lever for reducing energy consumption**. Heating is the use that contributes most to energy savings through efficiency. This result confirms the essential role of high-performance renovation in achieving energy/climate objectives. **Policies aiming at accelerating household renovation decisions are thus critical to the transition**, as sufficiency cannot, by itself, reach the 2050 targets.

Interestingly, however, when looking at carbon emissions, analysis shows that for three scenarios (S1, S2 and S3), it is the decarbonisation effect that comes first. This is due to the substitution effect (electrifying uses such as heating and hot water with heat pumps) and the very rapid deployment of renewable energies in the scenarios, resulting in a sharp drop in emission factors. This result confirms that the development of less carbon-intensive energy sources is essential if buildings are to contribute to achieving carbon neutrality.

Limits

Our study suffers some limitations, mainly:

- **It is focused on the use-stage on buildings (scope 2 emissions).** Considering scope 3 emissions (extraction, manufacturing, transport, implementation, renewal, and waste management related to the construction products), which were not calculated in the Transition(s) 2050 scenarios, may change considerably the conclusions drawn here, as they represent 33% of the sector's total carbon footprint (CSTB, 2023).
- **Its conclusions are very closely related to the hypothesis introduced in the scenarios.** For instance, as far as heating is concerned, the sufficient scenarios do not explore situations in which a large proportion of the population would reduce their setpoint temperature, as it was considered that renovation was a more relevant strategy i n the long-term. As a matter of fact, in S1, 30% of the population reduces their setpoint temperature in 2030, and then the proportion drops to 10% in 2050, when renovation of the housing stock in complete.

CONCLUSION

This study aimed at exploring, thanks to a decomposition analysis, the respective role of sufficiency, efficiency and decarbonisation in the French residential sector within the "Transition(s) 2050" scenarios.

Main findings show that energy efficiency is responsible for most of the energy savings in all scenarios, whereas decarbonisation is responsible for most of the GHG reduction, in particular in the three scenarios displaying a very rapid deployment of renewable energies. This however, does not mean that sufficiency is not a valuable vector for the energy transition. Sufficiency, efficiency and decarbonisation go hand in hand, as lower consumption enables the deployment of less carbon-intensive energies to meet demand.

Indeed, scaling up sufficiency solutions represents a relevant strategy as the analysis shows that it can offset the increase in consumption linked to population growth. This confers this lever a pivotal role in the energy transition. Both activity-related and use-related sufficiency need to be integrated in policies, meaning that all types of practice changes entailed by sufficiency are needed to achieve the 2030 and 2050 targets. They provide an additional and cost-effective avenue of flexibility in a highly-constrained and uncertain energy and environmental system. However, if use-related sufficiency policies have already been developed in France (the latest being the "Plan de Sobriété" (Sufficiency Plan) published in 2022 in the wake of the energy crisis, with the 19°C heating setpoint being at the centre of public communication), policies exploring activity-related sufficiency are still very much in the infancy.

REFERENCES

Ademe, Enerdata (2023). Analyse en composantes du volet bâtiment des scenarios Transition(s) 2050. Méthode LMDI par période appliquée au Résidentiel-Tertiaire.

Ang, B.W., Zhang, F.Q. (2000). A survey of index decomposition analysis in energy and environmental studies. *Energy (25)*, 1149–1176. https://doi.org/10.1016/S0360-5442(00)00039-6

Bigo A. (2020). Les transports face au défi de la transition énergétique. Explorations entre passé et avenir, technologie et sobriété, accélération et ralentissement. *Economies et finances. Institut Polytechnique de Paris*, 107-112. http://www.chair-energy-prosperity.org/wp-content/uploads/2019/01/These-Aurelien-Bigo.pdf

Gaspard A., Château L., LaruelleC., Lafitte B., Léonardon P., Minier Q., Motamedi K., Ougier L., Pineau A., Thiriot S. (2023). Introducing sufficiency in the building sector in net-zero scenarios for France. *Energy and Buildings(278)*, 112590. https://doi.org/10.1016/j.enbuild.2022.112590

IPCC (2018): Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, US, 3-24. https://doi.org/10.1017/9781009157940

Vidalenc, E., Bergey, J., Quiniou, V., Marchal, D. & Combet, E. (2022). Four scenarios for ecological transition: The ADEME foresight exercise Transition(s) 2050. *Futuribles(448)*,5-21. https://doi.org/10.3917/futur.448.0005

CSTB (2023). Feuille de route décarbonation du cycle de vie du bâtiment. Les propositions de lafilière.https://www.ecologie.gouv.fr/sites/default/files/Proposition%20de%20feuille%20de%20route%20de%20decarbonation%20du%20batiment.pdf

RESIDENTIAL SPACE COOLING BEHAVIOUR – RESULTS FROM A COUNTRY-WIDE REPRESENTATIVE SURVEY IN CENTRAL EUROPE

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Keywords: Space cooling, Residential behaviour, Thermal comfort, Households Survey

Abstract

Building space cooling (SC) demand has increased steadily in Europe for decades and is expected to rise even further. The CoolLIFE project aims at better understanding SC technologies, and passive, active and lifestyle measures. Literature on occupant behaviour in residential buildings with the focus on indoor air quality and heating energy use is available, while data on the penetration of SC devices and their usage, as well as indoor summer temperatures in dwellings is scarce and ambiguous. The paper presents results of a representative, multidisciplinary survey developed by engineers and social scientists that has been conducted in Hungary. The residents' interaction with SC devices and building elements to reduce their thermal discomfort, and specifically, their actions to restore thermal comfort through personal measures in summer were investigated and presented.

1. INTRODUCTION

Building space cooling (SC) demand has increased steadily in Europe, the average 10% European residential penetration rate has nearly doubled to 19% in 2022, which is expected to rise even more due to climate change (IEA, 2023). The CoolLIFE project, founded by the LIFE Programme of the European Union, aims at better understanding SC technologies and measures, including interventions on the levels of buildings, neighbourhood, and urban planning. CoolLIFE not only concerns of active space cooling technologies but aims at comprehensively addressing various aspects of SC technologies, including also passive SC measures and non-technological aspects of comfort, lifestyle, and user behaviour, together with an in-depth investigation into the economic, policy, social, and cultural dimensions associated with SC and actions that can avoid the need for space cooling.

While policies focus on energy efficiency requirements for building design, HVAC and building services, the improvement of the technological aspects alone does not guarantee the low-energy buildings that are needed to achieve the current carbon goals of our society. While climate has a strong influence on the theoretical SC demand, the actual penetration of air-conditioning devices in households not only correlates to climatic conditions, but also, to per capita GDP (Lapillonne, 2019). Occupant behaviour (OB) is one of the six influencing factors of the energy performance of a building (IEA, 2022), and the energy performance gap between the predicted and actual building performance is in the range of −38% and +96%. (Mahdavi et al., 2021). Building occupants perform various actions to satisfy their physical and non-physical needs to achieve acceptable indoor comfort, i.e open or close windows, use blinds, adjust their clothing or turning on the air-conditioning system. Increasing the knowledge base of OB interventions is hence a key factor for the successful implementation of energy efficiency strategies, including the reduction or limitation of SC demand in buildings.

Occupant behaviour in residential buildings has been in focus for space heating and also ventilation, e.g. (Schakib-Ekbatan et al., 2015) (Calì et al., 2016) (Schiela & Schünemann, 2021); however, OB studies on summer thermal comfort and space cooling are unbalanced both regionally, both regarding building types. While many studies exist in the US and in China, limited information is available for Europe. (Stazi et al., 2017) Buildings typologies with high SC dominance are more frequently covered, e.g. offices (Karjalainen, 2009). Among European countries, the study of Mediterranean cities is more frequent (Italy, Portugal, Spain) e.g. (D'Oca et al., 2014), while countries with less dominant SC demand are yet to be addressed.

Literature revealed that the occupants approach maintaining thermal comfort in summer and winter is different. For example, as opposed to setting a setpoint on the thermostat for heating, aiming for a constant space cooling temperature is not widely adopted. Instead, AC devices are operated intermittently, and several temperature thresholds might exist where residents start to take actions. (Zhang et al., 2011) A combination implementing passive measures within the adaptive comfort range is anticipated with activating SC devices only when the thresholds of unacceptable temperatures are reached. There is a growing body of research aiming at obtaining information and link comfort requirements, occupant behaviour patterns, drivers, causes and perceived effects of behavioural parameters, e.g. (Memon, 2022) (Zhang et al., 2018), (Yan et al., 2015), (Deme Belafi et al., 2018). Literature also points out the importance of obtaining information on contextual factors (e.g., available control options, social factors), to enable a more accurate prediction of occupant thermal response. (Becker & Paciuk, 2009), (Wei et al., 2010). OB in residential buildings was found to be driven by building age and characteristics, and also the level of family income influences an occupant to sustain the desired or comfortable indoor environment. (Memon, 2022). While the occupant's role in the building energy use has been researched by engineers for decades, specialists with behavioural and social science backgrounds are underrepresented in the field (Deme Belafi et al., 2018).

The current work has been done by a team of engineers and social scientists to address the multidisciplinary approach that is needed to identify OB patterns, and gather information on not only the occupant behaviour, but technical aspects and the sociocultural background of the respondents. The composition of the survey has been developed to address the following aspects:

1. What are the main daily household activities related to space cooling and how do they differ in different dwellings?
2. What is the combination of factors that influence the space cooling behaviour on individual and household levels and how they differ across dwellings?
3. What are the characteristics of groups that are less committed to energy-conscious space cooling practices?

As a first step, the research concentrates on the presence of SC infrastructure in dwellings, together with the preferred temperatures, and the extent the inhabitant's implement different passive and lifestyle measures in achieving these. The paper summarizes i.) what drives the occupants in changing their thermal environment ii) what temperatures are maintained during summer, and to what extent are they satisfactory; iii) finally, how are these temperatures maintained: to what extend are SC devices and measures installed, and how are they used in the dwellings. The findings of this study can serve as a baseline for further research on the topic of how to limit and avoid the needs for the growing space cooling energy demand.

2. SPACE COOLING IN HUNGARY

Hungary can be characterized by an average 80 cooling degree days (CDD), which is the 10th largest CDD among EU countries, and is close to the average value of 74.5 considering the whole EU (Eurostat, 2023). When energy performance prediction is considered per the EPBD implementation 7/2006 (V.24.) TNM Decree, the summer comfort requirements can be met without space cooling in residential buildings by meeting the requirements for the limits of overheating, however, if overheating temperature difference limit is exceeded, space cooling needs to be considered with a constant temperature of 26 °C. Additionally, 23-26 °C has been defined as the acceptable temperature range. Hence, Hungary is a good example of a country where SC in residential buildings could be limited and avoided with careful planning and conscious operation, relying on personal actions and user behaviour. However, the air-conditioning penetration rate in dwellings is constantly rising. The estimated penetration was around 3% in 2010 (ENERDATA, 2013), which rose to 26.54% in 2022 (KSH, 2022). In 2018 the Enable.EU project conducted a surveyed confirming 11% AC penetration rate, in line with the statistical data at that time (Galev & Gerganov, 2016). Occupant behaviour in residential buildings in summer has not yet been surveyed on the large scale in Hungary, except for the actual summer temperatures in the dwellings, covered by the Enable.EU project. Hence, there is no representative data on how occupants approach SC and summer thermal comfort needs.

3. METHODOLOGY

A nationally representative survey was conducted, covering external (e.g. infrastructure) and internal factors (e.g. attitudes and habits) that affect both individual and collective space cooling behaviour, thus providing an insight into the factors that influence individual and collective decision-making. For specific topics (energy consumption patterns and everyday space cooling practices), the possible gender-specific perceptions were given special consideration. The questionnaire comprised 75 questions in 5 sections and was to be completed in 20 minutes. Five interrelated topics were addressed:

1. Patterns of energy demand, energy efficiency, and energy use in everyday situations (e.g. home office, use of smart meters, etc.), with a focus on space cooling;
2. Schedules of occupancy, differentiated by weekdays and weekends; The temporal resolution of occupations and practices;
3. Space cooling related comfort requirements; Thermal comfort and practices, including coping strategies with hot weather;
4. Location and characteristics of dwelling: housing type and size, tenure; insulation of dwellings, space heating and space cooling systems, and availability of smart meters;
5. Characteristics of households: socio-economic characteristics as gender, age, education level and financial situation.

The majority of the questions were multiple choice, with some open questions, and also several Likert scale questions (1 = strongly disagree, 5 = strongly agree) were used to capture respondents' opinions. To ensure the same survey can be replicated in further countries in the future, the questionnaire was prepared in English, which was then fully translated to Hungarian. The pilot phase of the survey took place in early April 2023. The final data collection lasted one month between mid-April and mid-May 2023. The survey was conducted online using a pool of 165,000 possible respondents from a survey panel of a market research company. The panel was created using incentives to reward participation in the survey. Unique personal links were sent to the respondents of the panel. The sample consisted of residents 18 years and older. A quota sample was used with a combination of age, gender, education, region (NUTS1) and settlement type. Respondents were selected randomly. The response rate was high: 99.9% of the respondents completed the entire questionnaire.

4. RESULTS

The survey results cover a wide range of factors that determine preferences and choices at both the individual and household level in order to understand the socio-cultural, economic and technological factors that influence the everyday practices of citizens regarding the topic of SC, which cannot be fully presented in the current paper. A first selection of the results has been done, to include the SC infrastructure available to the occupant, and their behaviour in using it.

4.1. Triggers of changing indoor temperatures in summer

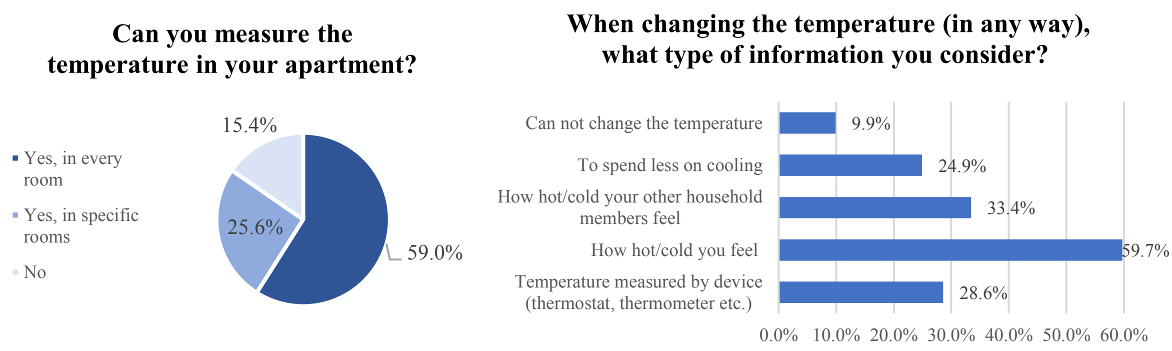
Nearly 85% of the respondents can measure the temperature in their dwellings at least in one of the rooms, however, only 28.6% of the respondents take the measured values into account when initiating a temperature change in the room. The majority of the respondents change the temperature based on how they or their household members feel, instead of considering the measurement data. (Figure 1)

4.2. Actual temperatures in the dwellings and satisfaction with these

The usual temperature in the dwellings was asked during typical day of July, when no one at the household is on holiday and everyone carries out their everyday activities for three occupancy scenarios. (Figure 2) The mode (25°C) and median values (24°C) are the same for daytime, independently of household members being at home or not. The temperatures show a higher diversity at night, the mode value is 20°C and the median value 22°C. The temperature distribution in the dwellings has not changed significantly compared to the results of the Enable.EU project in 2018.
The means of satisfaction with the temperatures was also surveyed, scores were given between: 1=very uncomfortable - 5=very comfortable. The actual temperatures indicated by the respondents were compared with their response on how satisfied they felt with the temperature in their dwelling. (Figure 3). Calculated means of the scores show that all in all up to 24 °C the temperature is considered neither comfortable nor uncomfortable, mean values are close to the middle of the scale. Specific differences, however, reveal that a temperature of 18 °C is considered rather comfortable when household members are at home – both at daytime and at night – as the average is above value 3 in these cases. A turning point can be detected at a temperature of 25 °C since the average scores of feelings of comfort decline sharply from this point on as the temperature rises. This value is lower than what is indicated as the upper limit of the thermal comfort range in the comfort standards.

4.1. Passive space cooling techniques applied in the homes

comfort. Almost everyone (97.1%) applies wearing lighter clothing but opening or closing of the windows (86.0%) and shading (82.7%) also prove to be wide-spread techniques. Also, a relatively higher share of the respondents mentioned moving less, resting (76.1%) and taking a cold shower or bath (69.6%). (Figure 4) A high portion of respondents indicated that they use shading during hot days. When narrowing down the answers to the portion of households that have some type of movable shading (89% of all households), 84% of them use it, while 16% responded not to use their movable shading it on hot days. Occupants also take several actions before leaving home: nearly 70% of the respondents shade their windows, but only around 45% closes the windows, followed by 26.9% who turn off the fans.



a) b)

Figure 1. a) Presence of measurement devices in the dwelling b) Information considered when taking actions

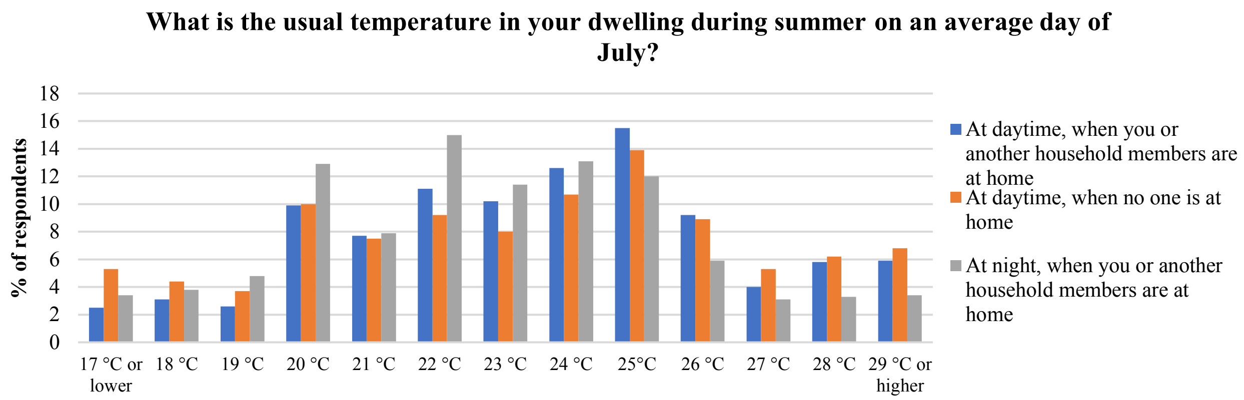


Figure 2. Usual temperatures in the dwelling during summer on an average day of July, when no one at the household is on holiday and everyone carries out his/her everyday activities. (If different in specific rooms, the coldest is indicated)

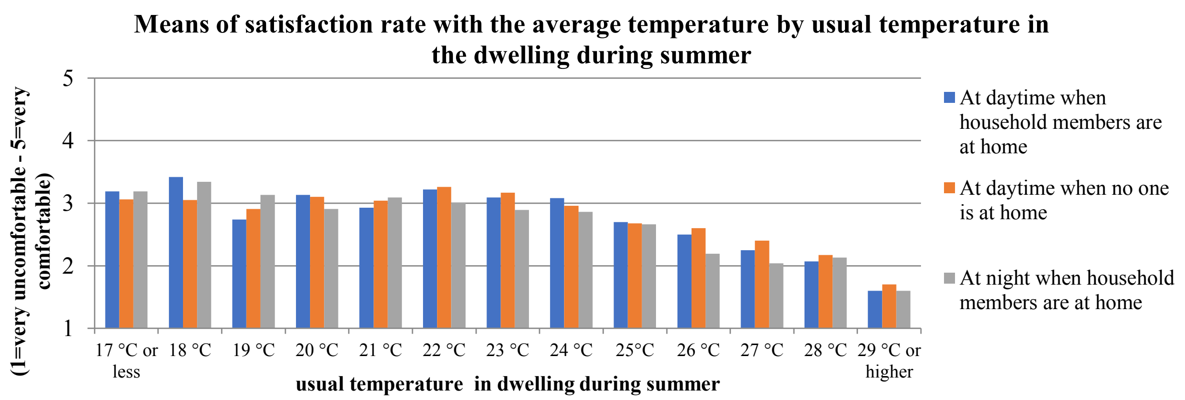


Figure 3. Means of satisfaction rate with the average temperature by usual temperature in the dwelling during summer

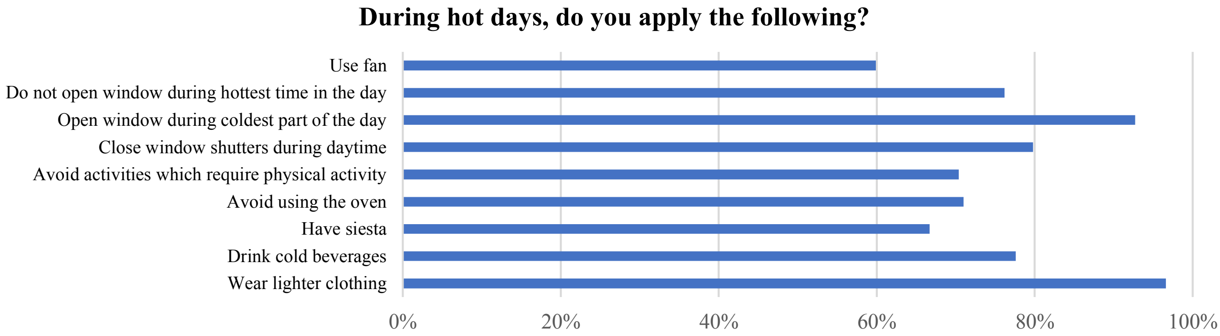


Figure 4. Behavioural measures applied in the households during hot days

4.1. Air-conditioning penetration and use

The questionnaire included answer possibilities for three types of space cooling devices in the multiple-choice question: combined space cooling and space heating devices, air conditioners for space cooling and portable air conditioners. The proportion of dwellings equipped with any kind of air conditioning units is 37.07%, and the highest share is for combined heating and cooling devices (27.3%). (Figure 5) However, when comparing the results of ownership and the use of air-conditioning devices, some inconsistencies were found in the answers for 5.35% of the respondents, all of those who have indicated to have portable air conditioning devices.

The use of the devices is mainly driven by personal comfort, activated when occupants feel warm (52.9%), while further 42.2% answered that they limit the use of SC devices to cases of extreme heat. (Figure 6a) In the "Other" category, 1.87% added they never use the air-conditioning, despite being installed.

As for the habits of the air conditioning use, the highest proportion of the respondents (33.8%) use air conditioning only during the warmest part of the day, but an essentially same rate (33.5%) tends to use air conditioning according to their comfort with an attitude to rather switch it on and off from time to time. (Figure 6b) The air conditioning is used only until the dwelling cools down to the set temperature in the case of 30.0% of the respondents, but a 13.5% operate the device all day, or most of the day. In contrast, 5.6% of the cases do not use the air conditioning during the day, 2.37% in the "Other" indicated a custom response that they use it in the evening or at night, before going to sleep.

The majority of the respondents adjusts the air conditioning to a fixed temperature (53.7%), and the rest of the sample (46.3%) controls it depending on the outside temperature.

From those who apply a fixed temperature, the majority of the respondents indicated that they set the SC device to a temperature between 22-25°C namely: 24°C, 23°C, 25°C, 22°C has been indicated by 20.9%, 17.5%, 17.3%, 16.6% of the respondents respectively. However, a number of people mentioned rather low temperature values below 20°C (7.7%) and value up to 28°C. (Figure 7a) From those, who select temperatures based on the difference of external and internal temperatures, the highest difference was 20 °C, while the most popular responses were 10 °C, 5 °C, 8 °C and 15 °C. (Figure 7b)

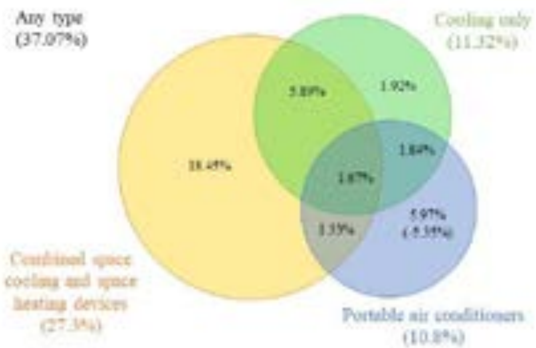
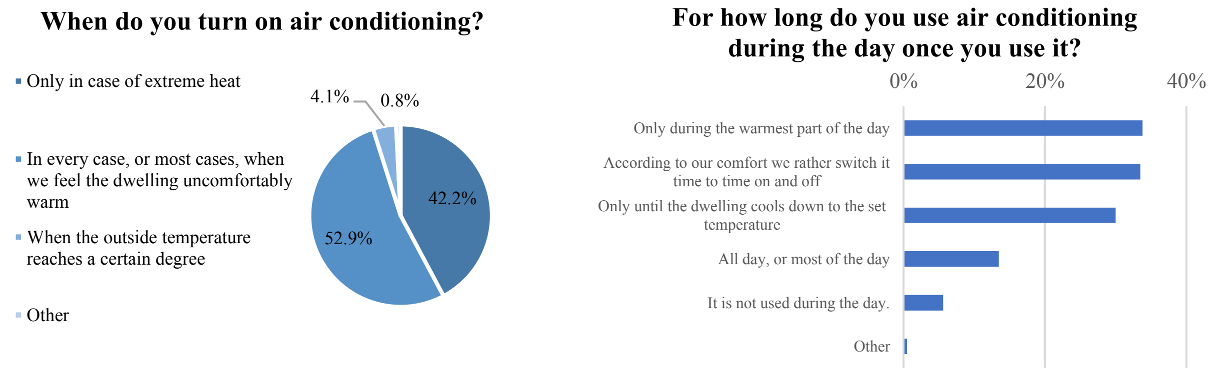
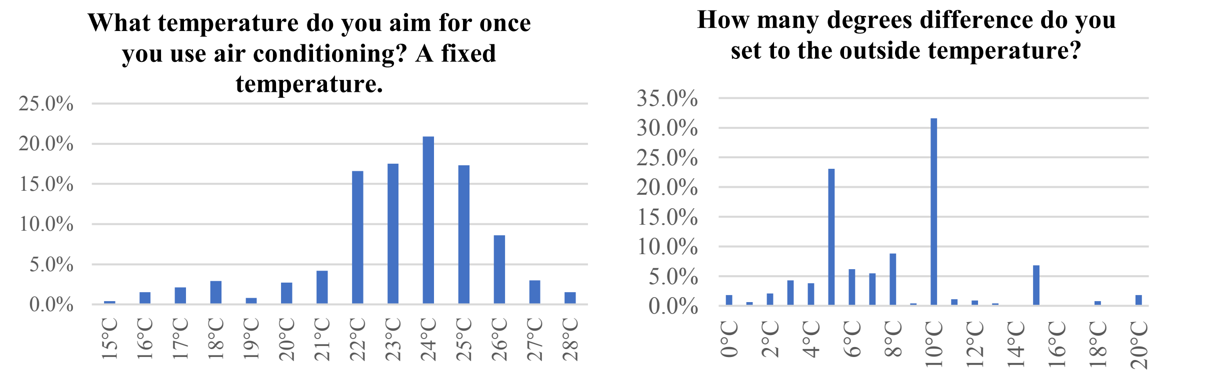


Figure 5. Percentage of dwellings with air conditioning



a) b)

Figure 6. AC usage: a) Triggers of actions for turning on air-conditioning, b) Length of time using air conditioning



a) b)

Figure 7. The preferred indoor temperature setpoint a) when setting the air conditioner on a fixed temperature b) when defined by a temperature difference compared to the outdoor temperature

When the respondents were asked what actions they take before leaving home, the majority said they switch the device off, while some respondents only change the temperature setpoints. These latter indicated temperatures in a range of 15 °C-28 °C, values that were from 4 °C lower up to 3 °C higher than what was indicated as a setpoint by the same respondents, when at home, as seen above.

5. DISCUSSION

The portion of the air conditioning equipment in households was found to be higher than the statistical values found in the literature, however, still much lower than the theoretical maximum of 69.4% calculated based on the country specific CDD values. (Jakubcionis & Johan, 2017). (Figure 8)

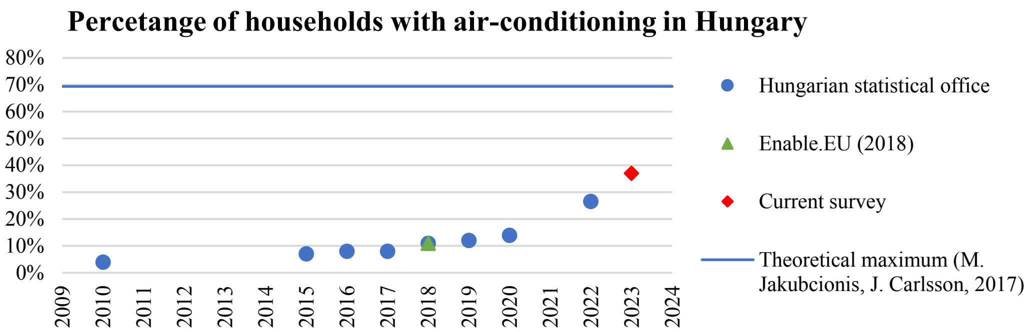


Figure 8. Percentage of households equipped with some type of air-conditioning (ENERDATA, 2013) (KSH, 2023) (KSH, 2022) (Galev & Gerganov, 2016) (Jakubcionis & Johan, 2017)

There are several assumptions for the reasons of this. Firstly, the most recent values in the literature are from 2022, already showing a rising percentage of dwellings with AC compared to the 2020 data. This can be explained by the effect of the increased occupancy of residential buildings during the pandemic. Since 2022, due to the energy crises, a disproportionate rise in the Hungarian domestic gas and electricity prices was experienced, steering the residents towards electricity instead of gas. While this trend was driven by the rising heating energy costs, it has also led to a 5-10 times higher customer demand towards combined heating-cooling equipment, which investment were not viable in the previous economic environment. Consequently, it is reasonable to assume that the amount of SC equipment in households has also risen steadily in the last year. Secondly, when using the terminology of air-conditioning equipment in homes within the statistical surveys, only a general "air-conditioning" had been considered. In the current survey the three most widespread equipment types had been included, which might have captured answers that remained hidden previously. Nevertheless, some responses might not cover reality, due to not understanding, or misunderstanding the abstract notions for energy systems used in the questionnaire. (Börcsök et al., 2020) Finally, the survey has been completed via internet. The sample is thus representative of households with internet access. According to the National Media and Communications Authority, (Nemzeti Média- és Hírközlési Hatóság, 2022) 15% of households does not even have a mobile internet connection by 2022. Among households without internet access, households in small villages, with uneducated head of the family and with an older age composition are overrepresented. This segment of households is therefore underrepresented in the sample.

Regarding the indoor temperature values, the mode and median values for the actual temperatures in the dwellings are within the comfort ranges that are indicated in the EN16798 standard, and also the values considered in the energy performance calculation for Hungary. The nighttime temperatures are however lower than the standard values and the satisfaction with the indoor temperatures also shows that people tend to find environments even cooler than the standards comfortable. As the majority of the households do not have any air conditioning devices it is confirmed that these values are reached by passive measures, possible do to the high application of window opening at night.

The setpoint temperatures for the majority of respondents, who use the air conditioning, was indicated to be between 22-26 °C, resulting in an average temperature of 22.67 °C and the median is 23 °C. While these values are within the comfort range, they are lower than the values used in energy calculations for the energy performance certificates. Additionally, the respondents have indicated setpoint values in a much wider range of, between 16 °C and 28 °C. Despite aiming for the given temperatures, only a small portion of the respondents use the mechanical SC devices all day, which is in line with the findings in the literature that AC devices are operated intermittently, in contrast to how heating is operated, and how cooling is considered in energy predictions. Also, in the majority of the cases it is justified that some setback in the setpoint temperature is applied when the building is unoccupied, however, also precooling the home while being away is applied to some extent.

6. CONCLUSIONS

The current work has been done by a team of engineers and social scientists taking a multidisciplinary approach towards surveying space cooling related occupant behaviour in dwellings in Hungary, covering a wide range of questions. The results presented here were limited to the penetration of SC devices in dwellings, their usage patterns, implementation of active, passive and user behavioural measures, together with the achieved temperatures and satisfaction with those. The results show that the majority of the occupants prefer temperatures that are within or lower than the comfort standard range, however, these are achieved mainly by passive means. The penetration of mechanical space cooling devices in dwellings has been measured to be higher than the estimations and statistical data retrieved from previous studies, which can be mainly associated with recent socio-economic trends, as well as the more detailed questioning methodology.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Becker, R., & Paciuk, M. (2009, 5). Thermal Comfort in Residential Buildings – Failure to Predict by Standard Model. *Building and Environment, 44*(5), 948-960. https://doi.org/10.1016/J.BUILDENV.2008.06.011

Börcsök, E., Ferencz, Z., Groma, V., Gerse, Á., Fülöp , J., Bozóki, J., . . . Horváth, Á. (2020). Energy Supply Preferences as Multicriteria Decision Problems: Developing a System of Criteria from Survey Data. *Energies, 15*(13), 3767. https://doi.org/https://doi.org/10.3390/en13153767

Calì, D., Andersen, R., Müller, D., & Olesen, B. (2016, 7). Analysis of Occupants' Behavior Related to the Use of Windows in German Households. *Building and Environment, 103*, 54-69. https://doi.org/10.1016/J.BUILDENV.2016.03.024

Deme Belafi, Z., Hong, T., & Reith, A. (2018). A Critical Review on Questionnaire Surveys in the Field of Energy-related Occupant Behaviour. *Energy Efficiency, 11*(8), 2157-2177. https://doi.org/10.1007/s12053-018-9711-z

D'Oca, S., Corgnati, S., & Buso, T. (2014, 9). Smart Meters and Energy Savings in Italy: Determining the Effectiveness of Persuasive Communication in Dwellings. *Energy Research & Social Science, 3*(C), 131-142. https://doi.org/https://doi.org/10.1016/j.erss.2014.07.015

ENERDATA. (2013). *Share of dwellings with air conditioning.* Retrieved 06 23, 2023, from https://entranze.enerdata.net/share-of-dwellings-with-air-conditioning.html

Eurostat. (2023, 02). *Heating and cooling degree days - statistics*. Retrieved from Eurostat: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Heating_and_cooling_degree_days_-_statistics#Heating_and_cooling_degree_days_by_EU_Member_State

Galev, T., & Gerganov, A. (2016). *D4.1 | Final report on comparative sociological analysis of the household survey results.* ENABLEING THE ENERGY UNION. Letöltés dátuma: 2016. 01 11, forrás: http://www.enable-eu.com/wp-content/uploads/2018/02/ENABLE.EU-D4.1.pdf

IEA. (2022). *Residential behaviour changes lead to a reduction in heating and cooling energy use by 2030*. Retrieved 02 10, 2023, from https://www.iea.org/reports/residential-behaviour-changes-lead-to-a-reduction-in-heating-and-cooling-energy-use-by-2030

IEA. (2023, 06 16). *Share of population living in a hot climate, 2022, and penetration of air conditioners, 2000-2022*. Retrieved 07 25, 2023, from https://www.iea.org/data-and-statistics/charts/share-of-population-living-in-a-hot-climate-2022-and-penetration-of-air-conditioners-2000-2022

Jakubcionis, M., & Johan, C. (2017). Estimation of European Union residential sector space cooling potential. *Energy Policy, 101*, 225-235. https://doi.org/http://dx.doi.org/10.1016/j.enpol.2016.11.047

Karjalainen, S. (2009, 6). Thermal Comfort and Use of Thermostats in Finnish Homes and

Offices. *Building and Environment, 44*(6), 1237-1245. https://doi.org/https://doi.org/10.1016/j.buildenv.2008.09.002

KSH. (2022). *Népszámlálási adatbázis*. Retrieved 10 10, 2023, from https://nepszamlalas2022.ksh.hu/adatbazis/

KSH. (2023). *14.1.2.9. A tartós fogyasztási cikkek éves átlagos állománya régió és településtípus szerint [100 háztartásra jutó darab]*. Retrieved from KSH.hu: https://www.ksh.hu/stadat_files/jov/hu/jov0049.html

Lapillonne, B. (2019. SEPTEMBER 26). *The Future of Air-Conditioning*. Forrás: Enerdata: https://www.enerdata.net/publications/executive-briefing/the-future-air-conditioning-global-demand.html

Mahdavi, A., Berger, C., Amin, H., Ampatzi, E., Andersen, R., Azar, E., . . . Verbruggen, S. (2021, 3). The Role of Occupants in Buildings' Energy Performance Gap: Myth or Reality? *Sustainability, 13*, 3146.

Memon, L. (2022, 9). *A Review of Methods for Examining Behaviours of Occupants in Residential Buildings.*

Nemzeti Média- és Hírközlési Hatóság. (2022). *Az elektronikus hírközlési piac fogyasztóinak vizsgálata - Internetes felmérés 2022.* Retrieved from https://nmhh.hu/dokumentum/237510/nmhh_internetes_felmeres_2022.pdf

Schakib-Ekbatan, K., Çakici, F., Schweiker, M., & Wagner, A. (2015, 1). Does the Occupant Behavior Match the Energy Concept of the Building? – Analysis of a German Naturally Ventilated Office Building. *Building and Environment, 84*, 142-150. https://doi.org/10.1016/J.BUILDENV.2014.10.018

Schiela, D., & Schünemann, C. (2021, 8). *Window Ventilation Behavior for Overheating Evaluation: Residents' Survey and Derived Ventilation Profiles.* https://doi.org/10.11113/ijbes.v8.n3.852

Stazi, F., Naspi, F., & D'Orazio, M. (2017). A Literature Review on Driving Factors and Contextual Events Influencing Occupants' Behaviours in Buildings. *Building and Environment, 118*, 40-66. https://doi.org/https://doi.org/10.1016/j.buildenv.2017.03.021

Wei, S., Buswell, R. A., & Loveday, D. (2010). *Probabilistic Modelling of Human Adaptive Behaviour in Non-air-conditioned Buildings.*

Yan, D., O'Brien, W., Hong, T., Feng, X., Burak Gunay, H., Tahmasebi, F., & Mahdavi, A. (2015, 11). Occupant Behavior Modeling for Building Performance Simulation: Current State and Future Challenges. *Energy and Buildings, 107*, 264-278. https://doi.org/10.1016/J.ENBUILD.2015.08.032

Zhang, H., Arens, E., & Pasut, W. (2011). Air temperature thresholds for indoor comfort and perceived air quality. *Building Research & Information, 39*(2), 134-144. https://doi.org/http://dx.doi.org/10.1080/09613218.2011.552703

Zhang, Y., Bai, X., Mills, F., & Pezzey, J. (2018, 8). Rethinking the Role of Occupant Behavior in Building Energy Performance: A Review. *Energy and Buildings, 172*, 279-294. https://doi.org/10.1016/J.ENBUILD.2018.05.017

SUPPORTING FACILITY MANAGERS FOR BOOSTING ENERGY PERFORMANCE: A LIVING LAB APPROACH

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Keywords: Facility management (FM), Energy performance, Behavioural interventions, Living lab, Energy savings

Abstract

Facility managers (FM) may have a relevant impact on the actual energy performance of buildings. They influence energy performance by deciding about default settings of building technology, maintaining technology and infrastructure, monitoring their performance, and reacting to user demands. In an ongoing project for the German Federal Environment Agency, the factors are explored that shape FMs current approach towards energy performance through low-invest and behavioural interventions. Among those are client and user expectations, motivation, knowledge, and organisational routines and roles. In an adapted living lab approach, we therefore cooperatively develop and examine innovative socio-technical measures or instruments with FM from six facilities of different sectors (education, economy (hotels), health (hospital and nursing home) in real-world contexts (experiments). In this paper, we present the mid-term evaluation findings which show a high motivation of the FM staff but at the same time manifold structural and knowledge constraints. Based on these findings we conclude on needed conditions and structures to successfully engage facility managers in energy efficiency measures development and implementation for the German situation.

1. INTRODUCTION

Given the growing importance of building energy use in addressing climate change and CO2 reduction initiatives, implementing energy-saving measures has become imperative. Although research on building owners and users exists, less has been explored concerning the socio-technical and behavioural aspects of those actors who stand as intermediaries between owners and users. These include facility management (FM) actors and their energy management practices.

Due to the complex building and technical system structures, legal requirements and obligations, user requirements and behavior, the energy management of buildings is a complex task (GEFMA, 2020). According to the German Facility Management Association GEFMA (2020), central tasks for energy management include providing energy and optimizing consumption as well as costs, without compromising user comfort. FM are relevant actors for the implementation of energy management, either explicitly or because their professional practices are closely interrelated with building energy use. For a better understanding of the FM context in Germany, it is necessary to distinguish between two types of FM. FM as a commercial service is typically hired by large companies which are often in international competition. Since March 2021, German companies with a consumption of an annual consumption of fossil fuels of more than 10 GWh must prove that they have established an energy management system in accordance with ISO 50.001. Therefore, many commercial FM service providers offer a full service for energy management to fulfil the national requirement. The second type of FM is found in SME, non-profit and public institutions where staff of the organisation are in charge for the operation and maintenance of technical infrastructures like heating, cooling, ventilation, and other energy-consuming equipment. These facility managers (mostly they are entitled as technical manager) of such properties possess the most extensive knowledge about the buildings and occupants. Hence, they are a particularly relevant target group for strategies to optimize energy management (Klimaschutz- und Energieagentur Niedersachsen, 2019). Also, they often have a fixed budget for investments in the infrastructure and typically do not directly have to justify their expenses both for staff and low to medium sized investments.

This paper as well as the research project focuses on FM in SME, non-profit and public institutions and the question how to increase energy saving and efficiency through non- or low-investment measures, behavioral changes and adaptation under a socio-technical framework of those actors who stand as intermediaries between owners and users, i.e. actors of FM and their practices.In an ongoing research project for the German Federal Environment Agency, the factors are explored that shape FMs current approach towards energy performance through low-invest and behavioral interventions. Among those are client and user expectations, motivation, knowledge, and organisational routines and roles. In an adapted living lab approach, the research partners Öko-Institut (Ecological research Institute) and the Fraunhofer ISE cooperatively develop and examine innovative socio-technical measures or instruments with FM from six facilities of different sectors (education, economy (hotels), health (hospital and nursing home)) in real-world contexts (experiments). Following energy efficiency measures are expected to be adapted within the living lab phase of the project:

- Identification and decommissioning of unnecessary energy consumers
- Identification and temporal decommissioning of energy-consuming equipment
- Demand adjustment like temperature adjustment (e.g., heating temperature down, cooling temperature up), airflow reduction for ventilation and automatic control (e.g., lighting)

In the research – and within this paper – the following three research questions are aimed to be answered:

- What are the crucial factors with determine energy-efficiency activities by FM in SME, non-profit and public institutions?
- What effects can be achieved by non- or low-investment measures FM in SME, non-profit and public institutions?
- What measures and instruments are required by such SME and institutions to implement systematically energy efficiency activities in their organisations?

3. EXISTING RESEARCH AND METHODOLOGIES

3.1. Empirical research with FM and energy efficiency: Barriers, success factors

This chapter reviews existing scientific literature obstacles and factors related to leveraging low-investment or non-investment energy-saving potential in organizations. Elmualim et al. (2010) investigate the conditions under which facility managers successfully engage in sustainability. Obstacles found by Elmualim et al. (2010) match strongly with findings from German research findings which were elaborated in projects focusing on energy efficiency in (small and medium) companies (Fischer et al., 2019; Böhm et al., 2019; Böhm, 2021; A.U.G.E., 2017). Based on their findings and those from Elmualim et al. (2010) following obstacle categories can be described:

Priorities, motivation, organizational climate: Often other priorities are set in companies by the top management as often energy costs are not a relevant cost factor. Also, from a strategic marketing position saving energy has become so much common knowledge that a company can hardly stand out positively with it. Another obstacle derives from the missing openness to innovation within the organization expressed by ingrained habits and blanket rejection of innovations, or resistance from technical staff.

Knowledge and data management: In this category falls the lack of (or "wrong", outdated) knowledge about the right opportunities and of the own energy infrastructure and consumers as well. Furthermore, in operation there is the lack of documentation and the complexity of the plants. Such missing documentation is also related to the lack of a system for collecting and managing energy data that can be expanded and parameterized without external help. If such data management systems are in use, data protection rules may prevent detailed evaluations, e. g. on room occupancy and electricity consumers.

Incentives: Apart from intrinsic motivation, there are hardly any incentives, e.g., financial bonuses for commitment. Therefore, the circle of committed people often remains limited to the intrinsically motivated. In the absence of energy savings targets and noticeable high energy

costs being priced into the budget, there is often no incentive to save energy.
Human and financial resources: During the planning phase potential savings from non-investment measures often cannot be quantified precisely or at all in advance. The allocation of energy consumption to individual employees or processes is time-consuming, fraught with great uncertainty, and often not even feasible. Even if it is feasible, it is often overseen that efforts for organization and coordination have to be allocated accordingly. Generally, the lack of or insufficient time budgets or positions for the task of energy efficiency are reported in all cited papers: For example, energy managers are formally employed. However, they do not have the time to deal with the issue instead activities were additional tasks for the personnel. Despite great interest, time was not always available for them. From financial and energy efficiency perspective rebound effects might occur, e. g. in the case of many newly installed devices whose procurement was not reflected in terms of energy consumption.
Professional qualifications: Efficient operation is often not considered to be a key task of the staff; rather, it is assumed that the technology does this automatically, or that external maintenance and repair companies take care of it. However, this task is often not part of the contract.
Building technology: For the personnel operating the systems, user comfort and trouble-free operation are in the foreground, so that they are often over-dimensioned and run in continuous operation. Default settings are not adjusted and there is no monitoring. Even it might be in place not correctly functioning measurement technology might cause additional obstacles. Also, a lack of user-friendliness (usability) of the control technology used (thermostats) is reported.
Ownership, contractual and legal conditions: ownership and conflicting contractual conditions with the operators of buildings or control technology which do not allow the identification or implementation of efficiency measures are another dimension of barriers.
Socio-cultural variance: An additional obstacle which was mentioned during a result from a project workshop with GEFMA was the fact that FM staff often has a migration background and are not native speakers. Besides language also the awareness and attitude towards energy efficiency might vary among technical staff and might impact on the motivation to act.

3.2. Maturity model of the ISO 50.005

During the project, we looked for a methodology which helps to classify the achieved state of the partners and to show them a development perspective. We found the ISO 50.005 standard which describes the structure of a non-certified energy management system (EnMS). The goal of the standard is to enable companies to initiate and improve energy management practices by taking a systematic approach and making reasonable efforts, given their resources and context, to continuously improve energy-related performance (cited after Umweltbundesamt, 2022).
To this end, ISO 50005 describes twelve central elements, each with four implementation stages or levels of maturity. The four levels represent a graduation from a low level of

experience in energy management to a level approaching compliance with the requirements of ISO 50001 (see figure 1).

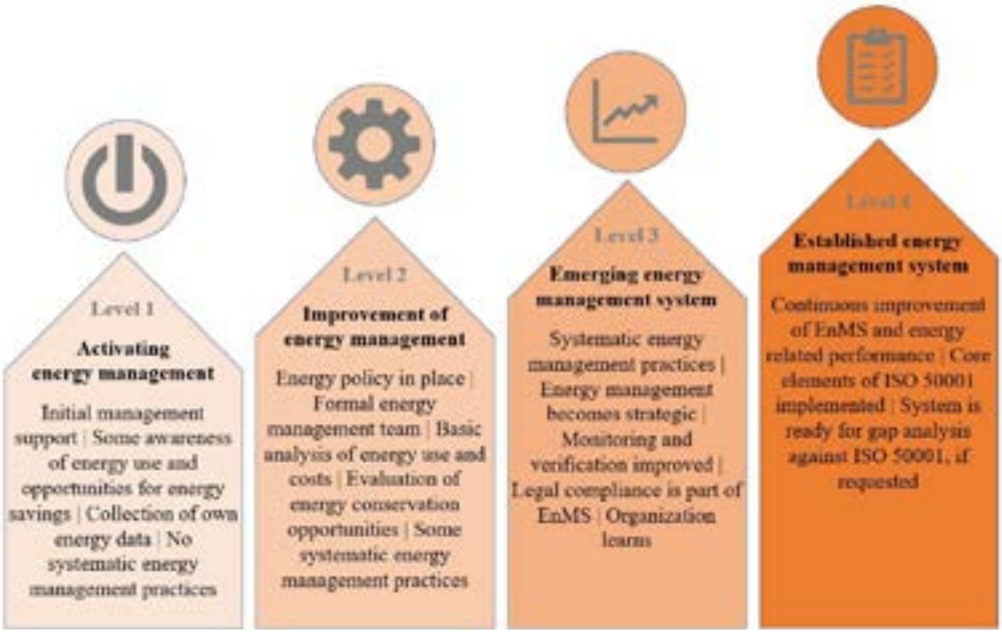

Figure 1: Implementation levels of the ISO 50.005

For each of the 12 elements (see also Annex 1) specific tasks are described to reach from level to level the final goal of the element. For example, element 3 “Resources” which specifies as a goal that an energy team, or an energy officer, must be established and that energy efficiency and the EnMS must be included in budget planning. Therefore, the elements and levels provide a maturity model for organizations to determine their current maturity level and to set concrete targets regarding the desired maturity level of their EnMS.

4. METHODOLOGY

The research has been conducted in a transdisciplinary design. This means that we firstly co-designed the research project with the client as well as practitioners from different sectors (public and private) and branches, such as education, health, and tourism. Secondly, we collaboratively worked together with the practitioners from the different sectors on developing organizational and technical measures to reach energy efficiency. Our transdisciplinary approach was inspired by the living lab approach. Due to rather scarce resources and a beforehand defined problem and goal orientation the researchers couldn’t react as flexible to wishes or expectations of the practitioners as it would be desirable from a living lab perspective. Nevertheless, adaptions have been made where possible and necessary within the existing framework conditions.

4.1. Selected Institutions

For the transdisciplinary research setting we acquired practitioners from the areas of health care (public sector), education (public sector e. g. university) and tourism (private business). Partners from the public healthcare sector are a residential and care centre as well as a district clinic with two locations. A University of Applied Sciences joined as partner from the public education sector. Partners from the tourist sector are a commercial privately family run hotel and a hotel that is run on the principle of inclusiveness (30-50% of the employees are people with a significant disability).

4.2. Core elements of the living lab concept and their application

At the beginning of the living lab phase, the research team had on-site meetings with the respective practitioners, including an inspection of the buildings, to get to know the conditions and basic requirements of each partner.
The transdisciplinary setting was based on the living lab format (Singer-Brodowski, Beecroft, Parodi; 2018) and takes up the central living lab elements of co-design and, co-production with its experimental character of a living lab. In regular meetings, the participating practitioners come together with the research team. The topics, frequency and scope of the meetings are discussed and jointly determined with the practitioners (co-design). In the meetings, the practitioners learn about the problems and solution strategies of the other partners, can thus exchange information and knowledge, receive impulses from the research partners and develop measures and instruments for energy saving together and with the research team (co-production). In addition, researchers accompany individual practitioners bilaterally in testing energy-saving measures on-site and support them in reflecting on their experiences.

The research team also aimed at co-evaluation to reflect the collaboration and the benefits of the developed measures. Therefore, firstly, the 7th living lab meeting (online) in January 2023 included an interim evaluation composed of questions asked and answered via mentimeter and a roundtable discussion on the mentimeter results and additional aspects contributed by the participants. Questions asked were e. g. What have you been able to take away or use for energy saving from the collaboration and meetings so far? Or from today's point of view, what are the main challenges in your company to tackle the concrete (energy saving) measures mentioned? Secondly, we conducted semi-structured online interviews in June and July.

4.3. Analysis schemes

Based on the above-described existing research and the maturity model of the ISO 50.005 an analysis structure was developed and applied. The analysis aimed at a) identifying the relevant factors that determined how successfully the practitioners dealt with energy management, and b) assessing the level of maturity of each organisation. For the purpose of a), we used the categories derived from the literature, while b) was assessed with the help of the ISO 50,.005 steps.

Individual factors	• Motivation and attitudes • Professional and social qualifications • Socio-cultural variance
Organisational factors	• Organizational structures Organizational climate • Priorities, targets and incentives • Human and financial resources
Technology-related factors	• Building technology • Knowledge and data management • Ownership, contractual and legal conditions

Table 2: Categories for qualitative content analysis

5. FINDINGS

5.1. Case example "Family run hotel"

The hotel is an owner-managed family business. Incentive and motivation for the hotel management to dedicate themselves with energy savings are the saving of costs, the improvement of its own image and the acquisition of new customers. As the hotel has come under financial pressure with Covid and rising energy cost, cost savings are a pressing need. Saving measures are difficult to communicate to guests, as they often want to have a carefree stay at the hotel. Restrictions for energy consumption, e. g. in the use of hot water for showers, can lead to poor ratings, which is to be avoided. Therefore, raising employee awareness is the main focus for increasing energy efficiency. In principle, employees seem to have a positive attitude toward the topic of sustainability: In an employee survey initiated by the management 100% of employees stated that it is important that the hotel is committed to sustainability. 70% think that too much waste is produced. 60% would like to be involved in sustainability.

However, there are still obstacles, as some employees do not understand German very well, do not have time for additional tasks or have a high work pressure and do not want to invest time in addition to their work.

Despite all motivation and intended focus of efficiency measures, there is a lack of technical knowledge on potential savings within the management and staff. Advice given by third parties does not always appear to be trustworthy for the management. Also, data management is very basic as energy consumption is noted and documented monthly, available for the four buildings but not further differentiated to appliances, rooms or processes.

During the project guest communication with flyers as well as stickers "Lights out - together we are strong" and on Instagram was launched. According to the project partner, these measures were well received. Opening time for the sauna was reduced, but the sauna still can be used on demand. An upper temperature limit for heating was set for the air conditioners (as requested by a national regulation in Oct. 2022 due to the German energy crisis). A sustainability group of employees including trainees from each department has been formed.

5.2. Case example "District Hospital"

The two hospitals are basic and standard care facilities. The clinic site 1 dates to 1962 and has been partly rebuilt and renovated during this time with numerous additions and extensions. There are 117 beds there. The clinic site 2, with 200 beds, was newly built in 1990 and several extensions have also been added here. There are 900 employees in total. Environmental management via EMAS certification is being re-introduced at both hospitals. This shows that the top management is backing up energy saving and climate protection measures. For years, the technical departments of the district hospitals have been striving to modernize the technical facilities, some of which are up to 60 years old, in an energy-conscious and environmentally friendly manner. In terms of energy-saving behavior, the biggest conflicts are with the increasing hygiene requirements. For example, permanent ventilation is required because of Covid. The financial situation in the healthcare sector is generally precarious. Technically, the FM employees are well trained. However, there is a lack of communicative skills to sensitize employees in other areas to energy-saving measures. Accordingly, there is a lack of capacity for knowledge transfer from facility management to other employees or patients. Data measurement is excellent in the clinic site 2; more than 100 meters provide information on the various consumption levels. Since there is a lack of suitable evaluation software, the data is evaluated twice a year. Here, only outliers are looked at. Clinic site 1 lacks meters, so almost no information is available on energy and heat consumption. Within the collaboration a circular on energy savings was sent to all employees in both sites. In clinic site 1 and 2 the heating curves were turned down by 0.5-1.5 points and documented in the building management system (BMS). Where there were complaints of cold, the heating curves were adjusted back up slightly. Most heating circuits were able to stay down. An evaluation software for the measurement data has been introduced. A webinar with software provider is planned to define interfaces how the data from the meters can be read into a software.

5.3. General intermediary results

Along the maturity model of ISO 50.005 we conclude that all FM partners have not yet been implemented many or most of indicated tasks throughout the elements 2 – 6 (which are the relevant ones) for the first level. Concerning leadership (element 2) neither a sensitization of the organization's employees to the energy-related environmental impacts nor any communication for the need to implement an EnMS nor the facilitation of the formation of an energy team was implemented. The university of applied sciences had communicated their approved climate protection strategy and its implementation to their staff and students. Two partners reported that they formed a task force which fulfils the second level of resources, the university of applied sciences had formed a group to implement the climate protection strategy (element 3). The hotel has established an informal energy team as a working group to implement the energy efficiency but not energy management. Up to now, none of the partners have allocated resources for energy management activities, mostly due to missing budgets and precarious financial situations. A very huge challenge also was the coverage for level 1 on the energy data and report (element 4): Record energy consumption for the last three years for the different energy sources was available in the hotel, the university, and the clinic site 2. Nevertheless, only the clinic identified all energy consumers that are worth mentioning and had the data base to run initial assessment of energy saving potentials – which was not executed due to the missing software. The university had applied for public funding to install a digital solution for building data management and analysis. Other partners just have started to collect and document consumption data, but no one was able to run an initial assessment of energy saving potentials. Consequently, energy performance indicators haven't been developed by any partner and energy baseline could only be provided by the clinic with the comprehensive data management. One crucial element towards a more systematic energy managements was therefore even not implemented on the first level. This led to the situation that no partner was able to set initial goals for improving energy consumption and plan measures based on the results of the Energy Report (element 4).

This level of incompleteness of the different elements corresponded with the difficulty to implement initial measures. This also reflects the documentation of the living lab meetings, in which partners were unsure which measures they best could implement as both their saving potential could not priorly been assessed and effectively no resources were available to put more efforts into such assessments – even if data was available.

6. CONCLUSIONS

From the intermediary evaluation it is obvious that individual, organizational and technology-related factors must be fulfilled to successfully implement energy efficiency measures. Despite all the motivation partners show through their engagement a central finding is that for non-investment and behavioral measures it needs orientation (1) and rational decisions (2), as well as (financial/personal) resources (3) in the focused companies and institutions. If there is no data to estimate the energy baseline or no knowledge about the significant energy users (SEU) is available (4) and therefore quantifiable influencing factors that significantly affect energy consumption and might be changed by new behaviors energy efficiency is more a lottery and its impacts more than questionable. The pathway described in ISO 50.005 elaborates an establishment of basic energy consumption knowledge for rational choices – which might be the crucial prerequisite for the targeted leverage of any efficiency potential even if the aim isn't the implementation of a non-certified EnMS.

Our living lab approach shows in many varieties central implementation barriers are of a social nature, as described above. Financial and staff resources, capacities and knowledge and tools for data collection, management and analysis are key. Partners use already public funding (university) or additional investment budgets (hospital) to build up tools for data management and in the case of public funding also additional staff resources. Still most partners only have started now with their top management to form organizational structures like task forces, energy teams or similar.

These initiatives will only survive if the energy teams can pursue the tasks continuously to achieve a more mature level in energy management. In addition, both organizational structure and skills for collaboration between technical, operational and administration units within the institutions must be build up and individuals must be appointed to coordinate both developments. As technical issues and management issues are prevailing in the development, such staff should be associated with existing FM units but need additional coordination and communication skills.

Major conclusion and requirement for improvement therefore is the financing of such activities. Generally, it would need options for subsidizing the establishment of tools and data management systems. Also, the systematic provision of external advice and co-coordination in the initial phase from energy agencies or consulting companies for quality and environmental management would secure missing internal competencies and could help to develop internal structures and competencies in rather short time. As savings of energy costs generally are a benefit for the institutions, they also should partly contribute to the implementation costs.

In addition, the creation of networks like the existing "energy efficiency networks", but targeted to small businesses, public and non-profit sector could be helpful, as it enables practitioners to motivate and learn from each other.

7. REFERENCES

A.U.G.E. - Hochschule Niederrhein. (2017). *Kurzbericht: Ressourceneffizienz im Gebäudebetrieb durch Nutzerintegration und Automation (REGENA)*. Retrieved September 18, 2023, from https://oekoinstev.sharepoint.com/:b:/r/sites/76152_UBA_STVAW/Freigegebene%20Dokumente/General/Literatur/Literatur_AP3/REGENA_2017_Ressourceneffizienz_Geb%C3%A4ude.pdf?csf=1&web=1&e=EVQJE4

Böhm, U. (2021). Akzeptanz von Maßnahmen für einen energieeffizienten Anlagenbetrieb in öffentlichen Nichtwohngebäuden und Möglichkeiten der Unterstützung. *Vortrag auf der Konferenz "Energiewende im Kontext der Gesellschaft - Partizipation - Akzeptanz"*. 15.11.2021. Berlin.

Böhm, U., Schäfer, M., & Stadler, M. (2019). Energieeffizienz im Spannungsfeld zwischen Anlagentechnik und sozialen Akteuren. Hemmnisse für den effizienten Betrieb komplexer Heizungsanlagen. *TATuP* *28*(3), 55–61. https://doi.org/10.14512/tatup.28.3.55

Elmualim, A., Shockley, D., Valle, R., Ludlow, G., & Shah, S. (2010). Barriers and commitment of facilities management profession to the sustainability agenda. *Building and Environment* *45*(1), 58–64. https://doi.org/10.1016/j.buildenv.2009.05.002

Fischer, C., Cludius, J., Fries, T., & Keimeyer, F. (2019). *Stromverbrauch senken. Energieeinsparung durch Suffizienzpolitiken im Handlungsfeld Stromverbrauch*. Dessau. Öko-Institut e.V., Umweltbundesamt (ed.).

GEFMA (2020): *E GEFMA 100-1 (2004-07): Facility Management - Grundlagen*, Berlin: Beuth Verlag GmbH. Online verfügbar unter https://www.din.de/de/wdc-beuth:din21:138506812.

Klimaschutz- und Energieagentur Niedersachsen. (2019*): Energieeinsparung in Gebäuden. Praktisches Anwenderwissen für Hausmeister*. Retrieved September 18, 2023, from https://www.klimaschutz-niedersachsen.de/_downloads/Broschueren/2019-06-14_Broschuere_Energieeinparung_in_Gebaeuden_Hausmeisterschulung1.pdf

Singer-Brodowski, M., Beecroft, R., Parodi, O. (2018): *Learning in real–world laboratories: A systematic impulse for discussion*, GAIA, 27(1), pp 23–27. https://doi.org/10.14512/gaia.27.S1.7

Umweltbundesamt. (2022). *Energiemanagementsysteme: ISO 50005*. Retrieved September 18, 2023, from https://www.umweltbundesamt.de/energiemanagementsysteme-iso-50005

8. ANNEX

Elemente	Level 1	Level 2
Element 2 Leadership Documentation	1.1. Raise awareness of energy-related environmental impacts among the organization's employees	1.2. Start data collection of energy-related environmental impacts
Element 2 Leadership – a) Energy policy	2.a.1. Leadership communicates the need to implement an EnMS and establishes initial rules and responsibilities for implementing the EnMS	2.a.2. Communication of an energy policy
Element 2 Leadership – b) Goals and energy targets		2.b.2. Energy targets in the company set by management
Element 2 Leadership – c) Responsibilities and competences	2.c.1. Leadership enables the creation of an energy team	2.c.2. Leadership Top management ensures that responsibilities and authorities are assigned to the energy team
Element 2 Leadership – d) Communication		2.d.2. Leadership ensures that the energy policy as well as the tasks of the energy team are communicated within the company
Element 2 Leadership – e) Documentation		2.e.2. Führung stellt sicher, dass die Energiepolitik (Thema a) als dokumentierte Informationen verfügbar ist
Element 3 Resources – a) EnMS-Team	3.a.1. Formation of an informal energy team (EnMT) as a working group for the introduction of the EnMS	3.a.2. Put energy team in active status

Element 3 Ressourcen – b) Budget	3.b.1. Allocate resources for energy management activities	3.b.2. Provide budgeting for initial training for employees and implementation costs
Element 4 Energy report – a) Energy use and cosumption	4.a.1. Record energy consumption for the last three years for the different energy sources	4.a.2. Record costs for the different energy sources, if possible also record them in monthly values, analyze the data (outliers, trends, load curve analysis)
Element 4 Energy report – b) Significant energy inputs/ SEU	4.b.1. Identify all energy consumers that are noteworthy	4.b.2. Classify areas, plants and machines and thereby define the SEUs
Element 4 Energy report – c) Energy saving potentials	4.c.1. initial assessment of energy saving potentials	4.c.2. Preparation of an "energy savings analysis”
Element 5 Energy performance indicators and energy baseline – a) Relevant variables	5.a.1. Search for relevant variables, i.e., quantifiable influencing factors that significantly affect energy consumption and change routinely	5.a.2. Quantify variables potentially relevant to energy consumption. Perform basic initial analysis based on energy consumption using a selected variable
Element 5 Energy performance indicators and energy baseline – b) Energy Performance Indicator (EnPI)		5.b.2. Definition based on results from "Relevant variables" first EnPIs. Use of help "Energy performance indicators“
Element 5 Energy performance indicators and energy baseline – c) Energy baseline (EnB)	5.c.1. Analysis of historical energy data, selection of a year that is so representative of energy consumption that it is most suitable as a starting point, i.e. as a reference year	5.c.2. Define basic EnB for an EnPI. If necessary, use the "Energy Performance Indicators" guide
Element 6 Goals, Energy targets and	6.a.1. Set initial goals for improving energy	6.a.2. Definition of energy targets and underpinning of

action plans – a) Goals and energy targets	consumption. Use of the "Energy savings analysis" guide	strategic corporate objectives
Element 6 Goals, Energy targets and action plans – b) Action plans	6.b.1. Planning of measures based on the results of the Element 4 Energy Report, implementation of initial measures.	6.b.2. Concretization and prioritization of planned projects and measures, with the help of the "action plans" guide
Element 7 Competence and awareness – a) Employee awareness		7.a.2. EnMT promotes awareness of energy policy, goals and targets so that employees understand how their actions affect energy consumption. Various communication measures
Element 7 Competence and awareness – b) Competence		7.b.2. Conduct specific energy management training as needed
Element 8 Operation and maintenance – a) O&M criteria		8.a.2. Establish initial operating and maintenance criteria, or procedures.
Element 8 Operation and maintenance– b) O&M practices	8.b.1. Record effects of operation and maintenance on energy consumption	8.b.2. Conduct specific training or workshops as part of energy management to communicate the impact of operations and maintenance practices on energy to relevant personnel
Element 9 Procurement and design – a) Design		9.a.2. Occasional consideration of energy efficiency in facility and manufacturing planning, design of equipment, devices, systems, and energy consumption

		processes
Element 9 Procurement and design – a) Procurement		9.b.2. Conduct specific energy management training as needed

Peak demand reduction – who is flexibility, when and how?

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Abstract

The energy crisis experienced in the UK during the winter 2022/23 forced the network operator to offer rewards as part of their Demand Flexibility Service (DFS). For the first time in the history of the national grid, private customers could be paid for using less during peak demand events. The scheme was delivered via energy suppliers and was considered successful enough to be repeated in winter 2023/24. For reasons of commercial sensitivity little data has been made available about the distribution of responses within the population. We share detailed responses from a sample of 200 UK households, who attempted to avoid peak demand across four seasons. Alongside high-resolution electricity use data, we present results from socio-demographics and detailed activity diaries collected during response events and during 'normal' control days. They show the impact of load shifting on everyday practices and gives insights into conditions that might inhibit greater flexibility. Our results show that it is not the extent of the financial reward that determines the load responsiveness. Some activity patterns are unexpectedly flexible, including meal preparation. Despite the perceived technical potential to shift heating appliances, gas heated homes only showed modest shifts in gas demand during flexibility events. We present detailed findings and an outlook for the continuation of this research as part of the newly established UK Energy Demand Observatory and Laboratory (EDOL), an £8m national and longitudinal data resource for the zero-carbon demand transition.

1. INTRODUCTION

Demand side response has long been proposed in literature as a means to support the integration of renewables, avoid network reinforcement and achieve system wide savings from more efficient operation of assets. (Grunewald & Diakonova, 2018; Grünewald et al., 2014)

Espey & Espey (2004) estimate the short-term elasticity of electricity demand to be -0.35. Such figures are widely used in models and simulations of demand response and electricity system models (Bradley et al., 2013; Roscoe & Ault, 2010). Numerous studies state significant short-term responses to price-based demand response trials (Schofield et al., 2014; Torriti & Yunusov, 2020). However, Zhu et al. (2018) conclude after extensive meta-analysis of international reviews that residential electricity demand is almost inelastic in the short term.

In addition to price-based incentives, Buckley (2020) and Andor & Fels (2018) review non-price signals and nudges as an alternative signal for change. Importantly, they point out that small and short-lived studies tend to report greater effect sizes than larger and longer lasting studies.

Demand Flexibility Services were trialled commercially for the first time by National Grid ESO in the UK during the winter 2022/23. Among the motivations for the trial were supply uncertainties resulting from high gas prices.

The Guaranteed Acceptance Price (GAP) is £3,000/MWh for most auctions. This translates to approximately ten times the price of using electricity, for *not* using it. Suppliers bidding to provide the service can choose to pass on part of the savings to their customers or motivate them in other ways to participate.

1.6 million households and businesses supported the service. The ESO judged the trial to be a success and expects to continue the service and run 12 'test events' between November 2023 and March 2024. (ESO, 2022)

The exact breakdown and contribution from different sectors, suppliers or households is not published and is in some cases commercially sensitive.

This paper therefore draws on a study that made comparable demand reduction requests and collected additional information about participating households and their activities during interventions and on control days.

2. METHODS

2.1 The Energy Demand Observatory and Laboratory (EDOL)

Energy Demand Observatory and Laboratory (EDOL, 2023) is a major UK energy data infrastructure investment, funded by the Engineering and Physical Sciences Research Council (EPSRC), led by University College London in partnership with the University of Oxford. The programme seeks to provide a longitudinal, disaggregated, consistent and flexible resource of UK residential energy data. Representative and reliable data are made available to scientists, industry and policymakers. EDOL will innovate new, cost-effective, smart data solutions for collecting energy data at scale.

EDOL's Observatory will include 2,000 representative UK households and builds on the 12,000 households for which the Smart Energy Research Lab (SERL) is making smart meter and survey data available for research. In addition, EDOL will implement contextual data, such as temperature readings and occupancy.
EDOL Laboratories provide an environment for interventions, targeted panels and additional instruments. Technology trials, retrofits or engagement strategies will be tested for their effectiveness with respect to the observatory, which acts as a control group.

2.2 EDOL Flexibility Lab

The flexibility is an EDOL subset smart metered homes, which periodically receive requests to reduce demand. To assess how different publics respond to such requests, electronic diaries need to be submitted for the intervention day and a control day. The reward for two complete diaries and at least 10% demand reduction is £10.

2.3 The sample

The EDOL Flexibility lab sample consists of 157 participants that were recruited with the help of a commercial partner. From a proprietary online research panel of 100,000 members participants are recruited to be demographically, geographically and attitudinally representative of Great Britain. To improve the representativeness of the sample for the GB population with a smart meter, quotas by gender, region and work status have been applied at the recruitment stage.

The panel is regularly subjected to online surveys, for which they get financially rewarded. For this survey the incentives is £2. The survey covers socio-demographic and energy-use relevant questions, including affordability of energy and ownership of a smart meter.
To grant access to their smart meter data, participants have to provide the 16-digit alphanumerical GUID number underneath their in-home-display, which came as part of their smart meter installation. The GUID is validated against their post-code and uniquely identifies their smart meter. If the GUID-post-code pair is valid, participants receive a follow-up email inviting them to take part in the study by agreeing to the terms and conditions to access and process their smart meter data (Hildebrand, 2022).

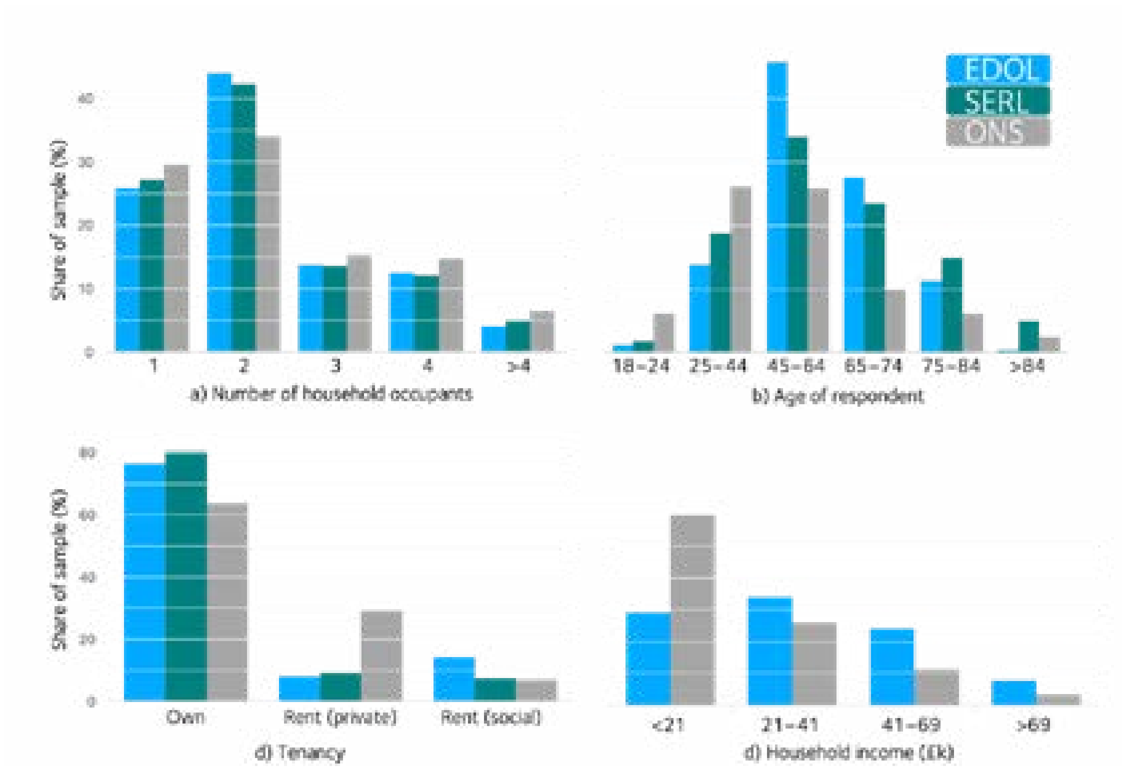

Figure 1: Sample distribution comparing the EDOL lab with SERL (Webborn, 2020) and national census data (National Statistics, 2022)

For participating in the study, installing a Consumer Access Device (CAD) and sharing their data for research purposes, participants receive a total annual reward of £15 in 2022, increasing to £20 in 2023. The survey is completed by 248 respondents. Of these, 200 have a valid smart meter ID and 157 provided consent and valid data.

Attempts to ensure representativeness of the sample do not entirely guard against selection and other biases. The smart meter population in Great Britain at the time of recruitment (January-February 2022) is just below 50%, with private rented properties slightly under-represented. The panel itself is likely to be self-selecting in favour of people who are more disposed to online engagement and monetary rewards. Some key characteristics of the sample are compared to the larger SERL sample and national statistics in Figure 1.

The sample has a good representation of household sizes, an over-representation of the 45 to 75 age group, and fewer households in privately rented accommodation. The tenancy bias is consistent with the SERL sample and stems from the complication of gaining landlord consent for smart meter access. The bias towards higher incomes is consistent with the over-representation of the middle-age distribution.

2.4 Trial conduct

All members of the Flexibility lab (n=157) receive an email one week before the control day. The email contains a personalised link to their activity diary and invites them to:

1. Record 20 activities each on the two consecutive days
2. On the second day between 5 p.m. and 7 p.m. they should attempt to reduce electricity use by at least 10%

The reward for successful completion of these tasks is £10. The Terms & Conditions are included in all correspondence. The email for any participant who reaches the required diary entries on the control day is shown in Appendix Figure 9. The dates for the four intervention trials is shown in Table 1. For the April 2022 trial the challenge was stated as 20% demand reduction. This was subsequently reduced to 10%.

All trials take place on adjacent Wednesdays and Thursdays, being two weekdays with similar load profiles under normal conditions. Mondays and Fridays follow different patterns and were therefore avoided.

Table 1: Trial and control day dates

Trial	Control date	Treatment date
April 2022	Wednesday 27th	Thursday 28th
June 2022	Wednesday 29th	Thursday 30th
October 2022	Wednesday 19th	Thursday 20th
January 2023	Wednesday 25th	Thursday 26th

After the treatment day participants receive personalised emails, depending on whether they reached the requirements. An example of the feedback provided to explain their results in the form of a graph is shown in Figure 2.
The first three trials were not within the core heating season. The request to reduce gas consumption was only added to the January 2023 trial.

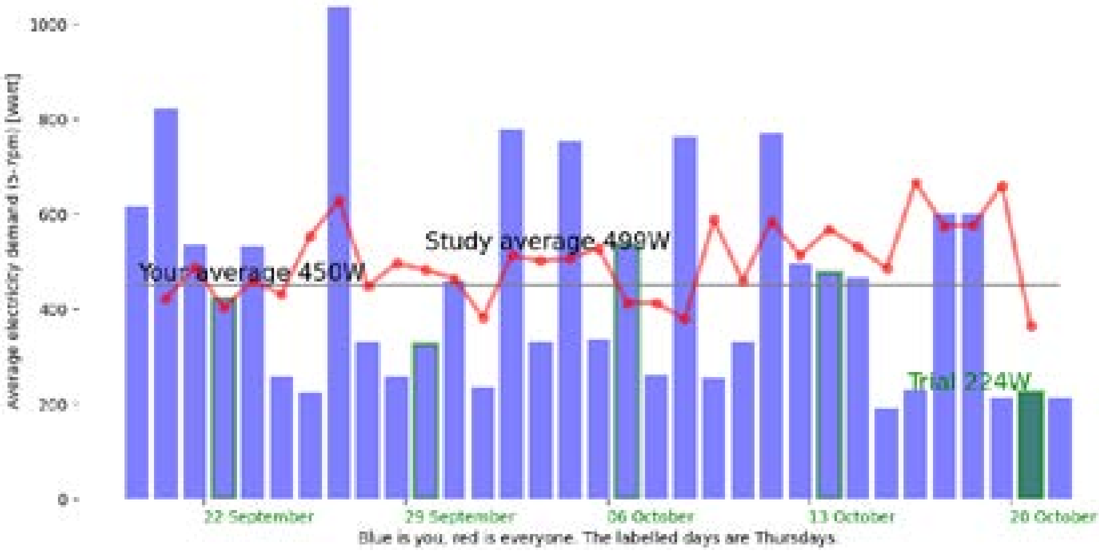

Figure 2: Example of the feedback sent to participants. Load reduction is assessed against the previous three Thursdays, labelled with dates and marked in green.

2.5 The data

Survey information is collected at the recruitment stage (see above) and in annual follow-up surveys, where participants receive an email inviting them to update appliance stock, household composition and attitudinal questions.

Smart meter data is obtained via two routes. Half-hourly data is transmitted from the smart meter via mobile signal and accessed through the Data Communications Company (DCC). One minute data is transmitted from the smart meter via the Home Area Network (HAN) to the Consumer Access Device (CAD) which is connected via Ethernet to the home router and transmitted via the internet to the Glow Service. The Glow Service makes both DCC and CAD data available via secure APIs. The data flow is illustrated in Figure 3.

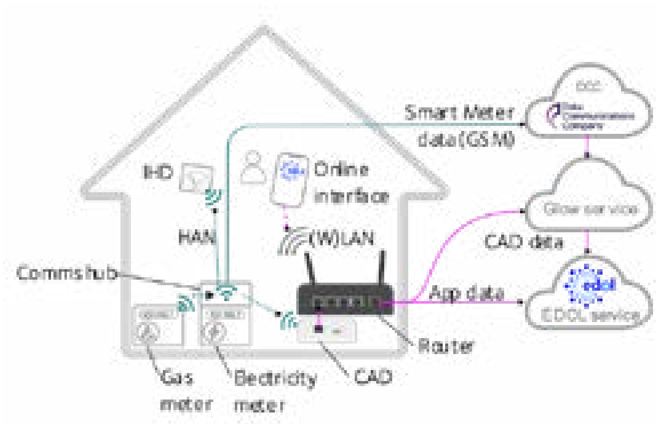

Figure 3: Data flow illustration. Smart Meter data is transmitted via GSM to the Data Communications Company, or via the internet to the GLOW service, which provides secure APIs for EDOL. User interfaces connect directly to EDOL services.

Smart meter data contains electricity and gas consumption and the cost of this energy at the time of use.

2.6 Activity diaries

The JoyMeter.uk (2023) interface allows participants to record everyday activities and appliances they use. This can be done on any mobile or desktop device. It is also possible to annotate one's load data directly. Recording the required number of activities on the control day is a pro-condition for participation. Only those who completed the diary day get the reminder email on the treatment day. The participation level is steady as shown in Figure 4.

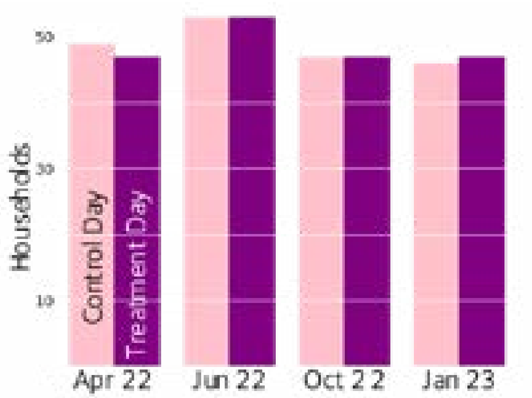

Figure 4: Participation rates are stable throughout the trial. Approximately a third of households take up and complete the challenge each time.

Energy, survey and activity data are linked via unique IDs and stored in a secure database. The data is anonymised and aggregated to protect the identity of participants.

Data collection is ongoing. At the time of writing electricity consumption and tariff data is available for 157 households. Gas data is also available, but the data quality is less suitable for time resolved analysis, because periods without readings are sometimes followed by a single half hour with the accumulated consumption of the missing periods. This can distort the temporal attribution performed as part of the elasticity analysis.

2.7 Analysis

Relative changes in electricity consumption (E^*) are derived as

$$E^* = \frac{E_t - E_c}{(E_t + E_c)/2} \tag{1}$$

where E_t and E_c are the electricity use on treatment and control day respectively. Using a differences-over-sums metric means that when plotting results, increases and reductions are distributed evenly around the zero point.

Participants are assessed individually based on the previous three Thursdays. This serves two purposes. Firstly it avoids gaming, whereby households may artificially increase demand in order to inflate their assessment baseline. Secondly, as apparent from the example in Figure 2, demand over a two-hour period can be volatile and a larger number of reference point makes the comparison fairer at the individual level.

For aggregate analysis, only the control day itself is used. This day is closest temporally and is the day for which comparable activity records are available.

3. RESULTS

The profiles of participants and non-participants exhibit similar peak time demand, suggesting that participants have not unduly attempted to game the challenge by increasing demand on the control day.

Comparing ‘opt-in’ participants with themselves, the peak demand reduction is 36.7% (relative change). When using non-participants on the same day as control, it is 31.6%.

The activity records suggest that most activity patterns remain unaffected by this intervention, as the example of one of the most commonly reported activity categories (‘screen time’) shows in Figure 6. A notable exception is “preparing hot meals”, which is reported noticeably fewer times during the treatment period (Figure 5).

Two thirds of participants successfully reduce demand by at least 10%, regardless of season. However, the average reduction is noticeably lower in January, as shown in Figure 7 and Table 2.

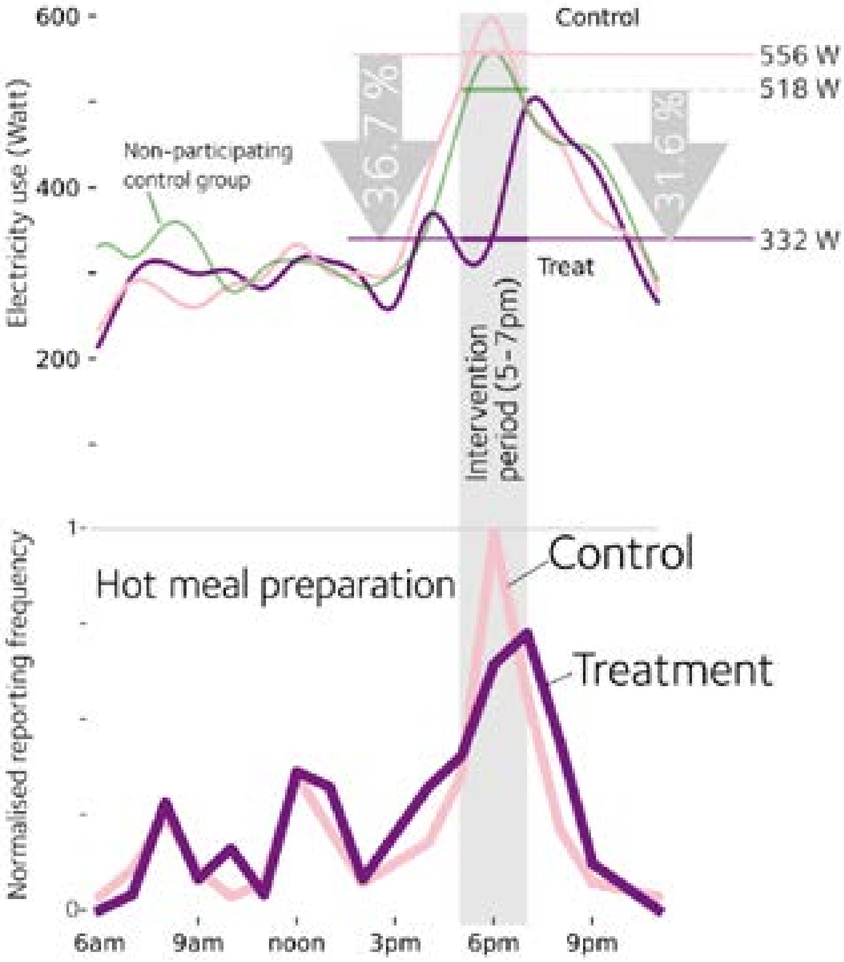

Figure 5: Load reduction with respect to the control day is 36.7% on average. Relative to non-participating households on the same day the reduction is 31.6%

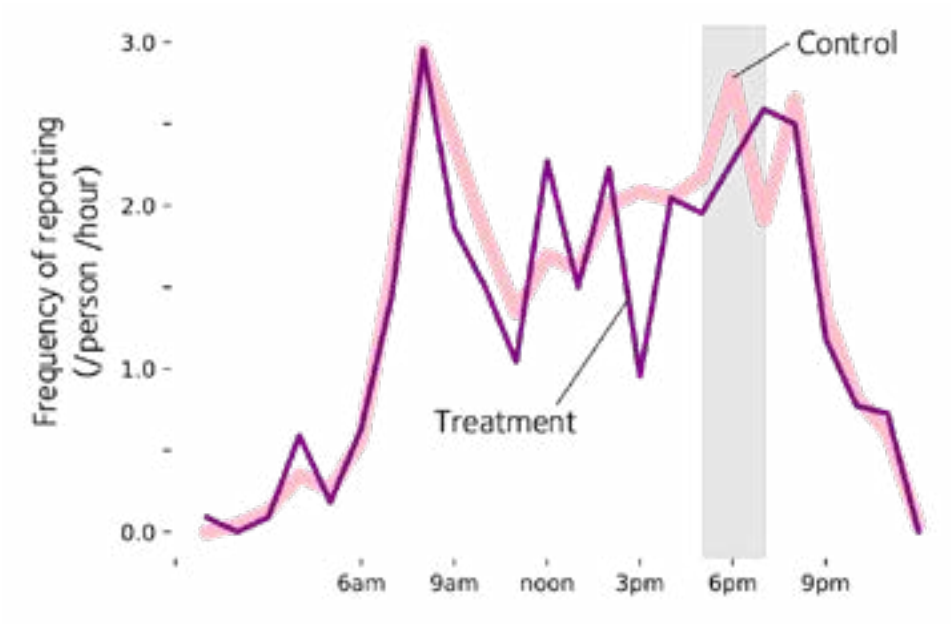

Figure 6: Screen time is among the most frequently reported activities and remains largely unchanged by the request to reduce demand.

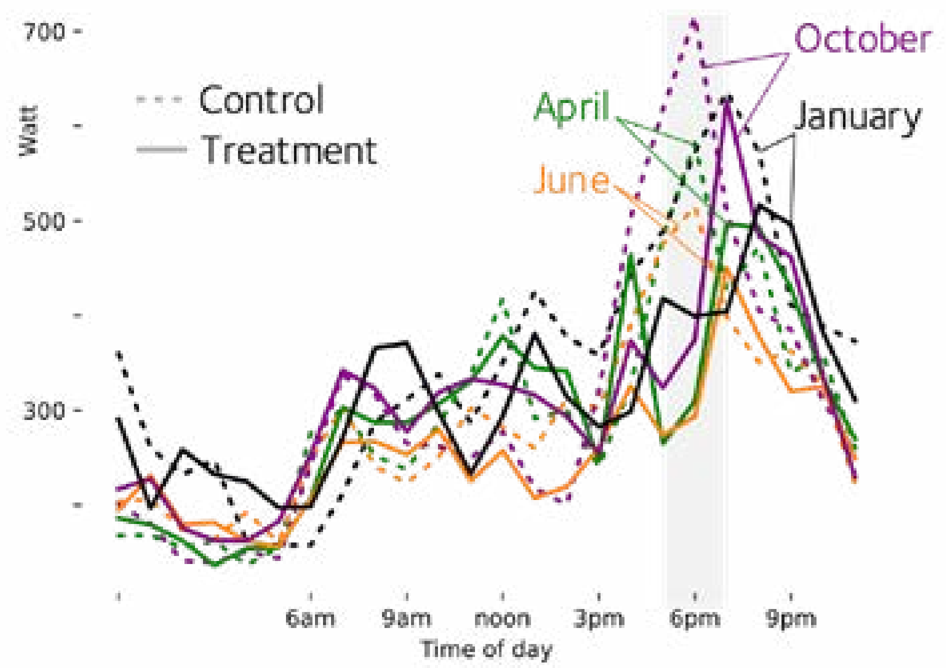

Figure 7: Participants achieved significant savings during the 5 p.m. to 7 p.m. window, regardless of season.

Whether participants are asked to reduce by 20%, as in trial 1, or merely 10% as in the subsequent trials, does not appear to make a material difference to the average reduction. Participants tend to reduce 'as best they can'. A larger number of trials would be required to verify this relationship, given the variability of responses.
Some participants reported that they failed to reach the 10%, despite their best efforts. The variability in demand over such short periods is high, as shown in Figure 2. It may therefore not always be under the participants control if they reach the target on a given day. Some aggregation may help to mitigate this risk.

Table 2: Electricity use between 5 p.m. and 7 p.m. on control and treatment day

Trial	Control (Watt)	Treatment (Watt)	Change (%)
April 2022	532	287	44.3
June 2022	495	283	39.9
October 2022	666	349	46.5
January 2023	530	409	18.0

Figure 8 confirms that households with lower demand on the control day are less likely to reduce demand. This is to be expected in both absolute and in relative terms. Households with a higher baseline have greater potential to shift or avoid demand.

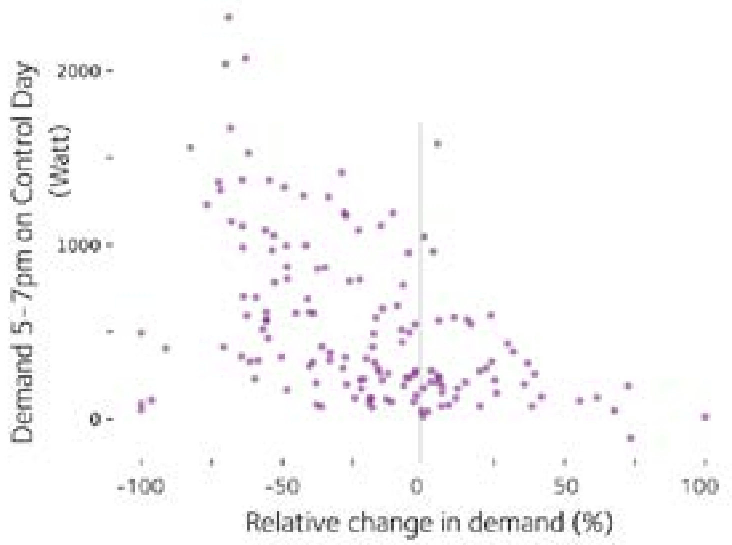

Figure 8: Participants with lower electricity demand between 5pm and 7pm on the control day achieve lower relative reductions during the trial.

4. DISCUSSION

GB households have demonstrated significant, repeated and reliable peak demand reduction potential.

Some participants were highly engaged and requested detailed feedback and advice. Among them were extremely low energy users who questioned what else they could do to reduce demand further during the trial, given that they already avoid energy use as much as possible. Participants who are in the bottom decile of electricity use were therefore given a compassionate exemption and received their reward regardless of load reduction (or in recognition of load reduction on a different scale). For policies and market arrangements, this raises equity questions over who 'deserves' rewards for peak demand reduction: those who reduce from a high base, or those who are low users all the time.

The ability to reduce load appears to be impacted when constraints on demand or attempts to reduce demand are already in place. Figure #results2 shows that lower users have less reduction potential. Furthermore, in January 2023, just after the energy price cap reached its record high of £4,279, households may have already been trying to reduce demand as evident from Figure 7. On this occasion the load response was lower than in the three trials the previous year.

Only on the January trial were participants asked to reduce gas consumption as well. The smaller sample makes analysis less reliable, but the data indicates that the load reduction was less successful than for electricity. This is surprising, given that heating is considered one of the more flexible loads. Participants may have had less agency over the timing of their heating system settings, but further work is required to verify how responses may be improved.

5. CONCLUSIONS

Dynamic load responses have proven to be an effective way to reduce load at critical times. Repeated trials across all four seasons have shown that load reductions are repeatable and reliable in aggregate.

A third of invited panellists participate in each trial, of which two thirds successful reduce demand at peak times by at least 10%. The average reduction across the sample is 36.7%, which is at the high end of responses reported in the literature. The monetary incentive is not the only motivation. Participants report enjoying the challenge and repeat their participation.

Many activity patterns do not appear to be adversely affected by the intervention. Hot meal preparation is among the most consistently shifted activities.

The ability to reduce demand depends on baseline demand patterns, with high users most able to act flexibly. The equity of reward schemes for flexible 'high demand households' over persistently low users requires policy attention while programmes are translated from trials into mainstream market instruments.

ACKNOWLEDGEMENTS

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REFERENCES

Andor, M. A., & Fels, K. M. (2018). Behavioral economics and energy conservation – a systematic review of non-price interventions and their causal effects. *Ecological Economics*, *148*, 178–210. https://doi.org/10.1016/j.ecolecon.2018.01.018

Bradley, P., Leach, M., & Torriti, J. (2013). A review of the costs and benefits of demand response for electricity in the UK. *Energy Policy*, *52*(0), 312–327.

Buckley, P. (2020). Prices, information and nudges for residential electricity conservation: A meta-analysis. *Ecological Economics*, *172*, 106635. https://doi.org/10.1016/j.ecolecon.2020.106635

EDOL. (2023). *Energy demand observatory and laboratory (EDOL)* [EPSRC Programme EP/X00967X/1]. University College London; University of Oxford. https://edol.uk

ESO, N. G. (2022). *Demand flexibility service* [Webinar slides]. National Grid ESO. https://www.nationalgrideso.com/document/287716/download

Espey, J. A., & Espey, M. (2004). Turning on the lights: A meta-analysis of residential electricity demand elasticities. *Journal of Agricultural and Applied Economics*, *36*(1), 65–81.

Grunewald, P., & Diakonova, M. (2018). Flexibility, dynamism and diversity in energy supply and demand: A critical review. *Energy Research & Social Science*, *38*, 58–66. https://doi.org/10.1016/j.erss.2018.01.014

Grünewald, P., McKenna, E., & Thomson, M. (2014). Keep it simple: time-of-use tariffs in high-wind scenarios. *IET Renewable Power Generation*, *9*(2), 176–183. https://doi.org/10.1049/iet-rpg.2014.0031

Hildebrand. (2022). *Terms and conditions for use of glow service* [Online]. EDOL JoyMeter App. https://joymeter.uk/22_01_TC_Glow.html

JoyMeter.uk. (2023). *Activity and appliance recording interface* [Online]. EDOL JoyMeter App. https://joymeter.uk

National Statistics, O. for. (2022). *UK population - demographics* [Online - accessed June 2022]. ONS. https://www.ethnicity-facts-figures.service.gov.uk/uk-population-by-ethnicity

Roscoe, A. J., & Ault, G. (2010). Supporting high penetrations of renewable generation via implementation of real-time electricity pricing and demand response. *Renewable Power Generation, IET*, *4*(4), 369–382.

Schofield, J., Carmichael, R., Tindemans, S., Woolf, M., Bilton, M., & Strbac, G. (2014). *Residential consumer responsiveness to time-varying pricing* [Report A3 for the ``Low Carbon London'' LCNF project]. Imperial College London.

Torriti, J., & Yunusov, T. (2020). It's only a matter of time: Flexibility, activities and time of use tariffs in the United Kingdom. *Energy Research & Social Science*, *69*, 101697. https://doi.org/10.1016/j.erss.2020.101697

Webborn, E. (2020). *Survey data: Summary of responses* [Report]. Smart Energy Research Lab. https://serl.ac.uk/

Zhu, X., Li, L., Zhou, K., Zhang, X., & Yang, S. (2018). A meta-analysis on the price elasticity and income elasticity of residential electricity demand. *Journal of Cleaner Production*, *201*, 169–177. https://doi.org/10.1016/j.jclepro.2018.08.027

APENDIX

Δεαρ{ναμε},

Ωελλ δονε φορ ρεαχηινγ {χντ} διαρψ εντριεσ ψεστερδαψ!

Πλεασε δο τηε σαμε αγαιν τοδαψ ανδ τρψ το **reduce your energy use between 5pm and 7pm**. Τηε αιμ ισ α 10% ρεδυχτιον ιν ελεχτριχιτψ υσε.

Tips for the day:

- Φορ τηισ χηαλλενγε ιτ δοεσν∋τ ματτερ ηοω μυχη ενεργψ ψου υσε βεφορε 5πμ ορ αφτερ 7πμ. Ιφ ψου χαν μοϖε αχτιϖιτιεσ ορ ηεατινγ το εαρλιερ ορ λατερ ιν τηε δαψ, τηατ∋σ γρεατ
- Δεμανδ ψου χαν αϖοιδ αλτογετηερ ισ εϖεν βεττερ
- Φοχυσ ον τηε βιγ ιτεμσ: ηεατινγ, οϖενσ, ωασηινγ μαχηινεσ, δισηωασηερσ – τηεψ αλλ υσε α λοτ.

Παρτιχιπατιον ρεμαινσ ϖολυνταρψ ανδ τηισ χηαλλενγε ισ νοτ μεαντ το βε α βυρδεν ον ψου. Ιφ φορ ανψ ρεασον ψου φινδ ιτ διφφιχυλτ το χομπλετε, πλεασε γετ ιν τουχη.

Γοοδ λυχκ τοδαψ!

Πηιλ

Dr Phil Grunewald, FICE
Ενεργψ Δεμανδ Οβσερϖατορψ ανδ Λαβορατορψ (ΕΔΟΛ)
Υνιϖερσιτψ οφ Οξφορδ

Terms and conditions

- Τηε ρεωαρδ ωιλλ βε ≤10 ΒΑΧΣ τρανσφερ ορ εθυιϖαλεντ Νεως ιστα ποιντσ βασεδ ον ψουρ χηοσεν παψμεντ μετηοδ
- Τηε 10% ρεδυχτιον ισ ασσεσσεδ αγαινστ τηε παστ φουρ ωεεκσ οφ ελεχτριχιτψ ανδ γασ δατα βετωεεν 5πμ ανδ 7πμ.
- 20 αχτιϖιτιεσ ηαϖε το βε ρεχορδεδ ον εαχη οφ τηε τωο δαψσ υσινγ ψουρ περσοναλισεδ λινκ
- Υνιϖερσιτψ οφ Οξφορδ ανδ Νεως ιστα σταφφ αρε εξχλυδεδ φρομ χλαιμινγ τηισ ρεωαρδ
- Τηε Υνιϖερσιτψ οφ Οξφορδ ρεσερϖεσ τηε ριγητ το ωιτηδραω τηε χομπετιτιον ανδ αλτερ τηε τερμσ ατ ανψ τιμε ωιτηουτ νοτιχε

Figure 9: Email sent on the morning of the trial day with instructions and terms and conditions.

THE THIRD SUCCESS FACTOR OF ENERGY TRANSITION IN DISADVANTAGED NEIGHBOURHOODS

Findings of a Dutch experimental programme

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Keywords: energy transition, behaviour, neighbourhood policy, poverty, sustainability, merger of interests

Abstract

To mitigate climate change in line with the Paris Agreement, and in response to uncertainty about energy supplies and soaring energy prices, many governments worldwide have set ambitious targets to reduce energy consumption. Human behaviour is an important factor in achieving those ambitions. However, this factor often remains underexposed; the focus is almost always on the success factors costs and technology. In the Netherlands, the term 'Third Success Factor' was introduced to draw attention to the important aspect of behaviour within the energy transition in the residential environment: integrating residents' interests from a broader perspective than the energy transition alone. The way of working promoted by the Third Success Factor is based on the so-called Merger of Interest Strategy. The working method of the Canadian Sustainable Neighbourhood Action Program shows great similarities with this method and has been an important source of inspiration for the Dutch experimental programme Sustainability in Disadvantaged Neighbourhoods. This programme has sought to answer the question of how a sustainable neighbourhood approach can be utilised as a lever to improve the quality of life in so-called 'disadvantaged' neighbourhoods across the Netherlands. This paper describes the experiences of working with the Third Success Factor in this Dutch programme and (to some extent) in Canadian projects. It also explains what working with the Third Success Factor aims to achieve and briefly highlights the strategy on which it is based. The aim of this paper is to increase the likelihood of a successful energy transition in disadvantaged neighbourhoods.

1. INTRODUCTION

To mitigate climate change in line with the Paris Agreement, and in response to uncertainty about energy supplies and soaring energy prices, many governments worldwide have set ambitious targets to reduce energy consumption. (CfCaES, 2015) The Dutch Climate Agreement describes how the Dutch government aims to phase out fossil fuels. It stipulates that by 2030, 1.5 million homes need to have undergone renovations to become fossil-free. Municipalities are encouraged to apply a neighbourhood approach (Klimaatakkoord, 2018). In 2018, an estimated 10 percent of Dutch households experienced energy poverty; they struggled to pay energy bills, let alone invest in energy-saving renovations (Van Middelkoop, Van Polen, Holtkamp & Bonnerman, 2018). At the time, this group was expected to double in size by 2030 (Schellekens, Oei & Haffner, 2019). However, due to the recent surge in energy prices – in part resulting from the current war in Ukraine – the number of 'energy poor' has grown much faster (Torkington, 2023). As such, the urgency to progress with the energy transition in neighbourhoods with a high prevalence of energy poverty has increased.

In the Netherlands, energy poverty is most prevalent in post-war neighbourhoods (or sometimes residential areas built in the 1970s). Besides poverty, these neighbourhoods tend to be riddled with issues relating to liveability and safety and are characterised by worn-down public spaces and buildings. Many residents in these areas furthermore not only face socio-economic challenges such as poverty, debts, and unemployment, but oftentimes also face (mental) health problems like loneliness, substance abuse, and tend to have otherwise generally unhealthy lifestyles (Van Hal, Uyterlinde & Coen, 2019).

Nyenrode Business University and knowledge institute Platform31 initiated an experimental programme called Sustainability in Disadvantaged Neighbourhoods (*Verduurzaming van Kwetsbare Wijken,* SDN) in early 2019, in collaboration with the Dutch Ministry of Interior and Kingdom Relations. Initially, fifteen municipalities joined in with a disadvantaged neighbourhood, and four more joined along the way. In 2021, the Verwey-Jonker Institute became involved as well. The aim of the programme is to integrate the energy transition into a comprehensive neighbourhood approach that aims to make disadvantaged neighbourhoods more liveable and safer. This requires difficulties relating to coordination between organisations and departments to be addressed and residents to be involved in the planning process.

The setup of the SDN experimental programme draws on previous experiences from different contexts. Most notably, this programme has drawn inspiration from the Tower Renewal project in Toronto (City of Toronto, 2023). These tower neighbourhoods house half a million people, many of whom are migrants. Many residents have (very) limited financial means. Furthermore, the structural and energy qualities of the homes are generally rather poor.

Sparked by concerns about poverty-related issues, the city of Toronto started a collaboration with the Sustainable Neighbourhood Action Program (SNAP), an initiative of the Toronto and Region Conservation Authority. Together, they initiated retrofits and climate adaptive measures in these neighbourhoods starting in 2010 (Sustainable Neighbourhood Action Program & Toronto and Region Conversation Authority, 2020). SNAP's approach shares many similarities with the principles of working with the Third Succes Factor which is a Dutch approach to integrate the interests of residents in the energy transition process from a broader perspective than the energy transition alone (Van Lidth de Jeude, Mastop, Uyterlinde, Coen & van Hal, 2017). The Third Succes Factor is introduced by the chair Sustainable Building and Environment of Nyenrode Business University (Van Hal, 2016). This chair also co-initiated the SDN experimental programme.

Lessons learned within this programme have been continuously monitored and analysed rigorously. After four years, experiences from the Dutch programme were compared with those from SNAP. This paper first explains the Third Succes Factor and highlights its theoretical basis. It then describes the methodology of several analyses of the experiences with the programme (at the beginning, after three years and after the turbulent year 2022) and the data selection method of the comparison with SNAP. Then, the results are described, followed by a concluding discussion.

2. THEORY

The involvement and cooperation of residents are essential in order to create successful neighbourhood approaches, but are notoriously complicated. Human behaviour is an important success factor in achieving energy ambitions in the residential environment (Vringer, Van Middelkoop & Hoogervorst, 2016; Johansson, Gentile & Neij, 2021). The Dutch approach of working with the Third Success Factor of renovations with energy ambitions was introduced within this context. The aim of applying the Third Success Factor is to support professionals who are active in the energy transition in houses and neighbourhoods, like municipal officials and employees of housing associations and construction companies. This support is focused on fostering enthusiasm amongst residents by integrating the interests of residents from a broader perspective than the energy transition alone. It is called the Third Success Factor because integrating human interests is an element of the success factor human behaviour. This is an often neglected third success factor next to the two success factors technology and costs – which always receive attention.

Working with the Third Success Factor is an elaboration of a general approach, developed by Nyenrode Business University, to increase enthusiasm for sustainability measures. This approach, the Merger of Interests Strategy, originate from experiences gained in the construction sector (Van Hal, 2014). The approach builds on the Green Mindset approach as introduced by Bhatsholom and Cohen (2002) which is inspired by the work of Harvard's Program on Negotiation (PoN), especially by the publication ‘Getting to Yes' (Fisher and Ury, 1983). The work of PoN focuses on Interest-Based Bargaining (IBB) (Kennedy, 1999).

2.1. Interest-Based Bargaining

This form of negotiation differs from usual forms of negotiation because interests, rather than positions, are the starting point. To illustrate the difference, consider the explanation given on the YouTube channel of one of the writers of Getting to Yes, William Ury, in a video (Getting to Yes, 2015). Two people both want an orange, but there's only one. Traditional negotiation might involve splitting the orange in half, assuming both need the entire fruit. However, by exploring their interests further, it's revealed that one person needs the peel for cooking while the other needs the juice for drinking. In this case, the solution is to grate the peel first and then hand over the orange for juicing. This is a very simple example, but it clearly illustrates that working from an interest's point of view also involves creative thinking and alternative solutions beyond the norm.

2.2. The Merger of Interests Strategy

Like IBB, when applying the Merger of Interests Strategy, one starts by creating an inventory of the interests of the various stakeholders involved in a project – in the broadest sense. It explicitly encompasses *all* interests; not exclusively those that relate to sustainability. Pelenur

(2018) recognises this view and states that environmental concerns is not enough for households to start with energy efficiency measures. This is Step 1 of the Merger of Interests Strategy. An important distinction from IBB is that there is always at least one interest of at least one stakeholder, related to sustainability. Next, solutions for addressing these interests are sought. Also, a difference with IBB; the toolkit at hand is largely filled with sustainability interventions. The broader the definition of sustainability, the more comprehensive the toolkit becomes. Often the Sustainable Development Goals are used as a definition (United Nations Development Programme). This is Step 2 of the Merger of Interests Strategy.

Once there's a shared notion of the desirable interventions, actors move on to the third and final step of the Merger of Interests Strategy: finding a way to finance the solution. The fact that financing comes last does not mean it is not an important step in the process. The reason it comes last is because people tend to think about financing differently when they really want something. For example, despite having limited financial means, many university students own the most popular but expensive phones because they really wanted them. They saved money or found other solutions to be able to purchase these gadgets. The Merger of Interests Strategy taps into this dynamic: the desire to fulfil a need or desire becomes a driving force in realising a solution. The first two steps of the Merger of Interests Strategy primarily revolve around instilling this desire.

2.3. The Third Success Factor

The slogan for working with the Third Success Factor is 'together x3': wanting together, bringing together, and working together. In concrete terms, wanting together means striving to ensure that all stakeholders, including residents, endorse the choice of the selected measures for energy transition in the neighbourhood concerned. To promote this, energy measures must be brought together with what residents genuinely value (which means that professionals must expand their perspective to include other needs that are more important for residents than energy savings such as a safe residential environment, increased employment, health promotion, etc.). And because of these other needs this encompasses working together by energy transition professionals with parties that one is not accustomed to working with (Homemates).

2.4. The Sustainable Neighbourhood Action Program-approach

To support and inspire municipalities and their partners, the Canadian SNAP developed a step-by-step plan that also shares many similarities with the first two steps of the Merger of Interest Strategy. First, various means such as surveys, neighbourhood events, and workshops are used to determine what is happening in the neighbourhood. Special attention is given to what residents value and where they see opportunities. Based on this analysis it is determined what the ideal result should be (often referred to as *dream*). The emotional attachment of residents to their neighbourhood is considered the most important motivation for engaging in neighbourhood activities in this approach. In the second phase, sustainability themes that are important for the neighbourhood are identified, and then a co-creation action plan is designed with concrete measures. The concept of sustainability is broadly defined. The result of this approach is that residents have developed a more positive attitude toward sustainability." (Van Hal, 2019).

This overview determines the lens through which the authors of this paper look at the research results of the SDN programme in section 4. Only aspects related to (an inventory of) interests, a link between the energy transition and other interests, innovative financing structures and cooperation between professionals and residents and among professionals themselves are highlighted.

3. METHOD AND MATERIAL

To date, the SND experiment programme has produced eight publications presenting lessons and findings of the programme. All these publications are based on our research. Two of these publications are based on a very detailed study of all data available, one during the first year (the starting phase) (Uyterlinde, Van Hal, Kunst, Coen & Bouwman, 2019) and the second after the end of the first round of the programme (after three years) (Uyterlinde, Van Hal, Coen & Can, 2022). The data include interviews with programme participants, neighbourhood profiles, reports of individual support trajectories, reports of plenary meetings, logbooks, and reports of thematic workgroups.

A third publication describes the analysis of experiences during the fourth year in which the programme had a different format (Uyterlinde & Can, 2023). This describes the turbulent year of 2022. Various recent societal and geopolitical developments deeply impacted the living climate and policies for disadvantaged neighbourhoods during that year. For the purpose of this publication, several programme participants representing five selected neighbourhoods within the programme were interviewed.

Finally, in 2023 the programme published a paper in which experiences from four years of running the SDN programme and thirteen years with SNAP were compared. (Van Hal, Uyterlinde & Tom, 2023). In 2022, a series of three virtual meetings was organised which allowed representatives of both programmes to exchange their findings. These four publications form the basis of the results which are described in the following chapter.

4. RESULTS

This results section describes experiences with applying the Third Success Factor within the SND-programme based on the conclusions of the four publications described in the previous chapter. First observations from three different phases of the programme are provided for this purpose: (1) the starting phase (Uyterlinde et al., 2019), (2) three years on the road (Uyterlinde et al., 2022), and (3) after the turbulent year 2022 (Uyterlinde et al., 2023) Then, a comparison between four years of experimenting with the Dutch programme and thirteen years of employing the SNAP approach in Canada is discussed (Van Hal et al., 2023). The analysis of experiences during the turbulent year 2022 and the comparison between Canada and the Netherlands took place approximately around the same time.

4.1. Experiences with the Third Success Factor in Dutch Disadvantaged Neighbourhoods

4.1.1. The Starting Phase. The Third Success Factor involves relating the interests of stakeholders in a neighbourhood (including professionals and residents) to the energy transition. In Dutch policy documents, this is also referred to as utilising 'linking opportunities'. (Baart, 2019) (ELi, 2018) (WEE, 1998) During the starting phase of the SDN-programme, the following five thematic links were most referenced by the fifteen participating municipalities:

1. Energy Transition & Employment:

The participants' thoughts behind this: Unemployment rates tend to be high in disadvantaged neighbourhoods. At the same time, there is a shortage of technically educated workers to carry out the energy transition. So, in the starting phase of the SDN-programme municipalities wondered if gaining work experience related to the energy transition could benefit unemployed residents. The Technology Experience Centre that is being built in Utrecht was already an example of this link. This Centre aims to provide young people with training in the energy field.

2. Energy Transition & Health:

The participants' thoughts behind this: Health is related to a multitude of factors, including lifestyle, surroundings (such as socioeconomic status and employment), as well as environmental factors like air quality and noise pollution. Three of the fifteen municipalities searched for linkages between health and the energy transition. They thought, for example, of achieving improved air quality by means of good ventilation when renovating homes. However, concrete examples were rarely found in the starting phase in these fifteen neighbourhoods.

3. Energy Transition & Poverty and Debt:

The participants' thoughts behind this: Disadvantaged neighbourhoods are characterised by a relatively high number of residents facing poverty, and in some cases, debts. This makes the affordability of energy bills a crucial theme. On a policy level, all participating municipalities and housing associations were exploring ways to support residents financially. Examples of support were offering special financial arrangements or deploying so-called energy coaches for home visits.

4. Energy Transition & Climate Adaptation:

The participants' thoughts behind this: Resulting from climate change, the Netherlands is experiencing and expecting rising sea levels, heavy rainfall, and increasingly hot weather. Hence, some municipalities want to implement climate-adaptive measures in neighbourhoods. This could imply, for example, creating additional green spaces – thereby managing water and mitigating heat stress. The energy transition provides an excellent opportunity for these sorts of measures, according to these municipalities. Especially in neighbourhoods where the roads need to be laid open for the installation of a district heating network. However, concrete examples were rarely found in the starting phase in these fifteen neighbourhoods.

5. Energy Transition & Improvement of Public Spaces:

Some municipalities wanted to improve the appearance and quality of public spaces. The energy transition could offer significant opportunities for this as well. Making substantial changes to the underground infrastructure in public spaces may, for example, offer concrete opportunities to address parking issues, create safe and attractive pedestrian and cycling routes, or establish community gardens. However, concrete examples were rarely found in the starting phase in these fifteen neighbourhoods.

What stood out in the fifteen neighbourhoods in the starting phase of the SDN-programme is that oftentimes, professionals would propose linking opportunities without these being the result of a thorough analysis of the neighbourhood. Only in a few cases were linking opportunities suggested based on a clear vision and related objectives at the municipal level. An example of this can be found in Selwerd, Groningen. The transition process started with the selection of an overarching and unifying theme for that neighbourhood: health. After that the neighbourhood coordinator conducted an analysis of social issues of each neighbourhood, asking, for example, the following questions: are there individuals avoiding healthcare, is there poverty? Next, city planners were asked to design public spaces with the input of residents, gathered through various groups – from seniors and children to the local running group.

Another example of cooperation with residents is the approach taken by the municipality of Zoetermeer, which consulted residents by means of storytelling. In Nieuwborgen, the vision document for the village as was written by residents served as the basis for new policies relating to the energy transition on the neighbourhood level.

When asked why linking opportunities were not (or rarely) addressed, some municipalities mentioned resistance of other parties. This resistance often came from fear of the complexity of linking the liveability and sustainability challenges. At the other hand showed the case of Tilburg that the presence of an enthusiastic partner, in this case the local housing association, can greatly promote the chances of successful linking liveability and sustainability challenges. The importance of the role of local police officers (who have built a personal relationship with youth in the neighbourhood) in identifying linking opportunities or social professionals – such as the community builder in the municipality of The Hague – has also been emphasised.

Developments regarding physical neighbourhood renewal were found to have a major impact on local collaborations – both positively and negatively. The example of Kerkrade displays a positive side: two housing associations, the municipality, the regional government (Parkstad), and the province started a collaboration to achieve a vital and future-proof neighbourhood using an approach that combines restructuring of the neighbourhood and tackling privately-owned properties over a period of twenty to twenty-five years. Liveability and sustainability were synergised within this approach.

4.2.2. Three years in. Over the course of the three-year SDN-experiment programme, three more municipalities joined, whereas one dropped out after two years. The evaluation that took place three years in showed substantial differences between these eighteen participating neighbourhoods – not just in social and physical aspects, but also in how they had dealt with challenges, organised (collaborative) processes, and the extent to which they met their original goals.

Like the starting phase, it was evident that even after three years of experimenting, integrated ambitions were often (unintentionally, involuntarily, or unconsciously) narrowed down to sector-specific implementations of plans, measures, and activities along the way. This can be explained by a difference in interests, mindsets, and policy logics between professionals in different fields. Each field uses its own terminology and budgets – which, in some cases were subject to cuts. The fear of losing budget reinforced the focus on individual, sectoral tasks.

In most neighbourhoods, the primary focus lay on the technical side of the energy transition. However, in a few neighbourhoods, the starting phase revolved around residents' experiences. For example:

- In Groningen and Rotterdam, the project manager initiated a broad exploration of the neighbourhood across various policy domains. This was done by speaking to residents and other stakeholders and collecting data and policy documents about the neighbourhood.
- In Zoetermeer, the project manager started with a data-driven neighbourhood analysis, followed by analysing the views of residents (storytelling was used to gain insights into their experiences).
- In Dordrecht, the project manager (who was also neighbourhood manager at the time) focused on residents’ perspective from the outset, using a social design approach.

In neighbourhoods where a unifying and integrating (policy) framework was established early on in collaboration with various policy domains, it proved to be easier to work in a more integrated manner. This was particularly the case in neighbourhoods where the municipality actively addressed other area-specific challenges alongside the energy transition.

Involvement of external parties in some cases resulted in letting go of traditional, project-based, and systematic approaches, due to the new insights and experimental methods they were able to introduce. Not only did these external parties sometimes alleviate the workload of project managers; they also helped to loosen entrenched structures and practices, thereby driving change.

In some neighbourhoods, there was an open, playful, and approachable dialogue with (often a relatively small group of) residents from the beginning in order to explore their wishes and needs relating to the neighbourhood.

Inspiring examples of civil service entrepreneurship were encountered in multiple neighbourhoods. For example, in Groningen, two civil servants mobilised residents to help plan the redevelopment of a street where the underground was reconstructed. The *gas-free living room* for residents in Rotterdam is another example.

The COVID-19 pandemic made it considerably more challenging to establish direct (face-to-face) contact with residents from early 2020 onwards. However, it did not stop municipalities from making serious attempts to connect with residents. In Nieuwborgen, the instalment of small energy-saving measures was used as an opportunity to truly engage with residents. In Nijmegen, professionals went into the neighbourhood on electric cargo bikes and baked pancakes for residents on an induction stove. Deventer also used the electric cargo bike, filled with energy-saving tools. The above examples show a creative and playful approach. Contact with residents was sought in an open manner, often providing professionals with crucial insights and information for the further planning process. However, in quantitative terms, the reach of these methods has been limited, as these tend to be incidental or one-time events. As such, they have limited impact on strengthening social structures and building sustainable networks in the neighbourhood.

Discussion with participants of the SDN-programme has brought to light that involving residents is sometimes seen as a compulsory step; something that must be done out of necessity (for instance because the housing association requires the approval of 70 percent of tenants). Policymakers don't always feel comfortable engaging with residents when there is no concrete plan or offer for them (yet) – they want to avoid appearing unprepared. However, when residents are engaged only when plans are already in place and technical uncertainties have been minimised, they may be left feeling excluded or sidelined. Radio silence can furthermore lead to suspicion among residents, as the experiences in the programme have shown.

The experiment programme showed also that unforeseen events can disrupt the continuity of what is already an unpredictable process. A much-observed disruptive event is the turnover of key professionals in the neighbourhood. A painful lesson drawn from three years of experimenting in eighteen neighbourhoods has been that municipal staff (dis)continuity can be a decisive factor in the progress of a neighbourhood approach. During the time span of three years, there had been significant staff turnover in the participating neighbourhoods which thus hindered successful collaborative projects. The original core team only remained largely intact during the three years in a handful of neighbourhoods. The same applied to neighbourhood officials who serve as mediators between the municipal organisation, residents, and other local organisations. They also changed jobs very often.

Opportunities for synergy between technical and social activities were indeed realised in the participating neighbourhoods during the first three years. These often involved people-centred interventions that aimed to benefit residents by investments in their neighbourhood. For example, housing associations in Tilburg (*Dubbel Duurzaam,* translated: Double Sustainable) and Utrecht (social renovations) conducted home visits focused on the energy transition together with the municipal social neighbourhood team to get to know tenants better and also provide appropriate help for social issues at home. In Groningen, the *Wijkbedrijf* (neighbourhood company) mobilised residents to participate in neighbourhood initiatives.

There are also compelling examples of area-specific synergy opportunities where investments in energy infrastructure were used to improve the quality of public spaces, such as the redevelopment of the street Plutolaan in Groningen and the renewal of the Cromvliet parc in The Hague. Promisingly, these examples are now being replicated in other municipalities. For instance, the *Dubbel Duurzaam* approach is now also being implemented in Nijmegen, and drawing from the approach of Plutolaan in Groningen, the municipality of Utrecht is exploring the possibility of applying integrated project management for underground measures in streets of Utrecht.

Despite various participants having observed little to no progress within their own trajectories, the evaluation shows that organisations and collaborations are indeed transforming, with different work methods and thought processes being applied, and in search of different principles and values. These are meaningful steps that enable new solutions. In the studied neighbourhoods, this led to small breakthroughs that often fly under the radar. Mostly, this is because the fruits of these efforts are only harvested at a later point; when more people understand that change is inevitable and have seen what changes are possible. Overall, the Third Success Factor can be said to gradually receive more attention within the program, albeit slowly.

4.1.3. After the turbulent year 2022. In 2022, several societal and geopolitical developments coincided that deeply impacted Dutch society. These developments also affected (and continue to affect) lives in and policies for disadvantaged neighbourhoods. The war in Ukraine put pressure on the supply and affordability of energy, caused significant inflation, and as such increased the risk of being caught in the poverty trap for low-income households. At the same time, trust in institutions has been declining in the Netherlands. This trend has been noticeable for some time but has been further exacerbated – particularly in disadvantaged neighbourhoods – resulting from events such as the political benefits scandal, the consequences resulting from gas winning in Groningen, and government policies during the COVID-19 crisis.

The above-described developments had great impact on disadvantaged neighbourhoods. Liveability drifted further out of sight; many residents found themselves in survival mode. The rising energy prices did, however, align the interests of residents of disadvantaged neighbourhoods (affordability of energy bills and increased living comfort) more with interests the government pursues by means of the energy transition. Residents suddenly needed less convincing about the value of energy transition than before. This did not diminish the importance of the voices of residents, but it did change the tone of the conversation.

The above-described developments increased pressure and resulted in precedence being given to core tasks and short-term interests. Consequently, the Third Success Factor received less attention. Rather than adopting a more holistic approach towards challenges and investing in collaborations ad-hoc policies took precedence. Projects were rushed to alleviate the situations of residents who were facing existential uncertainty. Examples of crisis measures are deployment of energy coaches and the opening of neighbourhood centres where residents were provided with warm shelter. Many municipalities contracted external parties for the execution of these plans. Although many of these interventions turned out successful, coordination and management were at times sacrificed. As such, opportunities to engage with residents, build trust, and update them on developments in their neighbourhood were not utilised.

However, in Dordrecht, the municipality engaged local social entrepreneurs and active residents in their plans. They were subsequently able to strengthen or even solidify their position within the neighbourhood approach. In Rotterdam, despite the changed circumstances, the municipality maintained continuous contact with residents, contributing to growing trust and support among residents.

At times, it was necessary to engage independent intermediaries to make progress. Both in Groningen (Grunneger Power) and in Amsterdam (consulting firm STIPO), intermediary parties proved to be trusted, including in cases where trust in the municipality was lacking. Intermediary parties serve the neighbourhood's interest and, from that position, can mobilise both the people living in the neighbourhood as the more distanced professionals.

4.2 A comparison of SNAP's and the SDN's experiences

The Canadian SNAP has served as a significant source of inspiration for the Dutch SDN experiment. However, a comparison of the experiences and findings from the two programmes revealed that this works both ways. For example, within the Dutch programme, the general sentiment was that the subject to the experiment programme were progressing exceptionally slowly. The Canadians, however, were deeply impressed by the speed at which results were achieved in the Netherlands, especially seeing the complex circumstances, such as the pandemic. Furthermore, mutual lessons were learned concerning the Third Success Factor. We conclude this results chapter with a summary of the key lessons in this regard:

- Involve citizens from the start and throughout. Let the project be informed by the world as perceived through their eyes.
- Adopt an overall neighbourhood revitalisation strategy. Develop specific action plans and project designs in each neighbourhood (but be ready to adapt quickly). The detailed outcome differs of course from one place to the other and depends, amongst others, on the outcome of the following actions:
- Consider how the local population views the government and other organisations. Is this largely negative? Consider communicating about the projects from another source.
- Build in time for devising a high-quality neighbourhood analysis.
- Link top-down and (existing) bottom-up initiatives in your strategy.
- Customise this neighbourhood strategy to the social interests and spatial characteristics of the area. It is important to be adaptive and to tailor the project to local interests, challenges and characteristics. Finding a good balance between the aims of the municipality and the possibilities relating to the social dynamics in the neighbourhood in question is key.
- Work across policy fields. Adopt an integrated approach, by involving relevant policy fields based on the results of the neighbourhood analysis and the input from residents.
- Involve other parties besides municipalities such as NGOs, local entrepreneurs, and private builders. This could be an important model for future private-public partnerships toward ESG (Environmental-Social-Governance) goals.
- Be patient. Especially the early stages, meant for getting to know the neighbourhood and its residents and other parties, take a long time.
- Seek out trusted partners on site – because of the importance of relationship building. This can be someone who has been active in the neighbourhood for a long time and who can build trust among residents and other parties.
- Be prepared for staff turnover. To mitigate the risk posed by a change of staff, make sure that every party sends multiple people to participate in key meetings or require sign-off by senior levels from each organisation at regular intervals.

And keep in mind:

- The importance of an independent broker/third-party facilitator – which reinforces the need to have an external force to help facilitate this work and make it happen.
- The importance of a streamlined action planning process – focusing on collaborative, integrated implementation helps to get on with it faster.
- The importance of integrated design – it is important to understand different ways in which this may play out in projects.
- The importance of personal dedication – especially among project managers to achieve progress and the ability to adapt/innovate.
- The importance of supportive higher-level governments. Also, higher-level governments (national and regional) should identify a rationale for their investment in a neighbourhood-oriented programme. It is helpful when the neighbourhood-oriented programme delivers outcomes valued by higher-level governments.

5. CONCLUDING DISCUSSION

We begin this concluding discussion with a brief summary of the background of this paper.

Working with the Third Success Factor of renovations with energy ambitions elaborates on the Merger of Interests Strategy for the existing housing environment. The Merger of Interests Strategy aims to promote enthusiasm for sustainability measures by, using an inventory of interests as a starting point, arriving at solutions to sustainability issues that bring together as many interests as possible. Creativity and cooperation are two key prerequisites for creating such solutions. The construction sector at large formed the basis for the developments of this strategy.

The Third Success Factor focuses specifically on energy transition issues in the existing residential environment (homes and neighbourhoods). The Canadian SNAP was found to work on sustainability issues in the existing residential environment according to a strategy very similar to what is envisioned by working with the Third Success Factor. They do so in a variety of neighbourhoods, but their work in disadvantaged neighbourhoods in particular, was an important source of inspiration for the Dutch SDN-programme. This paper has described experiences gained from working with the Third Success Factor in this programme as well as experiences shared by SNAP and SDN.

When we take a closer look at the development from the Merger of Interests Strategy to working with the Third Success Factor in Dutch disadvantaged neighbourhoods, a few things stand out.

The inspiration for the Merger of Interests Strategy lies in interest-based bargaining (IBB) theories, specifically Fisher and Ury's Getting-to-Yes theory (Fisher and Ury, 1983). One of the four principles of this theory is literally reflected in the Merger of Interests Strategy: focusing on interests rather than positions (identifying the interests of involved parties constitutes step 1 of the Merger of Interests Strategy). One of the conditions for working with the Merger of Interests Strategy, the deployment of creativity, is based on another principle of Fisher and Ury. Namely: generating a variety of options before setting on an agreement. This condition is closely related to the second step of the Merger of Interests Strategy: addressing the inventoried interests through sustainability measures (using the Sustainable Development Goals as a definition for sustainability). IBB and the Merger of Interests Strategy are thus clearly an extension of each other.

Working with the Third Success Factor is summarised with the slogan 'together x3': wanting together, bringing together and working together. In concrete terms, wanting together means striving to ensure that all stakeholders, including residents, endorse the choice of the selected measures for energy transition in the neighbourhood concerned. To promote this, linking opportunities are sought; combinations of energy-related measures with what greatly concerns people. This is all about interests. And because the interests of residents may lie in various areas, such as a safe residential environment, increased employment, health promotion, etc., it is particularly important to cooperate with parties that professionals working in the energy transition are not typically used to working with (health professionals, police, landscape designers, etc.).

However, the literal concept of interests no longer appears in the slogan of the Third Success Factor and there is not sequentially in it either. This makes it possible to read it as: ‘Introduce linking opportunities so that residents are more likely to want the energy transition. To bring those linking opportunities in practice, cooperation is needed’. If the slogan is interpreted this way, the linking opportunities can be made up without involving residents. They will then not be based on the values of residents (which can only be found out by getting in touch with them). In this respect, SNAP's strategy is closer to the Merger of Interests Strategy and IBB then the SDN-programme because the starting point there is a thorough analysis of the neighbourhood that always includes an inventory of the interests of the residents based on interaction with them. After this analysis, professionals related to a SNAP project, in collaboration with residents, seek solutions that meet many of those interests. Thus, the second step of the Merger of Interests Strategy meets the SNAP strategy too.

Looking at the SDN findings, it is striking that the focus is mainly on linking opportunities and the resulting collaboration. Moreover, in many cases, linking opportunities are established without contact with residents. So, without their interests being inventoried. It can be concluded, for that reason, that the slogan of the Third Success Factor has almost always been interpreted within the SDN-programme differently from how it was intended. The analysis of interests, as an important point of attention at the beginning of the process, has become rather distant. This being regrettable is evident from the comparison between SNAP’s and SDN’s experiences; the added value of a thorough inventory of interests combined with a comprehensive analysis of the neighbourhood in a broad sense emerged clearly from this comparison.

The conclusion based on these findings could therefore be that the slogan of the Third Success Factor requires adjustment. It is not so much about wanting together, but about making an analysis of the interests of stakeholders, including residents, together. This changes the message of the Third Success Factor. There will then be, as in the Merger of Interests Strategy, a sequential approach.

Hence, working with the Third Success Factor of renovations with energy ambitions means: (1) identifying interests together, (2) bringing them together with the energy ambitions and (3) establishing good forms of working together. The slogan then still reads together x3, but without the risk of skipping the essential starting phase of identifying interests.

REFERENCES

Baart, J. (2019). *Energie voor kwetsbare wijken*. Rotterdam: Erasmus Universiteit Rotterdam and Delft: Technische Universiteit Delft.

Batshalom, B., & Cohen, M. (2002). *Negotiating a green mindset*. International Conference Sustainable Building, Oslo, Norway.

CfCaES (Center for Climate and Energy Solutions). (2015). *Outcomes of the U.N. Climate Change Conference in Paris*.

City of Toronto. (2023). *Tower Renewal Program.* Retrieved from https://www.toronto.ca/community-people/get-involved/community/tower-renewal/#:~:text=The%20City%27s%20Tower%20Renewal%20Program,and%20revitalize%20the%20surrounding%20community.

Fisher, R., & Ury, W. (1983). *Getting to Yes: Negotiating agreement without giving in*. New York: Penguin Books.

Getting to Yes: Interests vs. Positions. (2015). Retrieved from https://www.youtube.com/watch?v=MuJyDRgONls&ab_channel=WilliamUry

Hal, A. van, Uyterlinde, M., & Tom, N. (2023). *Learning from each other in times of change.* Den Haag: Platform31

Hal, A. van (2016). *The third success factor of renovations with energy ambitions,* conference SBE16 Toronto, Regenerative and Resilient Urban Environments, 19/20 September 2016, Toronto.

Hal, A. van (2014). *The Merger of Interests 2.0, the story behind a perspective shift*. Breukelen: Nyenrode Business Universiteit.

Hal, A. van, Uyterlinde, M., Coen, M. (2019). *De derde succesfactor bij het aardgasvrij maken van wijken*. Den Haag: Programma Aardgasvrije Wijken. Retrieved from https://www.aardgasvrijewijken.nl/documenten/handlerdownloadfiles.ashx?idnv=1442158.

Homemates. (n.d.). Retrieved from https://homemates.nl/

Johansson, M., Gentile, N., & Neij, L. (2021). Energy efficiency behavior in the built environment—an assessment of current evaluation practices in the Nordic countries. *Energy Efficiency Journal, 14*, 27. https://doi.org/10.1007/s12053-021-09938-z

Kennedy, B.L. (1999). *Interest-Based Collective Bargaining, a success story.* IRC Press, Queens University.

Klimaatakkoord. (2018). *Achtergrondnotitie ten behoeve van Sectortafel gebouwde omgeving*, Notitie Wijkgerichte Aanpak.

Lidth de Jeude, M. van, Mastop, J., Coen, M., Uyterlinde, M. & Van Hal, J.D.M. (2017). *De derde succesfactor ontrafeld.* Amsterdam: ECN.

Middelkoop, M., van Polen, S., Holtkamp, R., & Bonnerman, M. (2018). *Meten met twee maten. Een studie naar de betaalbaarheid van de energierekening van huishoudens.* Den Haag: PBL.

Pelenur, M. (2018). Household energy use: a study investigating viewpoints towards energy efficiency technologies and behavior. *Energy Efficiency Journal, 11*, p. 1825–1846. https://doi.org/10.1007/s12053-018-9624-x.

RLI (2018). *De stad als gezonde habitat. Gezondheidswinst door omgevingsbeleid.* Den Haag: Raad voor de leefomgeving en infrastructuur.

Schellekens, J., Oei, A., & Haffner, R. (2019). *De financiële gevolgen van de warmtetransitie. Een onderzoek naar de investeringsuitdaging, effecten op energie-betaalbaarheid en het potentieel van (nieuwe) financieringsvormen*. Ecorys.

Sustainable Neighbourhood Action Program, & Toronto and Region Conservation Authority. (2020). Retrieved from https://trcaca.s3.ca-central-

1.amazonaws.com/app/uploads/2020/12/22150004/3327-SNAP-SRW-FindingsReport_FA_WEB.pdf.
Torkington, S. (2023). *1 year on - the global impact of the war in Ukraine*. Retrieved from https://www.weforum.org/agenda/2023/03/ukraine-crisis-food-energy-poverty/.
United Nations Development Programme. (n.d.). Retrieved from https://www.undp.org/sustainable-development-goals?gclid=CjwKCAjwu4WoBhBkEiwAojNdXogpex4TiZgpng_RAKR8Rh4O7MKMwjpTfNmymx5HzKC2A38X1_Y5tBoCi2IQAvD_BwE.
Uyterlinde, M., Van Hal, A., Kunst, A., Coen, M., & Bouwman, R. (2019). *Betere wijken dankzij de energietransitie?* Den Haag: Platform31.
Uyterlinde, M., Van Hal, A., Coen, M., & Can, E. (2022). *Samen naar een duurzame en leefbare wijk.* Den Haag: Platform31.
Uyterlinde, M., & Can, E. (2023). *Wijken verduurzamen in turbulente tijden.* Den Haag: Platform31.
Vringer, K., Van Middelkoop, M., & Hoogervorst, N. (2016). Saving energy is not easy: An impact assessment of Dutch policy to reduce the energy requirements of buildings. *Energy Policy, 93,* 23-32. https://doi.org/10.1016/j.enpol.2016.02.047.
WRR (1998). *Ruimtelijke ontwikkelingspolitiek. Den Haag:* Sdu Uitgevers.

Settling for colder homes as energy prices rise: evidence from 4200 households in Great Britain

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Abstract

2022 saw steep rises in energy prices in Great Britain. With gas space heating responsible for around half of domestic energy consumption, reducing home thermostat setpoints has the potential to significantly reduce demand and household energy bills.

The Smart Energy Research Lab (SERL) has been collecting smart meter and contextual data from around 13,000 GB households since 2018. In early 2023 SERL sent a survey to participants about their recent energy-saving behaviours along with dwelling and household information (including income and usual heating thermostat setpoint), receiving over 5,000 responses.

This paper presents a statistical analysis of how self-reported SERL participant temperature setpoints changed in winter 2022/23 compared with those they had reported previously. We analyse the variation in temperature settings with household (e.g. size, ages, income) and building (e.g. floor area, EPC rating) characteristics. We combine smart meter and financial circumstance data to identify those likely to be in fuel poverty and compare the thermostat setpoints of this group with the wider sample. We also investigate the characteristics of the households most likely to have reduced their setpoint.

The results show a significant reduction in reported thermostat setpoints in winter 2022/23 compared to winter 2020/21. The proportion of households reporting a setpoint lower than 18°C increased from 6.7% to 15.2%. While there are obvious energy efficiency benefits from thermostat reduction, the large share of households with temperatures lower than the recommended minimum highlights a concern for policy makers.

1 Introduction

This paper investigates heating temperature settings for a group of 4202 homes in Great Britain, and how these changed following steep energy price rises in 2022. Domestic heating is responsible for more than a quarter of UK energy demand (Ofgem, 2016). Reducing the temperature to which homes are heated has clear energy efficiency benefits (EST, 2022). However, those aiming to influence heating behaviour are also conscious that too low an internal temperature could cause health problems. Temperatures below 18°C in living rooms in winter are not recommended (Public Health England, 2015) as these may cause or exacerbate medical conditions or lead to damp and mould.

The Smart Energy Research Lab (SERL) brings together half-hourly resolution household-level electricity and gas demand data with detailed socio-technical and weather data for a representative sample of over 13,000 households in Great Britain (Webborn et al., 2021). Participants completed a survey when they were recruited (between 2019 and 2021) which included a question about the usual temperature they set their heating controller (UKDS, 2023). This question should be set in the context of a typical British heating system. 90% of English homes have boiler systems with radiators and for 86% of homes the central heating is fuelled by gas (MHLC, 2021).

The sharp rise in energy prices which followed the Russian invasion of Ukraine in February 2022 brought public attention to potential for saving energy by reducing thermostat settings. Typical UK annual energy bills increased by 86% between winter 21/22 and winter 22/23 (DESNZ, 2023; Ofgem, 2021). Those struggling to afford rising energy bills sometimes had to choose whether to "heat or eat"; a shocking dilemma in 21st-century Britain highlighted by charities and in the media (Age UK, 2021; Viner, 2023).

A survey designed to investigate changes in energy using behaviours in this period of high prices was sent to SERL participants in January 2023. From answers received we can identify 4202 households which reported their heating temperature setting both in the recruitment survey and the 2023 follow-up survey. This paper analyses the trends in temperatures reported and the characteristics of those households most likely to reduce their setpoint.

We also investigate thermostat-setting behaviour linked to fuel poverty indicators. There are many ways in which Fuel Poverty can be measured (Moore, 2012; Siksnelyte-Butkiene et al., 2021; Thomson et al., 2017; Tirado Herrero, 2017). We use actual energy usage from the SERL observatory and calculate two metrics introduced by Waddams Price (2012) : Expenditure Fuel Poverty and Feeling Fuel Poor, explained further in Section 4.3. It was not possible to replicate British national fuel poverty definitions since these are not based on actual consumption, but derived from modelling the energy required to heat the home to a comfortable level (BEIS & BRE, 2020; DESNZ & BRE, 2023).

From the point of view of energy efficiency and emissions reduction, lower setpoints are beneficial. However this needs to be balanced with the potential negative effects of temperatures below the recommended level of 18°C (Public Health England, 2015), particularly on those who are vulnerable. Our interest in the changes in setpoint temperature leads to the following research questions:

1. How do heating temperature setpoints reported in early 2023 compare with those reported by the same household in the SERL recruitment survey (2019-2021)?

2. How do heating temperature setpoints reported in early 2023 vary with household and dwelling characteristics?
3. Which household/dwelling characteristics are associated with setpoint reductions?
4. Which household/dwelling characteristics are associated with setpoints below the recommended level of 18°C?

2 Method

2.1 Data sources

The SERL "recruitment survey" was completed by approximately 13,000 SERL participants who were recruited in September 2019, September 2020 and January 2021 (Webborn et al., 2021). This survey included the question "What temperature do you set your [heating] controller to in the winter months for the late afternoons or evenings?" Other questions asked about dwelling age and type (detached, semi-detached etc) (UKDS, 2023).

In order to investigate the impact of the large increase in energy prices seen in winter 202/23 the SERL Follow Up Survey 2023 was sent to 12,001 households in February 2023 and 5,829 responses were received. This survey included the question "During this winter, to what temperature do you set your heating controller for late afternoons or evenings?". Other questions asked about household income and how difficult it was to meet heating costs.

4,202 participants provided temperature setting information in both surveys, and it is this sample which provides the basis for the analysis of changes in temperature settings over time. The SERL Observatory contains Energy Performance Certificate (EPC) information for those homes which have an EPC (approximately 60% of the Observatory homes). This was used to provide information about EPC rating and floor area for the analysis.

This contextual information from surveys and EPCs allows our sample to be compared with the general English building stock. There is a higher proportion of owner-occupied homes (90.3%) compared to 65.1% of homes in the 2021 English Housing Survey (EHS) (DLUHC, 2022). The age profile of the properties is similar (36.8 % before 1949 compares with EHS 34.9% before 1944). Table 1 below shows there are some differences in the distribution of EPC ratings, with a higher proportion in the E/F/G categories.

Table 1 Comparing sample EPC split with general English building stock (DLUHC, 2022)

EPC rating	% of sample with EPC	% of owner-occupied homes in England (DLUHC, 2022)
A or B	6.0%	2.9%
C	29.1%	40.0%
D	45.5%	46.8%
E	16.3%	7.8%
F or G	3.1%	2.5%

In addition to the contextual information from the surveys and EPC data, this study drew on the smart meter data available in SERL. Data for 2022 annual gas and electricity consumption for each home was used to derive the fuel poverty indicator as described in section 2.2.

2.2 Analysis

The data processing (using R version 4.1.2), was carried out in a secure computing environment provided by the UCL Data Safe Haven. The individual survey and smart meter data is confidential and participants are assured that no information that allows individual homes to be identified will be published. Statistical data control processes include the requirement for no statistics from groups of less than 10 homes to be divulged. Where data from small groups has been suppressed, this is noted in the captions.

The income data from the 2023 survey was combined with the annual energy consumption to provide an "Expenditure Fuel Poverty" (EFP) indicator of households spending more than 10% of their income and energy bills (Waddams Price et al., 2012). A number of assumptions were made for this calculation:

- The survey asked participants to choose an annual income band (e.g. £30,00 to £40,000). The band midpoint was used in the calculation (£105,000 for the "above £100,000" band).
- It was assumed that the energy tariff for all households was the same as the Energy Price Guarantee cap level for January-March 2023. This level, set by the government, varies by region and payment method (DESNZ, 2023)[1]. Some households may have more favourable tariffs from their suppliers but the UK trend was for all supplier to set prices at or extremely close to this cap level. This annual estimate clearly does not represent actual expenditure for a year in which variable tariff levels are changing at 3 or 6 month intervals. It assumes there is no change in energy demand between 2022 and 2023.
- The annual expenditure for gas and electricity was calculated based on the annual demand for the calendar year 2022 recorded by the smart meters. Costs for non-metered fuels (oil, LPG etc) were not available from SERL data and so were not included.

The binary variable FFP was used to indicate those households which answered "no" to the question "During the cold winter weather, can you normally keep comfortably warm in your living room?" and additionally respond that they gave this answer because they "you feel it is difficult to afford the fuel to heat your home" (this is the same combination of questions and answers to which Waddams Price (2012) originally gave the label "Feeling Fuel Poor").

A final indicator of a potentially fuel poor household, "struggling to pay", identified those respondents who replied "fairly difficult" or "very difficult" to the question "How easy or difficult is it for you to meet your heating/fuel costs?".

Comparisons of mean temperature setting and odds ratio for setpoint reduction were carried out for subsamples with particular characteristics, listed in Table 2 below. For binary characteristics the comparison was between those for which the condition was true or false. For categorical variables the category with the greatest number of households was taken as the reference case with which to compare the others.

The number of households in each of a set of categories does not necessarily add up to the total sample size of 4,202 as some data is missing. Questions which were answered "don't know" or "prefer not to say" were not included in the analysis.

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[1] Subsides and support to households including the Energy Bills Support scheme discount of £400 over the period October 2022 to March 2023 were not included in the calculation, as the total amount for each household was unknown.

Likelihood of reducing the thermostat was analysed in addition to mean setting, since different groups had different mean temperature settings in the recruitment survey, so a lower meant setting in 2023 does not necessarily imply a higher likelihood of reduction.

Table 2 Household and building characteristics tested for association with mean temperature setting / odds ratio for temperature reduction

	Class of characteristic	**Binary / categorical**
Number of occupants (reference 2)	Household	Categorical
Household member over 65	Household	Binary
Household member over 85	Household	Binary
Household member under 5	Household	Binary
Household annual income band (reference £20k-£30k)	Household	Categorical
Floor area band (reference 50-100m^2)	Building	Categorical
Dwelling type (reference detached)	Building	Categorical
Dwelling age (reference 1950-1975)	Building	Categorical
EPC rating (reference D)	Building	Categorical
EFP	Fuel poverty indicator	Binary
FFP	Fuel poverty indicator	Binary
Struggling to pay	Fuel poverty indicator	Binary

A binary variable "reduction" was set to true if the reported temperature in 2023 was lower than that in the previous survey, and false otherwise. The odds ratio (OR) for the likelihood of reduction for a particular category compared to the reference was calculated using the R epitools package (Aragon et al., 2020).

The following explanation of the use of OR in an analysis of energy efficiency is based on that in Hamilton et al., (2014). The OR represents the odds of an outcome (e.g. reduction in setpoint) in a group, given a particular characteristic (e.g. household member under 5 years old) over the odds of not having that outcome given the same characteristic. If an outcome is associated with a characteristic the OR is greater than one. If an outcome shows no association with a characteristic the odds will be the same in both groups (i.e. OR= 1). If an outcome is associated with a lack of a feature the OR is less than 1. Upper and lower confidence limits (95%) are used to assess significance of OR results: where the upper confidence level is >1 and the lower confidence level is <1 there is no evidence of significant association.

3 Results and discussion

3.1 Variation in setpoint temperatures

For the group of 4202 homes with settings reported in two surveys, the mean reported setpoint decreased from 20.2°C to 19.2°C. A t-test confirmed that the difference in means is significant ($p<<0.01$).

Table 3 shows mean and standard deviation of temperature setting for homes with reported setpoints the original survey by year of survey completion. This indicates that the 2023 decrease is a step change rather than the result of a gradual trend over time, since there was very little change in the mean between 2019 and 2021. In the analysis that follows all the recruitment survey results are grouped together rather than separated by date of survey.

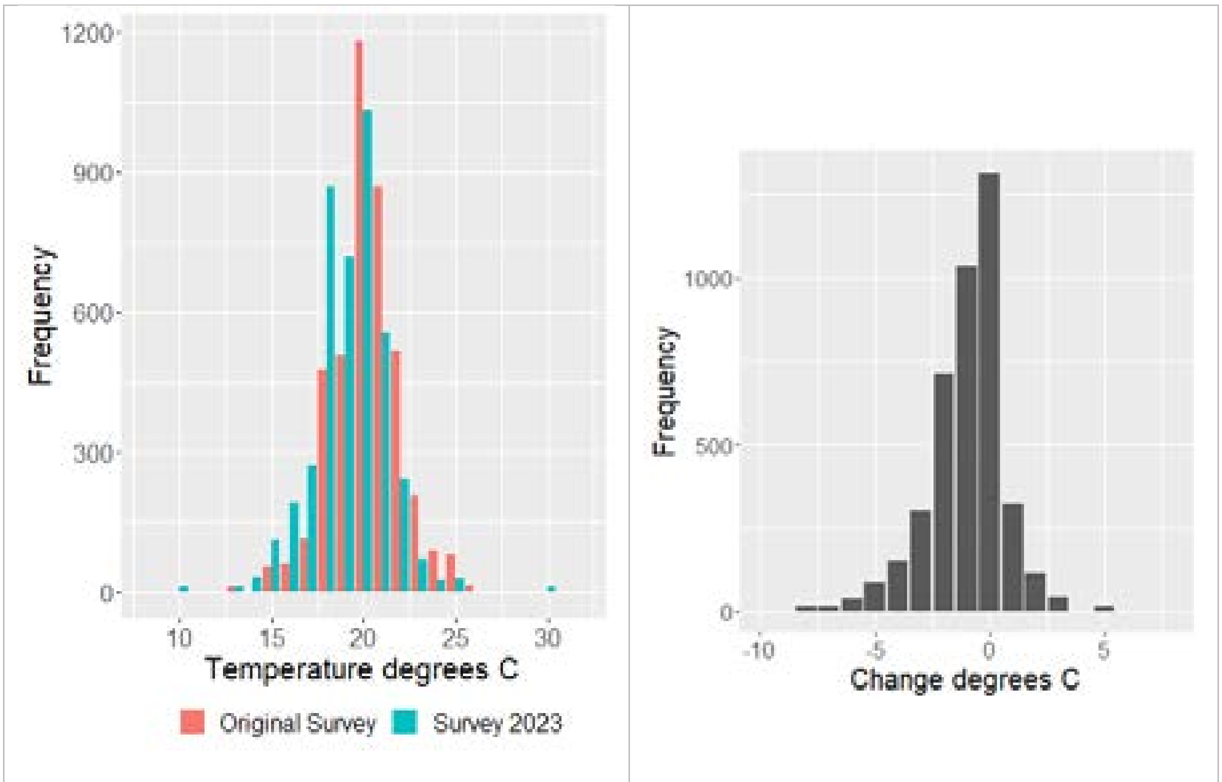
Figure 1 shows histograms of the two survey setpoint results and of the difference between these. It can be seen that, while the most common setting for both surveys is 20°C, a new peak at 18°C appears in the 2023 results. The proportion of homes with setpoints <18°C increases substantially (from 6.7% to 15.2%).

Figure 2 shows the sample divided by level of reduction (or increase). The largest group is those who reduced by over a degree. Around a quarter of the sample did not change their setting

Table 3 Mean temperature setting reported by survey year

Recruitment survey year	N	Mean of reported thermostat temperature (°C)	Standard deviation of reported thermostat temperature (°C)
2019	1264	20.49	2.14
2020	2254	20.46	2.20
2021	6222	20.35	2.46
All recruitment surveys	9740	20.35	2.37
All 2023 survey (unmatched)	4947	19.21	2.28

Figure 1 Histogram of temperature setting and change between surveys (bars <10 suppressed)



Thermostat settings reported in 2 surveys | Change in setpoint

Figure 2 Level of reduction in temperature setting

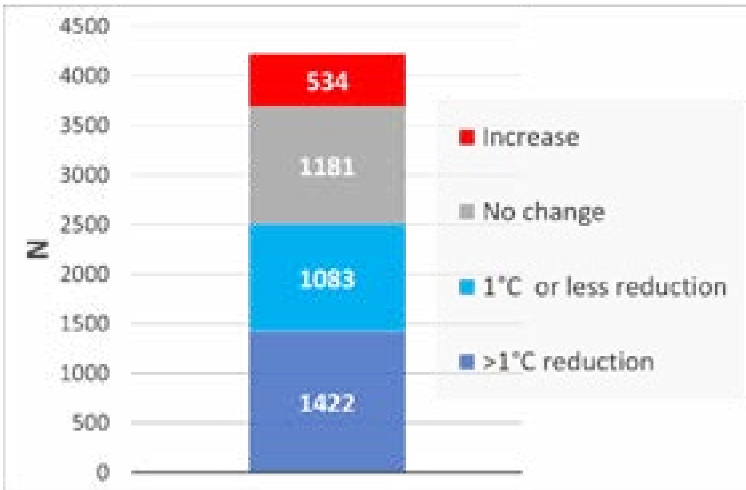


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Table 4 shows mean setpoints from both surveys for subsamples grouped by characteristic. The results for t-test comparison of means are shown, with categories where there is a significant ($p<0.05$) difference in the mean setpoint highlighted in yellow. The percentage of setpoints in 2023 <18°C is also included.

Homes with a single occupant have a significantly lower mean setpoint than those for multi-person households. The <£10,000 annual income category has a lower mean temperature than the reference £20,000-£30,000 group and the highest income band (>£100,000) has a significantly higher mean. Over a quarter of the lowest income bands is reporting thermostat settings under 18°C, as are more than a fifth of those living in social rented housing.

Households with someone over 65 present have a higher setpoint than those which do not contain pensioners, and the difference is greater for households with a member over 85 years. No significant differences were seen for households with a child under 5.

The two oldest categories of homes are the only ones which show a significant (but small) difference in setpoint from the reference category (those built 1950 to 1975). The homes with floor area of 150-200m^2 had higher mean temperatures than the reference 50-100m^2 group. Homes with EPC A or B have a significantly higher setpoint than the reference category (EPC D). This could be because it is both easier and cheaper to maintain warmer temperatures in these well-insulated homes.

3.2 Characteristics of homes where setpoints were reduced

Table 4 shows the odds ratio for whether the group is more likely to reduce thermostat setpoint than the reference category. Those categories where there is confidence that the odds ratio is lower than 1 (upper confidence interval <1) are highlighted in blue; those where the odds ratio lower confidence interval is greater than 1 (i.e. more likely to reduce) are highlighted in green.

Households with members over 65 were less likely to reduce the thermostat setting than those without, but the presence of a child under 5 made no significant difference to the likelihood of reducing the setpoint. No significant differences are seen in reduction behaviour by income band or number of occupants.

Table 4 Statistics for subsamples grouped by characteristics. T_{2023} is mean setting reported in 2023 survey, ΔT is change in setting from that reported in recruitment survey. Categories where there is a significant) difference in the mean setpoint highlighted in yellow Categories where there is confidence that OR <1 highlighted in blue; those with confidence OR>! are highlighted in green

Characteristics	N	T_{2023}	ΔT	% < 18°C	t-value	p -value	Odds Ratio		
							value	95% CI	5% CI
Household characteristics									
Household member over 65	2343	19.34	-0.97	13%	4.76	0.000	0.82	0.93	0.72
Household member over 85	198	19.67	-0.87	13%	2.93	0.003	0.67	0.90	0.51
Household member under 5	2343	19.24	-1.01	15%	0.29	0.773	1.06	1.42	0.79
Size of household Reference 2 people	1846	19.33	-0.90	14%					
1 person	941	18.85	-1.24	20%	5.27	0.000	0.98	1.15	0.83
3 people	443	19.26	-0.95	14%	0.61	0.545	1.07	1.32	0.86
4 people	346	19.25	-0.97	12%	0.64	0.521	1.18	1.50	0.93
Household annual income Reference £20k-£30k	719	19.15	-1.11	15%					
Below £10k	139	18.56	-1.36	28%	2.04	0.043	0.90	1.31	0.62
£10k-£20k	641	19.00	-1.28	21%	1.13	0.260	0.92	1.14	0.74
£30k-£40k	591	19.29	-0.93	15%	-1.26	0.208	0.97	1.21	0.77
£40k-£50k	483	19.28	-0.89	12%	-1.08	0.278	1.00	1.27	0.79
£50k-£60k	315	19.19	-0.93	15%	-0.30	0.761	1.00	1.31	0.76
£60k-£70k	230	19.15	-1.12	17%	-0.01	0.993	1.17	1.59	0.86
£70k-£80k	157	19.36	-0.85	11%	-1.26	0.208	1.10	1.58	0.78
£80k-£90k	139	19.12	-1.05	15%	0.16	0.875	0.95	1.39	0.66
£90k-£100k	127	19.31	-0.91	9%	-0.99	0.321	0.92	1.36	0.63
>£100k	339	19.45	-0.79	9%	-2.43	0.015	0.78	1.02	0.60
Building characteristics									
Floor area band Reference 50-100m^2	1065	19.12	-1.06	18%					
<50m^2	121	19.51	-1.27	15%	-1.51	0.133	1.16	1.71	0.79
100-150m^2	603	19.13	-0.92	15%	-0.12	0.904	0.98	1.21	0.80
150-200m^2	199	19.39	-0.89	11%	-1.89	0.059	0.91	1.24	0.66
>200m^2	117	19.25	-0.93	13%	-0.75	0.455	1.02	1.51	0.69
Dwelling type	1627	19.20	-0.97	14%					
Semi-detached	1285	19.16	-1.12	16%	0.53	0.596	1.09	1.27	0.94
Terraced	891	19.07	-0.97	16%	1.55	0.122	1.02	1.21	0.87
Dwelling age Reference 1950 to 1976	1162	19.31	-0.96	15%					
Before 1900	436	19.01	-0.97	16%	2.58	0.010	0.87	1.09	0.69
1900 to 1929	491	19.02	-0.86	17%	2.55	0.011	0.95	1.17	0.76
1930 to 1949	583	19.11	-1.13	15%	1.68	0.094	0.88	1.08	0.72
1976 to 1990	624	19.21	-0.99	15%	0.96	0.337	1.12	1.36	0.92
1991 to 2002	469	19.16	-1.17	16%	1.28	0.202	1.34	1.68	1.08
2003 onwards	343	19.46	-1.04	13%	-1.12	0.265	1.07	1.37	0.84
EPC rating Reference D	958	19.11	-0.96	17%					
A or B	128	19.81	-1.11	13%	-3.64	0.000	1.06	1.54	0.73
C	613	19.28	-1.01	14%	-1.51	0.130	1.04	1.27	0.84
E	342	18.99	-1.16	18%	0.92	0.359	1.30	1.68	1.01
F or G	64	19.05	-0.77	14%	0.19	0.850	0.91	1.53	0.55
Fuel poverty indicators									
EFP	401	19.15	-1.21	18%	2.39	0.144	2.39	2.93	1.95
FFP	276	18.24	-1.93	34%	2.20	0.139	2.20	2.93	1.67
Struggling to pay	570	18.91	-1.52	24%	1.47	0.138	1.47	1.77	1.22

There is a trend of higher likelihood of reduction as the age of the home decreases, but the only increase in the odds of temperature setpoint reduction that can be considered significant is for homes built between 1991 and 2002. Those with EPC E were more likely to reduce heating setpoint than those in the EPC D reference category. No other building characteristic showed a significant difference in odds of thermostat setpoint reduction.

3.3 Households likely to be in fuel poverty

Those households identified as “expenditure fuel poor” (EFP) were significantly more likely to have reduced their temperature setting in 2023 (OR 2.39) however the mean setpoint temperature for this group was not significantly different to the rest of the survey sample. This can be explained by observing that this group reported a slightly higher setpoint than those not in EFP in the original survey.

The group which reported that they could not afford to keep their living room comfortably warm (FFP) also had high odds for reduction and a very low mean setpoint reported in 2023 (18.24°C) with a mean reduction of 1.93°C. 34% of this group reported potentially harmful setpoints of less than 18°C.

The “struggling to pay” group (who said it was fairly or very difficult to meet their energy costs) also had a low mean setpoint temperature and high odds of reduction, but not to the same extent at the smaller FFP group.

3.4 Limitations

This analysis has focused on reported evening temperature setpoints. There are a number of reasons why the actual temperature experienced by the household may differ from the heating controller setpoint number reported by the respondent:

- The household may vary the setpoint frequently or the survey respondent may not recall the setpoint accurately. However, Smart Systems and Heat (2014) reported good agreement between reported settings and those observed by a surveyor in 2,287 homes.

- The setpoint may not be reached. A typical heating pattern in British homes is to run the heating intermittently, often for a short period in the morning and a longer period in the evening (Huebner et al., 2015; Rudge, 2012). Measurements of temperature in homes have shown considerable variation in temperature over the day and from day to day, with the temperature in some homes never appearing to reach a plateau that would indicate that the setpoint temperature had been reached (Huebner et al., 2013, 2015). The thermostat temperature should not be equated with the mean internal temperature, but considered as the maximum likely to be achieved at some point in the day.

- In many British homes the heating is controlled by a single wall-mounted thermostat in the hallway; the temperature at this location may differ significantly from the temperature in the living room or other areas of the house.

Despite these uncertainties, Few and Oreszczyn (2022) found a clear trend in energy demand reduction for each 1°C decrease in reported thermostat temperature between 22°C and 18°C in a typically sized house.

The indicators of fuel poverty used in this study do not match the current "Low Income, Low Energy Efficiency" definition for England (DESNZ & BRE, 2023) or the different definitions used in other UK nations (Office for National Statistics, 2023). These national measures are based on a model calculation of energy to achieve comfortable temperatures rather than the actual energy used.

4 Conclusions

There was a significant reduction in reported temperature settings between 2021 and 2023 (in contrast to the small changes recorded between 2019 and 2021). This strongly suggests that the increase in energy prices in 2022 and associated attention given to energy efficiency led to a large number of UK households reducing their heating setpoint. Homes with a pensioner present were less likely to reduce temperatures, as might be expected given the vulnerability of this group. No difference was seen for homes with young children. The strongest demographic associations with a lower setpoint were for households with an annual income under £10,000 and single-person households.

The physical characteristics of a building were not associated with large differences in setpoint. The oldest homes (built before 1929) have a slightly lower mean setpoint and this, combined with higher temperatures in homes with EPC A or B, suggests that those in modern, well insulted homes are likely to keep these at (slightly) warmer temperatures on average.

While the relatively small groups of those indicated as being in fuel poverty did not show significant differences in mean thermostat settings, there is strong evidence of greater setpoint reductions by those spending more than 10% of household income on energy and those reporting that they could not afford to heat their living room to a comfortable temperature. Overall, one sixth of the survey group reported setpoints lower than the recommended minimum of 18°C. The large increase in this proportion from the earlier survey is a cause for concern.

Policymakers must balance encouraging energy efficiency with ensuring that the basic needs for heating in wintertime are met. There are few clear trends associating particular dwelling characteristics with low temperature setpoints, but it is clear that low income and single-person households have disproportionately low mean setpoints. These groups should be supported to make heating more affordable. On the other hand, there is scope to encourage further setpoint reduction in high-income households without vulnerable members.

This study highlights the benefits of a large-scale, longitudinal data-gathering project such as SERL which allows researchers to track changes in energy using behaviour and the impact on energy consumption. Further work is underway to investigate the correlation between reported temperature setting reductions and reduction in winter energy demand (Zapata-Webborn et al., 2023). Future work will explore alternative indicators of fuel poverty using smart meter data in more depth.

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6 References

Age UK. (2021). *The cost of cold*. https://www.ageuk.org.uk/globalassets/age-uk/documents/campaigns/the-cost-of-cold/age-uk-the-cost-of-cold-nmp#:~:text=We%20cannot%20let%20a%20situation,and%20putting%20their%20heating%20on.

Aragon, T. J., Fay, M. P., Wollschlaeger, D., & Omidpanah, A. (2020). *epitools: Epidemiology Tools* (0.5-10.1) [Computer software]. https://cran.r-project.org/web/packages/epitools/index.html

BEIS, & BRE. (2020). *Fuel Poverty Methodology Handbook (Low Income High Costs)*. https://www.gov.uk/government/publications/fuel-poverty-statistics-methodology-handbook

DESNZ. (2023). *Energy Price Guarantee: Regional rates, October to December 2022*. https://www.gov.uk/government/publications/energy-price-guarantee-regional-rates/energy-price-guarantee-regional-rates

DESNZ, & BRE. (2023). *Fuel Poverty Methodology Handbook (Low Income Low Energy Efficiency)*. https://www.gov.uk/government/collections/fuel-poverty-sub-regional-statistics

DLUHC. (2022). *English Housing Survey 2021 to 2022: Headline report*. https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-headline-report/english-housing-survey-2021-to-2022-headline-report

EST. (2022). *Quick tips and home improvements to help you heat your home for less*. https://energysavingtrust.org.uk/quick-tips-and-home-improvements-to-help-you-heat-your-home-for-less/

Few, J., & Oreszczyn, T. (2022, December 2). *Energy bills: How much money does turning down the thermostat actually save?* The Conversation. http://theconversation.com/energy-bills-how-much-money-does-turning-down-the-thermostat-actually-save-194756

Hamilton, I. G., Shipworth, D., Summerfield, A. J., Steadman, P., Oreszczyn, T., & Lowe, R. (2014). Uptake of energy efficiency interventions in English dwellings. *Building Research & Information*, *42*(3), 255–275. https://doi.org/10.1080/09613218.2014.867643

Huebner, G. M., McMichael, M., Shipworth, D., Shipworth, M., Durand-Daubin, M., & Summerfield, A. (2013). The reality of English living rooms – A comparison of internal temperatures against common model assumptions. *Energy and Buildings*, *66*, 688–696. https://doi.org/10.1016/j.enbuild.2013.07.025

Huebner, G. M., McMichael, M., Shipworth, D., Shipworth, M., Durand-Daubin, M., & Summerfield, A. J. (2015). The shape of warmth: Temperature profiles in living rooms. *Building Research & Information*, *43*(2), 185–196. https://doi.org/10.1080/09613218.2014.922339

MHLC. (2021). *English Housing Survey Energy report, 2019-20*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1055629/Energy_Report_2019-20.pdf

Moore, R. (2012). Definitions of fuel poverty: Implications for policy. *Energy Policy*, *49*, 19–26. https://doi.org/10.1016/j.enpol.2012.01.057

Office for National Statistics. (2023). *How fuel poverty is measured in the UK: March 2023*. https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/howfuelpovertyismeasuredintheuk/march2023

Ofgem. (2016). *Ofgem's Future Insights Series The Decarbonisation of Heat*. https://www.ofgem.gov.uk/sites/default/files/docs/2016/11/ofgem_future_insights_programme_-_the_decarbonisation_of_heat.pdf

Ofgem. (2021). *Supplementary model—Default tariff cap level v1.9*. https://www.ofgem.gov.uk/publications/default-tariff-cap-level-1-october-2021-31-march-2022

Public Health England. (2015). *Adverse Weather and Health Plan*. https://www.gov.uk/government/publications/adverse-weather-and-health-plan

Rudge, J. (2012). Coal fires, fresh air and the hardy British: A historical view of domestic energy efficiency and thermal comfort in Britain. *Energy Policy*, *49*, 6–11. https://doi.org/10.1016/j.enpol.2011.11.064

Siksnelyte-Butkiene, I., Streimikiene, D., Lekavicius, V., & Balezentis, T. (2021). Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity. *Sustainable Cities and Society*, *67*, 102756. https://doi.org/10.1016/j.scs.2021.102756

Smart Systems and Heat (SSH) Technology Programme. (2014). *Quantifying heat energy needs and behaviours*. https://ukerc.rl.ac.uk/cgi-bin/eti_query.pl?GoButton=DisplayLanding&etiID=883

Thomson, H., Bouzarovski, S., & Snell, C. (2017). Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data. *Indoor and Built Enviornment*, *26*(7). https://journals.sagepub.com/doi/full/10.1177/1420326X17699260

Tirado Herrero, S. (2017). Energy poverty indicators: A critical review of methods. *Indoor and Built Enviornment*, *26*(7). https://doi.org/10.1177/1420326X17718054

UKDS (2023). *Smart Energy Research Lab Observatory Data, 2019-2022*. https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=8666#!/documentation

Viner, K. (2023, January 12). Millions in Britain are choosing between heating and eating. It's not too late to help them. *The Guardian*. https://www.theguardian.com/society/2023/jan/12/millions-britain-heating-eating-guardian-observer-charity-appeal-2022-kath-viner

Waddams Price, C., Brazier, K., & Wang, W. (2012). Objective and subjective measures of fuel poverty. *Energy Policy*, *49*, 33–39. https://doi.org/10.1016/j.enpol.2011.11.095

Webborn, E., Few, J., McKenna, E., Elam, S., Pullinger, M., Anderson, B., Shipworth, D., & Oreszczyn, T. (2021). The SERL Observatory Dataset: Longitudinal Smart Meter Electricity and Gas Data, Survey, EPC and Climate Data for over 13,000 Households in Great Britain. *Energies*, *14*(21), Article 21. https://doi.org/10.3390/en14216934

Zapata-Webborn, E., Hanmer, C., Oreszczyn, T., Huebner, G., McKenna, E. J., Few, J., Elam, S., Pullinger, M., Cheshire, C., Friel, D., Masters, H., & Whittaker, A. (2023). *Winter demand falls as fuel bills rise: Understanding the energy impacts of the cost-of-living crisis on British households*. OSF Preprints. https://doi.org/10.31219/osf.io/83a4t

THE ROLE OF GENDER, AGE, AND INCOME IN DEMAND SIDE MANAGEMENT ACCEPTANCE: A LITERATURE REVIEW

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Abstract
Demand-side management (DSM) programs aiming to both reduce and render household consumption more flexible, are becoming increasingly essential due to energy crises and the growing integration of renewable energy into energy production. The involvement of households and energy users is crucial to fully unlock the potential of DSM programs. As this paper demonstrates, despite more than thirty years of feminist scholarly work focusing on the home as an important site of the production of gender inequality, few of these insights have been taken into account by DSM-designers. Additionally, we note a broader pattern concerning gaps in knowledge regarding the diverse perspectives of energy users and their domestic contexts, all of which create obstacles to successful rollout and scalability. This paper uses the concept of the social license to automate and insight from feminist research to analyse the literature on DSM programs. We find three primary barriers in household DSM programs: 1) there is an unresolved tension between DSM technology being perceived as a masculine domain and the home as a feminine domain, 2) low-income households face challenges in accessing the technology needed to enable both flexibility and savings, and 3) disparities in opportunities for participation among elderly and young individuals in DSM programs and their complex reasons are insufficiently considered. Based on these findings we argue that user diversity needs to form a starting point in DSM program design for fair and scalable solutions.

1. INTRODUCTION

The world is currently facing a global energy transition from fossil fuels to renewable energy sources. The electrification of various sectors, from transportation to heavy industry, is driving an increasing demand for renewable energy, which adds pressure to the transitional process. At the same time, the energy transition has become more urgent in the context of current shortages in energy supply due to global developments such as the war in Ukraine and associated price escalation. In a system characterized by a high proportion of renewable energy sources, end-users possess the potential to play a significant role in ensuring the stability of the grid (Gelazanskas & Gamage, 2014). Successfully engaged, active participants in the grid, can become a source of flexibility through the close coordination of energy availability and consumption (Ballo, 2015). At the same time, flexible energy consumption does interfere with the everyday life practices of consumers (Silvast et al., 2018; Skjølsvold et al., 2017) posing a challenge to the availability of end-user flexibility as a resource.

Research in the field of promoting flexible energy consumption among households has primarily concentrated on the provision of economic signals, often coupled with technological interventions to facilitate the transmission of these signals, with the objective of encouraging individual households to modify their energy consumption patterns. This approach, commonly known as demand-side response (DSR) or demand-side management (DSM) (Adams et al., 2021), assumes that individuals' willingness to adapt their energy consumption is driven by economic incentives and rational decision-making (Fell et al., 2014; Fjellså, Silvast, et al., 2021; Throndsen, 2017). This assumption comes from a technical energy utility perspective where the main motivation is to stabilize the grid (Ballo, 2015), and is often based on the vision of the 'resource man'; a vision of a smart energy consumer interested in his own energy data and acting on price signals to optimize savings (Strengers, 2014). This vision represents the energy industry's resource bias projected into energy consumers that make his home into a "resource control station" (Strengers, 2014, p. 26). Another similar concept used to describe this phenomenon of assumption made on behalf of users by designers of technology and policy is the concept of "imagined lay persons" (ILP) where expectation of a version of the future—like that of the flexible costumer—creates certain types of innovation projects that yet again facilitate certain action strategies and politics (Maranta et al., 2003).

When it comes to end user flexibility the imagined lay person is "usually white, male, privileged, well-off, and young—that does not exist in reality" (Forlano, 2017). This bias has been addressed by social science researchers who have been calling out for more heterogeneity among participating energy consumers in pilots and studies (Silvast et al., 2018; Skjølsvold et al., 2017; Strengers, 2014), and underlined the need to pay more attention to social relations in energy consumption patterns (Hargreaves & Middlemiss, 2020).

The studies are part of an increasing body of research that critically reflects on the complex identities, use patterns, and social contexts of end users. In this review, we contribute to this strand of research by examining research into automated energy systems and their imagined gendered subjectivities. To what extent are DSM program designers and proponents thinking of different energy users within households? And to what extent are gender aspects a factor considered by DSM program planners? In the next section, we will describe the theoretical framework that has guided this review. This involves setting the *Social License to Automate* that allows us to focus on this diverse community and the social process of the energy management into dialogue with emerging perspectives in feminist energy research. Feminist perspectives aim to go beyond simply adding 'gender' as just another social category. Rather they aim to capture the ways in which social categories get intertwined with hierarchies of power, in this case operating within domestic management of energy consumption. The feminist lens "offers expertise in the study of power, one that is under-utilized yet applicable to many aspects of energy system design, planning, exchange, and use." (Bell et al., 2020). Our process has been feminist in the ways that it centers its inquiry on marginalized subjects of energy management and the extent to which their stories have been analysed and contributed to theorizations in the literature Further, it is guided by an intersectional way of thinking that foregrounds the complex identities of social subjects and their situatedness. While intersectionality is commonly understood as a concept that spotlights the intersections of identities such as gender, class, race, ability, and ethnicity to name a few, an intersectional perspective also offers ways to foreground so-called 'critical inquiry' (Collins, 2019). A critical inquiry investigates the never static, mutually constitutive processes of identity and agency formation to understand social differences and power and attend to the multi-dimensional dynamics of inclusion and exclusion (Cho et al., 2013; Collins, 2019). As such, it acknowledges the distinctively located 'standpoints' of energy consumers that are shaped by mutually reinforcing systems of power that open for ways of knowing about and acting upon the social-technical world. Through this literature review, we aim to understand to whose perspectives are included in the literature and to what extent their complexity and situatedness are considered.

1.1. Theoretical framing: The social license to automate, in dialogue with intersectionality

The concept of the 'social license' prompts an analysis of the intermediary space existing between the formal and informal codes of conduct applicable to electricity companies, grid operators, and network businesses as they engage in trials and innovations (Adams et al., 2021). The concept shifts attention from the dominant consumer-market relation in the energy industry to instead examine collective social relations to technology projects (Adams et al., 2021). The concept of a *social license to automate* recognises that many demand management programs will require intervention at faster speeds than systems of individual decision-making will allow. For example, Frequency Control Ancillary Services at the milli-second level require pre-set permissions. Thus, the question of who provides these permissions – which may encompass home appliances, batteries, HVAC systems, electric vehicle charging and more – is an important social and political one insofar as DSM requires users to modify their practices. Our starting point is that such permission is not merely a question of personal choice, but the subject of social conditions required by community stakeholders. Drawing on Science and Technology studies (STS) the social license to automate draws attention to the norms and institutionalized inequalities in which DSM interventions are made (Breukers, 2023). Only through recognising these social issues can DSM scale from resource man to everyday users. Our review of the literature on DSM is influenced by a feminist perspective. This perspective allows us to gain insights into three key aspects:

1. Gender Inequalities within the Household: We explore how flexible energy consumption is affected by gender disparities within households.
2. Power Dynamics in DSM Technology Development: We investigate the power imbalances that grant certain social groups a privileged position as initial users in the development of DSM technology.
3. Cumulative Burden on Marginalized Identities: We examine how individuals or households with multiple marginalized identities may face a greater burden when it comes to adapting to flexible energy consumption.

By adopting this analytical approach, we go beyond the traditional areas of study, such as analysing the experiences of tech-savvy, white, and privileged men as pilot users of DSM. In alignment with the SLA 2.0 concept, we aim to promote energy justice through the lens of recognition justice (Jenkins et al., 2016). Feminist research and the concept of intersectionality play a crucial role in providing a more nuanced perspective on user experiences, needs, and opportunities within the context of social justice. This approach directs our attention to how program design, when oblivious to these issues, can inadvertently reinforce existing injustices and further marginalize already vulnerable groups during the transition to sustainable energy sources. When we examine the SLA concept through the lenses of feminism and intersectionality and incorporate their insights into inequalities, power dynamics, and processes of marginalization, we expand the concept's scope to encompass fairness and justice aspects. This expansion enriches its utility as a tool to promote the democratization of energy systems by drawing attention to the multiplying effects of different forms of disadvantage. Furthermore, it allows us to consider how gender and social inequalities may emerge and persist in relation to Demand-Side Management (DSM) and can inform program design aimed at mitigating such disparities.

Essentially, for an equitable transition to sustainable energy solutions that incorporate automation, we need to SLA in dialogue with a feminist lens to understand not only gender dynamics and the experiences of women; we need to understand as well as those groups whose everyday realities are particularly susceptible to the unpredictable fluctuations in energy prices. It is this feminist lens that brings gender inequality, power, and intersectionality to the forefront of the review process, giving us the possibility to critically revisit the existing literature on demand-side management (DSM) with a specific focus on narratives outside of those of the dominant group (e.g., resource man).

3. METHODS OF THE REVIEW

Earlier work on social acceptance of automation suggests that “not all households are equally placed to participate in automated DSM” (Adams et al., 2021, p. 5), and at the same time concludes that there are remaining questions regarding “who is included and who is excluded, and who wins and who loses” (Adams et al., 2021, p. 9). A feminist lens was adopted within the literature review to try to answer those questions and understand *to what extent* such alternative perspectives are investigated in the literature. The approach of a narrative review was chosen to allow exploratory evaluation of the literature and to synthesize in-depth qualitative insights from a variety of perspectives and disciplines (Sovacool et al., 2018).

The researchers discussed potential issues in implementing automated DSM and their relation to axes of discrimination, based on their expertise. This discussion was guided by the terms of intersectionality (Schiebinger et al., (2011-2020)). From these talks, the search query and inclusion/exclusion criteria were formulated. Articles in English in peer-reviewed, scholarly journals and conferences that explicitly related to both energy consumption, flexibility or DSM, and the prioritized terms of intersectionality were included. The literature collection was then carried between January and March 2023 on the scientific databases W*eb of Science* and *Scopu*s with outcomes outlined in the PRISMA (Page et al., 2021) flow diagram (see Figure 1).

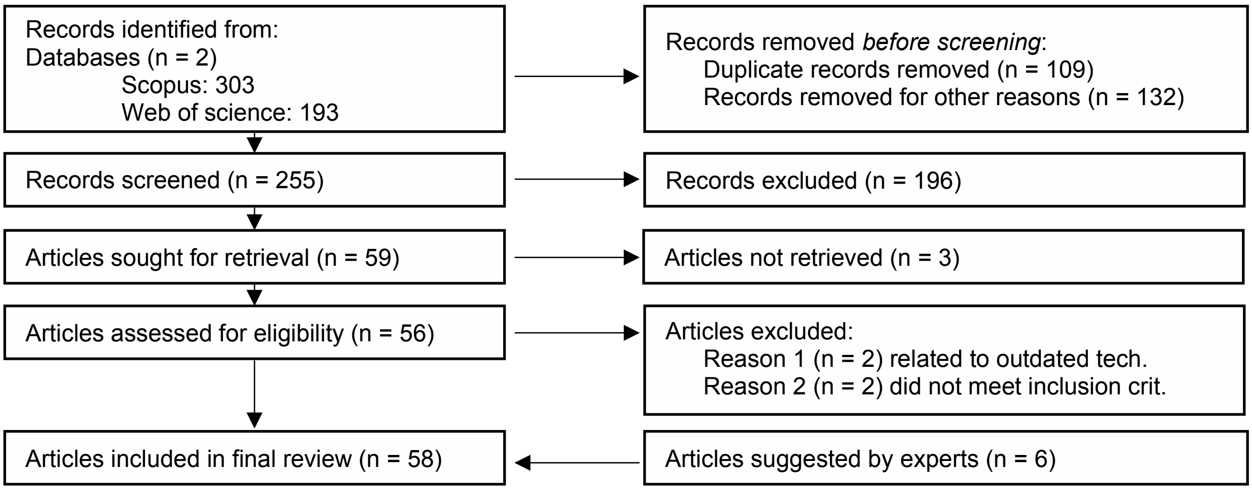

Figure 1. PRISMA flow diagram for the literature search and screening

In total 58 articles were included in the final review and the selected articles were distributed among all the authors, and a close reading was conducted. During this process, articles were analysed to see which alternative perspectives were included, and to what extent. This included qualitative evaluation of the extent to which a feminist intersectional perspective was applied in the research conducted. Three levels could be seen; ranging from (1) a lesser extent with analysis primarily describing socio-demographic factors; to (2) marginalization and social inequality are theory-based and referenced in the background literature; to (3) a greater extent where the analysis of marginalized groups is theory-based and serves as the central focus of the paper in analytical terms. The initial analysis revealed that three main perspectives have been considered in the literature: gender, age, and income/economic status. Within these perspectives, further analysis was carried out to uncover the nuances and themes related to each perspective, specifically focusing on the articles that had applied a feminist intersectional perspective to a greater extent. This then formed the basis for a discussion on participation in automated DSM and the need to further expand the social license to automate concept.

4. FINDINGS: GENDER, INCOME, AND AGE IN THE DSM WORLD

The reviewed literature reveals that few articles have engaged with or sought out marginalized perspectives in an in-depth manner in their analysis. Most articles primarily used gender, age, and income as descriptive statistics or socio-demographic variables, and therefore engaged with a feminist intersectionality perspective to a lesser extent. A fourth of the articles included a deeper analysis focusing on marginalised groups. Out of these, most focus on gender, but also relate peripherally to age and income. The following sections will present findings from the literature related to those three aspects.

4.1. The gender narratives in DSM

Studies report that women may be more willing to engage with energy conservation behaviours and flexibility practices (Clancy & Roehr, 2003; Grünewald & Diakonova, 2020; Khalid & Razem, 2022), or at least more willing to follow through on their intention (Tjørring et al., 2018), than men. However, in practice, the realities of family life including other members of the family undermining efforts present challenges (Johnson, 2020).

4.1.1. How women and their household labour disrupt DSM

This dichotomy between the home as a feminine realm, where women are often responsible for energy-consuming housework, and the masculine realm of Demand Side Management (DSM) and Direct Load Control (DLC), has been identified in several studies (Berg, 1992; Grünewald & Diakonova, 2020; Mechlenborg & Gram-Hanssen, 2022).

The installation and monitoring done by men is often a leisure activity but has consequences for the routine household tasks carried out by women (Håkansson et al., 2022), and can lead to the reinforcement of gender roles when technology interest is unequally distributed (Aagaard & Madsen, 2022). In addition, women, particularly mothers, tend to operate in an "always on" mode, resulting in a fragmented experience of time rather than distinct segments dedicated to work, family, and leisure, leaving less opportunity to experiment with sustainability practices and technology (Organo et al., 2013).

Furthermore, household labour is also related to gender difference in acceptance and responsivity to DSM. Like the acceptance of DLC is higher for devices such as heat pumps and PV systems compared to appliances such as washing machines and dishwashers (Yilmaz et al., 2020). Households tend to prefer automation of appliances that do not disrupt their daily routine – disruptions which typically affect women more directly. Additionally, men tend to be more accepting of DLC for electric vehicles while women are more likely to reject it. Females generally required a lower compensation to participate in the DR program than male respondents, suggesting that the latter might, from a relative perspective, care more about pricing while the former might be driven more by non-price factors (Srivastava et al., 2020).

In a study of text message prompts for manual load shifting showed that men and women had similar intentions to engage but men carried out fewer shifting activities than women (Tjørring et al., 2018). Responsivity was higher when the person responsible for most of the household chores – typically the woman – was also the receiver of the prompts. Women were to a higher degree responsible for laundry and cleaning while cooking and dishwasher use were shared responsibilities with dishwasher use being shifted most often. The authors conclude that to use the full potential of load shifting it is important to consider chore division and interactions within households but also underline the risk of making flexibility "women's work" through such a focus, while additionally reinforcing traditional gender roles.

Practice theory point on that energy peaks are about family routines, and therefore have low possibility to be flexible (Nicholls & Strengers, 2015), but on the other side households with overlapping practices, and shared perspectives and competencies use DSM technology more efficiently and build up new flexible practices together (Mechlenborg & Gram-Hanssen, 2022; Aagaard & Madsen, 2022).

4.1.2. The resource men and their man caves for direct load control

The concept of the "resource man," refers the idealised subject of 'smart home' energy management technologies: an individual who is technologically inclined, information-oriented, and economically rational when it comes to smart utopia consumption (Strengers, 2014, p. 36). "Resource Man as a male, not because he is always directly identified as one, but because he is cast in the image of the male-dominated industries of engineering and economics that permeate energy management. Moreover, visions of him exclude much of the productive work of the home, which is still carried out by women." (Strengers, 2014:26). This individual, often a man, exhibits a keen interest in his energy data and dedicates time to optimizing energy usage. With complete control and decision-making power over his own and his family's energy consumption, the resource man embodies the stereotype envisioned by energy technology developers as an active and engaged energy user. PV providers often assume that their customers are knowledgeable males, addressing them directly and expecting limited knowledge from women (Håkansson et al., 2022).

In 2022 in an ethnographic study of energy use in Australian households, the role of "Man caves" as gendered edges of homes in energy consumption pattern and DSM potential was explored (Strengers & Nicholls, 2022). "Men caves" served as a refuge for men in contrast to the feminine domestic sphere found in the rest of the house. These man caves, often located in sheds, emerged as essential spaces for personal withdrawal, creative pursuits, and activities like device charging and "digital housekeeping," as described by Tolmie et al. (2007). They also highlight the potential for including these spaces in energy efficiency efforts and promoting sustainable practices,

4.1.3. The masculinity bias of direct load control

It is important to challenge ingrained gendered assumptions in the perception of active home design and operation, where technology is often considered a masculine-coded artifact best operated by experts outside the feminine context of the home (Shirani et al., 2022). This is exemplified by technologies like PV which are often viewed as being in alignment with traditional masculinity, associated with masculine approaches to homemaking and considered forms of self-expression and status symbols (Mechlenborg & Gram-Hanssen, 2022).
To address these gender biases is it recommend to engaging female consumers in a more targeted manner, considering their often more impactful role in household energy consumption (Elnakat & Gomez, 2015). This includes creating brands that directly speak to women and equipping devices with features and settings that better align with their needs and priorities. Additionally, incorporating feedback mechanisms with a stronger emotional tone that are encouraging and rewarding can help improve female engagement (Elnakat & Gomez, 2015).
To tackle the masculinity bias of DSM it is suggested to expand the communicated reasons to purchase PV technology beyond economic advantages (Håkansson et al., 2022). By highlighting benefits such as self-sufficiency, resiliency, and environmental considerations, a broader audience, including women, may be attracted to PV adoption. It is also important to provide customer journeys that do not rely on existing in-depth technical knowledge, offering different starting points for purchase intentions, such as larger retrofitting projects or the purchase of electric vehicles (Håkansson et al., 2022).

4.2. Acceptance of direct load control and the income issue

Literature analysing preferences for Direct Load Control (DLC) in Switzerland and suggests that preferences for Demand Side Response (DSR) are quite heterogeneous and vary by socio-demographic and household characteristics, as well as by which technology. Employment status, presence of children, gender, and age were significant factors for appliance DLC acceptance (e.g., washing machines, EVs, dishwasher) which are more link to activities and daily routines, while dwelling type and education level were a significant factor for specific devices such as PV, heat pumps and batteries (Yilmaz et al., 2020). These findings emphasize the diversity of DSR preferences, suggesting that perceived control and socio-technical dynamics play a crucial role in achieving high participation in such programs.

4.2.1. Accessing low-income flexibility

Resource Man is an economically privileged subject, we should not be surprised that DSM designed with him in mind omit many hard-to-reach consumers. Demand side management was highlighted as a way for people to participate in the energy transition who are limited in their conservation possibilities, shifting loads rather than overall reducing them but still contribute and access the possibility of savings. But it also risks putting pressure on low-income households to carry out manually what high-income households pass on to smart energy management systems in the home or excluding them from participation, creating a risk of “being too poor to access the cheapest electricity” (Johnson, 2020). Income intersects with gender at this place as the need for manual load shifting asks women as the main chore doers to become “flexibility women” (as opposed to the much more privileged “resource man” from

4.1.2). Therefore, to get low-income households on board in DSM and DLC it is important that they have access to affordable DSM technology (Crawley et al., 2021; Ponce de Leon Barido et al., 2018).

Access to energy information had more impact than cash when incentivizing flexible demands for low and low-middle income communities in Latin America. This kind of intervention reduces energy consumption, but that temporal and financial resource scarcity at household level formed a barrier for scaling up (Ponce de Leon Barido et al., 2018).

The acceptance of device-specific DLC is influenced by dwelling type, ownership and education level. House residents are less likely to accept device DLC compared to apartment residents, possibly due to a greater sense of control over their own systems. Higher-educated individuals are more likely to accept DLC for heat pumps and batteries. Those who already own boilers are more likely to accept their DLC, while PV owners are less likely to support the DLC of their PVs because they may view it as an obstacle to their profits from selling power to the grid. Dwelling type and ownership also play a role in the acceptance of DLC for appliances like people living in rented homes are more likely to accept the DLC of washing machines and dishwashers compared to homeowners (Yilmaz et al., 2020).

4.2.2. Energy poverty and the question of flexibility capital

There is a lack of knowledge on the interplay of energy poverty and DSM. To present state, mainly single aspects supporting DSM are analysed. The perception of smart home technologies depending on income levels is researched by Sovacool et al (2021) and reveals no differences regarding income levels. Studies finds that engagement of low-income households in energy efficiency programs find that accessibility and affordability is the main barrier (Xu & Chen, 2019). The prevalence of smart meters is lower, and they also have fewer energy efficiency appliances. However, these studies rely on a purely quantitative level of energy poverty definition by setting income limits, which is quite a simplification of the complex situation of energy-poor households. On the other hand, energy poverty can be more comprehensively by including aspects regarding e.g., health and household size and composition. For example, people dealing with health issues show less potential for DSM as their energy consumption must cover more core needs. The same applies for multi-person households due to higher social constraints (Calver & Simcock, 2021). With the elderly often facing more health challenges we see an intersecting vulnerability with age here. Two-income households had greater energy use per capita than in households where the female partner did not work or working woman living alone (Clancy & Roehr, 2003, p. 46).

Households of high-income consumers were typically better equipped regarding both types of loads and due to occupants spending less time at home, flexibility windows were also wider. The reduced availability of flexibility-providing technology in lower-income households functions as a limiting factor and pushes the affected groups to the margins or outside of participation opportunities in flexibility services. To achieve a just energy transition, it is therefore important to find inclusion opportunities for consumers of socioeconomically disadvantaged consumer groups and to avoid designing incentivization strategies that only reach high-income, high flexibility consumer (Ribó-Pérez et al., 2021).

4.3. Ageism and the DSM

In the literature, the elderly are often mentioned as a potential vulnerable group when it comes to DSM Schöne et al (Schöne et al., 2022) and older people over 65 as less likely to adopt new digital technology like the smart phone (Anderson & Perrin, 2017). Technology adaptions in later life need an inclusion policy in their design, avoiding "one-size-fit all" approaches and instead considering the needs of different user groups. Digital literacy program targeting older people must consider both the individual skills of the elderly (with their experiences of mastering new technology or failing at it) and their social contexts. By consider older people as learning partners when they are introduced to new technology, allowing their relationship to the technology to develop dynamically (Neves & Mead, 2021).

4.3.1. The DSM narrative of the elderly customers

Studies in the Swiss context analyse preferences for load shifting in the case of lower automation. For example, the paper by (2019) shows that the willingness to shift electricity consumption to the middle of the day (11 am to 3 pm) is higher in households with a responsible person aged over 65, in households with a relatively high peak at noon and a low peak in the evening, and in households that received financial incentives. Another study finds four distinct groups of people with regards to their interest in DR schemes, with increasing age being a significant predictor for higher interest. Ecological and social motives (e.g., strong sense of community) of participating in DR were found to exceed financial motivation (Schöne et al., 2022).

4.3.2. The young and flexible narrative

Younger respondents had a high interest and willingness to manage electricity demand at home but with limited flexibility even if higher savings could be achieved. Students and young people are not typically perceived as vulnerable to energy poverty (Ferreira et al., 2018). However, Bouzarovski et al (2013) also discovered that students who engaged in flat-sharing and rented accommodations often experienced temperatures below what is considered an acceptable standard. This study highlights that this group indeed encounters fuel poverty, because students were more likely to feel colder in their student housing compared to their homes due to the higher cost of heating. At the same time the student narrative revolves around the idea of being free and flexible to pursue individual choices (Kousis et al., 2020). This narrative aligns with discussions about flexibility. Student's freedom at the individual level is contrasted by the constraints they face in their daily activities, which are interconnected with their communal living arrangements. Here, societal temporal rhythms and material factors impose inflexibility and when it is strong economic incentives for flexibility the student may paradoxically result in reduced flexibility and may even give rise to a phenomenon termed "flexibility poverty" (Fjellså, Ryghaug, et al., 2021; Fjellså, Silvast, et al., 2021).

5. CONCLUSIONS: SOCIAL LICENSE TO AUTOMATE 2.0

This review shows a scarcity of studies addressing DSM in relation to social factors and how the contextual situation in households including social dynamics influence consumer energy behavior and their potential for adaptability (e.g., Ellsworth-Krebs et al., 2015; Hargreaves & Middlemiss, 2020; Nyborg, 2015). We also show that although many studies point out that gender, income and age have an impact on the flexibility energy consumption through daily practices and material design such as DSM equipment, only a small number have approached this in a theory-based, in-depth manner that goes beyond simply differentiating results according to demographics.

The application of the SLA 2.0 concept in this context underlines the necessity of changing the fundamental starting point of DSM solution design, shifting it to a user perspective rather than the grid. Such a shift and the associated changes of design and framing of solutions has the potential to open up access for less technology-affine users and enables user-level connection with solutions through personal tasks and experiences. This allows for greater transparency regarding personal impact and a conversation on equal footing. The results further show that to enable participation of the energy-poor, their needs and limitations should be integrated from

the beginning into program design, finding ways to avoid disadvantaging and enabling benefits for users with little flexibility to offer and little to invest on their own.
To successfully incorporate these aspects into DSM program design, enabling participation of typically underrepresented groups such as ethnic minorities, indigenous communities, the elderly, and individuals with disabilities, we need more research on these entanglements. By acknowledging certain marginalized groups and going beyond categorical analysis alone, the SLA 2.0 applies the mind set of intersectionality, supporting not only a sustainable but also a socially just energy transition.

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6. REFERENCES

Adams, S., Kuch, D., Diamond, L., Fröhlich, P., Henriksen, I. M., Katzeff, C., Ryghaug, M., & Yilmaz, S. (2021). Social license to automate: a critical review of emerging approaches to electricity demand management. *Energy research & social science*, *80*, 102210.

Anderson, M., & Perrin, A. (2017). Technology use among seniors. *Washington, DC: Pew Research Center for Internet & Technology*.

Ballo, I. F. (2015). Imagining energy futures: Sociotechnical imaginaries of the future Smart Grid in Norway. *Energy research & social science*, *9*, 9-20.

Bell, S. E., Daggett, C., & Labuski, C. (2020). Toward feminist energy systems: Why adding women and solar panels is not enough☆. *Energy research & social science*, *68*, 101557.

Berg, A.-J. (1992). The smart house as a gendered socio-technical construction. *Dragvoll, Norway: Centre for Technology and Society, University of Trondheim*.

Bouzarovski, S., Petrova, S., Kitching, M., & Baldwick, J. (2013). Precarious domesticities: energy vulnerability among urban young adults. *Energy justice in a changing climate: Social equity and low-carbon energy*, 30-45.

Breukers, S. (2023). *What is the Problem that Smart Home Technologies Solve?* Retrieved 15.09 from

Calver, P., & Simcock, N. (2021). Demand response and energy justice: A critical overview of ethical risks and opportunities within digital, decentralised, and decarbonised futures. *Energy Policy*, *151*, 112198. https://doi.org/https://doi.org/10.1016/j.enpol.2021.112198

Cho, S., Crenshaw, K. W., & McCall, L. (2013). Toward a field of intersectionality studies: Theory, applications, and praxis. *Signs: Journal of women in culture and society*, *38*(4), 785-810.

Clancy, J., & Roehr, U. (2003). Gender and energy: is there a Northern perspective?1 1This paper is based on two pieces of work by the authors: a study by Clancy et al. (2001) entitled Gender and Energy – Women's Concerns in Energy: Background and State of the Art prepared for the European Commission Research Directorate, and a background paper by Roehr (2001), "Gender and Energy in the North" prepared for an expert workshop "Gender Perspectives for Earth Summit 2002: Energy, Transport, Information for Decision Making" held in Berlin, Germany, 10-12 January 2001. *Energy for Sustainable Development*, *7*(3), 44-49. https://doi.org/https://doi.org/10.1016/S0973-0826(08)60364-6

Collins, P. H. (2019). *Intersectionality as critical social theory*. Duke University Press.

Crawley, J., Johnson, C., Calver, P., & Fell, M. (2021). Demand response beyond the numbers: A critical reappraisal of flexibility in two United Kingdom field trials. *Energy research & social science*, *75*, 102032. https://doi.org/https://doi.org/10.1016/j.erss.2021.102032

Elnakat, A., & Gomez, J. D. (2015). Energy engenderment: An industrialized perspective assessing the importance of engaging women in residential energy consumption management. *Energy Policy*, *82*, 166-177.

Ellsworth-Krebs, K., Reid, L., & Hunter, C. J. (2015). Home-ing in on domestic energy research:"House,""home," and the importance of ontology. *Energy research & social science*, *6*, 100-108.

Fell, M. J., Shipworth, D., Huebner, G. M., & Elwell, C. A. (2014). Exploring perceived control in domestic electricity demand-side response. *Technology Analysis & Strategic Management*, *26*(10), 1118-1130.

Ferreira, P., Rocha, A., & Araújo, M. (2018). Awareness and attitudes towards demand response programs–a pilot study. 2018 International Conference on Smart Energy Systems and Technologies (SEST),

Fjellså, I. F., Ryghaug, M., & Skjølsvold, T. M. (2021). Flexibility poverty:'locked-in'flexibility practices and electricity use among students. *Energy Sources, Part B: Economics, Planning, and Policy*, *16*(11-12), 1076-1093.

Fjellså, I. F., Silvast, A., & Skjølsvold, T. M. (2021). Justice aspects of flexible household electricity consumption in future smart energy systems. *Environmental Innovation and Societal Transitions*, *38*, 98-109.

Forlano, L. (2017). Posthumanism and design. *She Ji: The Journal of Design, Economics, and Innovation*, *3*(1), 16-29.

Gelazanskas, L., & Gamage, K. A. (2014). Demand side management in smart grid: A review and proposals for future direction. *Sustainable Cities and Society*, *11*, 22-30.

Grünewald, P., & Diakonova, M. (2020). Societal differences, activities, and performance: Examining the role of gender in electricity demand in the United Kingdom. *Energy research & social science*, *69*, 101719.

Hargreaves, T., & Middlemiss, L. (2020). The importance of social relations in shaping energy demand. *Nature Energy*, *5*(3), 195-201.

Håkansson, M., Renström, S., Lööf, J., Sall Vesselényi, L., & Jonasson Tolv, J. (2022). " Do they pass the woman test?" Navigating and negotiating the gendering of residential solar panels. Nordic Human-Computer Interaction Conference,

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy research & social science*, *11*, 174-182.

Johnson, C. (2020). Is demand side response a woman's work? Domestic labour and electricity shifting in low income homes in the United Kingdom. *Energy research & social science*, *68*, 101558.

Khalid, R., & Razem, M. (2022). The nexus of gendered practices, energy, and space use: A comparative study of middleclass housing in Pakistan and Jordan. *Energy research & social science*, *83*, 102340.

Kousis, I., Laskari, M., Ntouros, V., Assimakopoulos, M.-N., & Romanowicz, J. (2020). An analysis of the determining factors of fuel poverty among students living in the private-rented sector in Europe and its impact on their well-being. *Energy Sources, Part B: Economics, Planning, and Policy*, *15*(2), 113-135.

Maranta, A., Guggenheim, M., Gisler, P., & Pohl, C. (2003). The reality of experts and the imagined lay person. *Acta sociologica*, *46*(2), 150-165.

Mechlenborg, M., & Gram-Hanssen, K. (2022). Masculine roles and practices in homes with photovoltaic systems. *Buildings and Cities*, *3*(1), 638-652.

Neves, B. B., & Mead, G. (2021). Digital technology and older people: Towards a sociological approach to technology adoption in later life. *Sociology*, *55*(5), 888-905.

Nicholls, L., & Strengers, Y. (2015). Peak demand and the 'family peak'period in Australia: Understanding practice (in) flexibility in households with children. *Energy research & social science*, *9*, 116-124.

Nyborg, S. (2015). Pilot users and their families: Inventing flexible practices in the smart grid. Science & Technology Studies, 28(3), 54-80.

Organo, V., Head, L., & Waitt, G. (2013). Who does the work in sustainable households? A time and gender analysis in New South Wales, Australia. *Gender, Place & Culture*, *20*(5), 559-577. https://doi.org/10.1080/0966369X.2012.716401

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., & Brennan, S. E. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International journal of surgery*, *88*, 105906.

Ponce de Leon Barido, D., Suffian, S., Kammen, D. M., & Callaway, D. (2018). Opportunities for behavioral energy efficiency and flexible demand in data-limited low-carbon resource constrained environments. *Applied Energy*, *228*, 512-523. https://doi.org/https://doi.org/10.1016/j.apenergy.2018.06.115

Ribó-Pérez, D., Heleno, M., & Álvarez-Bel, C. (2021). The flexibility gap: Socioeconomic and geographical factors driving residential flexibility. *Energy Policy*, *153*, 112282.

Schiebinger, L., Klinge, I., Paik, H. Y., Sánchez de Madariaga, I., Schraudner, M., & Stefanick, M. ((2011-2020)). *Gendered Innovations in Science, Health & Medicine, Engineering, and Environment*.

Schöne, N., Greilmeier, K., & Heinz, B. (2022). Survey-based assessment of the preferences in residential demand response on the island of Mayotte. *Energies*, *15*(4), 1338.

Shirani, F., O'Sullivan, K., Henwood, K., Hale, R., & Pidgeon, N. (2022). Living in an Active Home: household dynamics and unintended consequences. *Buildings and Cities*, *3*(1), 589-604.

Silvast, A., Williams, R., Hyysalo, S., Rommetveit, K., & Raab, C. (2018). Who 'uses' smart grids? The evolving nature of user representations in layered infrastructures. *Sustainability*, *10*(10), 3738.

Skjølsvold, T. M., Jørgensen, S., & Ryghaug, M. (2017). Users, design and the role of feedback technologies in the Norwegian energy transition: An empirical study and some radical challenges. *Energy research & social science*, *25*, 1-8.

Sovacool, B., Furszyfer-Del Rio, D. D., & Martiskainen, M. (2021). Can prosuming become perilous? Exploring systems of control and domestic abuse in the smart homes of the future. *Frontiers in Energy Research*, *9*, 765817.

Sovacool, B. K., Axsen, J., & Sorrell, S. (2018). Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design. *Energy research & social science*, *45*, 12-42.

Srivastava, A., Van Passel, S., Kessels, R., Valkering, P., & Laes, E. (2020). Reducing winter peaks in electricity consumption: A choice experiment to structure demand response programs. *Energy Policy*, *137*, 111183. https://doi.org/https://doi.org/10.1016/j.enpol.2019.111183

Strengers, Y. (2014). Smart energy in everyday life: are you designing for resource man? *interactions*, *21*(4), 24-31.

Strengers, Y., & Nicholls, L. (2022). Emerging technologies' impacts on 'man caves' and their energy demand. *Buildings and Cities*, *3*(1).

Throndsen, W. (2017). What do experts talk about when they talk about users? Expectations and imagined users in the smart grid. *Energy Efficiency*, *10*, 283-297.

Tjørring, L., Jensen, C. L., Hansen, L. G., & Andersen, L. M. (2018). Increasing the flexibility of electricity consumption in private households: Does gender matter? *Energy Policy*, *118*, 9-18.

Tolmie, P., Crabtree, A., Rodden, T., Greenhalgh, C., & Benford, S. (2007). Making the home network at home: Digital housekeeping. ECSCW 2007: Proceedings of the 10th European Conference on Computer-Supported Cooperative Work, Limerick, Ireland, 24-28 September 2007,

Xu, X., & Chen, C.-f. (2019). Energy efficiency and energy justice for US low-income households: An analysis of multifaceted challenges and potential. *Energy Policy*, *128*, 763-774.

Yilmaz, S., Weber, S., & Patel, M. (2019). Who is sensitive to DSM? Understanding the determinants of the shape of electricity load curves and demand shifting: Socio-demographic characteristics, appliance use and attitudes. *Energy Policy*, *133*, 110909.

Yilmaz, S., Xu, X., Cabrera, D., Chanez, C., Cuony, P., & Patel, M. K. (2020). Analysis of demand-side response preferences regarding electricity tariffs and direct load control: Key findings from a Swiss survey. *Energy*, *212*, 118712.

Aagaard, L. K., & Madsen, L. V. (2022). Technological fascination and reluctance: gendered practices in the smart home. *Buildings and Cities*, *3*(1).

GAS PRODUCTION MANUFACTURING COMPANY

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Abstract

Promoting energy efficiency in energy-intensive manufacturing industries poses challenges due to their high energy consumption. To address this challenge, eco-feedback services, driven by advances in computing technology, have emerged as potential solutions for energy conservation. However, understanding the long-term usage and effectiveness of these services remains a knowledge gap in the field. The study investigates the practical usage and impact of an eco-feedback service in a manufacturing compnay that has been using the service since 2010. The eco-feedback service follows the Plan-Do-Check-Act (PDCA) approach, where the company implements energy conservation measures using smart devices (Do), monitors energy consumption through 'demand browsing services' (Check), refines actions based on energy diagnoses (Act), and formulates future energy conservation plans (Plan). The findings reveal that the eco-feedback service significantly contributed to long-term energy conservation. Following its introduction, the company implemented four distinct actions, including demand-based strategies and energy conservation measures. Notably, the initiation of the demand-based strategies was prompted by energy diagnoses (Act). While the frequency of access to the demand browsing service decreased over time, the diagnoses continued to inspire the energy manager's engagement (Check), ultimately leading to the development of energy conservation measures (Plan). In light of these results, this paper offers valuable implications for the wider application of eco-feedback services and underscores the need for ongoing support to foster sustained, long-term energy conservation efforts, aligning with the principles of the PDCA cycle.

1. INTRODUCTION

Japan has announced a goal of achieving a 46% reduction in greenhouse gas emissions from its 2013 levels by 2030. This ambitious target necessitates significant changes in everyday life across all sectors of society. Of particular concern is the promotion of energy efficiency in the industrial sector, where energy consumption is notably high. In the fiscal year 2021, the industrial sector accounted for the highest share of energy consumption, representing 35.1% of the total CO_2 emissions (METI, 2023a). This sector encompasses four categories: manufacturing, agriculture-forestry-fisheries, mining, and construction, with the manufacturing industry alone contributing to 68.6% of total energy consumption (METI, 2023b).

In 1979, Japan enacted *the Act on the Rational Use of Energy*, with subsequent revisions in 1993, 1998, 2002, 2005, 2008, 2013, 2018, and 2023. This legislation encourages employers with high energy consumption to implement energy conservation measures and management regulations. In response to this legal framework, the industrial sector has made significant efforts to reduce energy consumption by introducing technological innovations and establishing environmental management systems, such as ISO 14001 and ISO 50001. Notably, the change in greenhouse gas emissions in Japan's industrial sector from 2013 to 2018 (prior to COVID-19) was 87.8%, which was lower than that of other developed countries, including the EU (102.2%), France (94.2%), Italy (95.5%), the UK (97.8%), and the USA (98.7%) (UNFCCC, 2023). Japan's energy efficiency rate (primary energy consumption per GDP) was also lower compared to that of other developed countries (JASE-W, 2023).

It is worth noting that computing technology have enabled the development of eco-feedback. Eco-feedback provides information during product-user interactions, encouraging users to adopt energy conservation behaviors (McCalley, et al. 1998). Novel products, such as real-time energy feedback devices, can be powerful tools for promoting energy conservation behaviors (Holmes, 2007). While many studies using eco-feedback technologies have traditionally focused on residential buildings (Dobson and Griffin, 1992; Kim, et al., 2013; Sanguinetti et al., 2018), Gulbinas and Taylor (2014) demonstrated significant energy conservation through behavioral means in already energy efficient commercial buildings by empowering employees and building occupants with web-based eco-feedback systems. However, it should be mentioned that many of these studies are limited to short periods of time. Few studies examine the effects of eco-feedback in the long term (Ma et al., 2018; Pereira, et al., 2013). Therefore, it is essential to understand how users interact with eco-feedback systems over the long term.

With the above considerations, this paper aims to examine the long-term effects of an eco-feedback system in Japan's manufacturing industry. It presents a case study of a gas production manufacturing company using a system called 'Electric Power Consulting Service (EPCS)' provided by NIHON TECHNO CO., LTD (NT). The gas production manufacturing company has been using NT's eco-feedback service since 2010. Thus, this paper addresses the aforementioned research gap by presenting a long-term study on manufacturing energy consumption using EPCS. The research questions for this study are as follows.

RQ1. Has the eco-feedback service contributed to long-term energy conservation?

RQ2. How have users interacted with the eco-feedback service over time?

The reminder of this paper is structured as follows. The next section provides an overview of EPCS. Following this overview, a discussion of this study's methodology is presented.

Subsequently, the impacts of eco-feedback are analyzed before addressing the two research questions. Finally, this paper offers valuable implications for the wider application of eco-feedback services and underscores the need for ongoing support to foster sustained, long-term energy conservation efforts, aligning with the principles of the PDCA cycle.

2. ELECTRIC POWER CONSULTING SERVICE (EPCS)

The Electric Power Consulting Service (EPCS), developed by NT, provides smart devices that visualize real-time electricity usage and offers information and consulting services to help contracted companies understand their electricity consumption. This service follows the Plan-Do-Check-Act (PDCA) approach, wherein contracted companies implement energy conservation measures using smart devices (Do), monitor electricity usage trends through ‘demand browsing service’ (Check), refine actions based on energy diagnoses (Act), and formulate future energy conservation plans (Plan).

In the ‘Do’ stage, NT offers two products (SMARTMETER ERIA and SMART CLOCK) which are designed for facilities equipped with high-voltage power-receiving and transforming equipment (cubicles) (see Figure 1). The former, developed in 2008, tracks electricity usage with demand value (kW) and displays it using five levels of facial expressions, ranging from a smile to a frown, depending on the current electricity consumption. Demand value refers to the average electricity consumption value recorded every 30 minutes. In Japan, high-voltage recipients such as factories and commercial buildings that require large-scale electricity consumption (more than 50 kW but less than 500 kW) have contracts with power companies for maximum power supply (contracted power). The contracted power is set as the highest value (demand peak value) among the monthly maximum power values for the current month and the past 11 months, so reducing contracted power is essential to save electricity costs from the demand side. Therefore, contracted companies can set their own demand target values using the SMARTMETER ERIA, with the expectation of controlling them. When the set target value is exceeded, not only do the facial expressions change, but voice alerts can also notify those nearby, encouraging energy conservation. The latter product, developed as an option for the former in 2011, is a wall clock that visualizes electricity usage status. In Japan, wall clocks are commonly found in everyday life. SMART CLOCK displays LED lights around it, and the color changes according to the current electricity usage compared to the target set value, similar to a traffic light. When electricity consumption is between 0% and 89% of the target set value, it displays the color green (normal). The number of LED displays does not exceed the position of the minute hand. When electricity consumption is between 90% and 99% of the target set value, the LED lights increase to the position of the minute hand, changing to yellow (attention signal). If electricity consumption exceeds 100% of the target set value, it changes to red (overuse), and an audio clip is played: ‘*Demand is about to exceed the target set value*.’ This traffic light-based approach simplifies the understanding of electricity usage without requiring users to read, write, or have detailed knowledge of energy conservation. The device offers an enjoyable ‘at a glance’ learning experiences (Holmes, 2007) to users.

Figure 1 SMARTMETER ERIA (Left) and SMART CLOCK (Right)

In the ‘Check’ and ‘Act’ stages, NT offers information and consulting to help contracted companies understand their electricity usage, referred to as ‘GIFT123’ service. Regular interactions with contracted companies, called ‘GIFT’, involve three steps throughout the year, aligning with the PDCA cycle of energy conservation. In the first step (GIFT1), NT staff initially explain how to use smart devices, such as setting demand target values. After about a month, they verify the effects of daily energy conservation measures through ‘the demand browsing service’ (see Figure 2). This online service displays electricity usage graphs for the previous day in 30-minute intervals on a daily, weekly, monthly, and yearly basis, enabling users to track electricity consumption trends (‘Check’ stage). Approximately six months later, NT staff provides the GIFT Report (GIFT2), which includes data analysis results, such as the top five data points for the highest demand value (kW) and daily electricity consumption (kWh), expected alerts from smart devices based on certain demand values, and daily electricity consumption during non-business hours. This report helps contracted companies understand when and how much electricity is consumed. Contracted companies may also receive an ‘energy saving procedure manual’ and ‘example sheets of the EPCS’ from the staff. In the third step (GIFT3), NT assess the effects of energy conservation measures compared to the previous year. The service continues with regular visits, phone calls, and faxes, providing energy managers with opportunities to monitor electricity usage and identify potential energy conservation measures in collaboration with NT. This PDCA approach aims to reduce both electricity consumption and contracted power.

Figure 2 The demand browsing service (revised from NT, 2023)

3. METHODOLOGIES

The study was conducted in collaboration with NT. To prepare for this research, a meeting with NT took place on June 6, 2022. During this meeting, the authors received '25 example sheets of the EPCS in Fukuoka prefecture,' where the authors reside. These sheets contained information about the timing and effects of the EPCS, including energy conservation measures prompted by the eco-feedback service. As the measurement for assessing the effects of the EPCS showed differences between specific points in time before and after the introduction of the EPCS, the results could not verify whether the eco-feedback service contributed to long-term energy conservation. Given that only one manufacturing company in Fukuoka Prefecture had implemented both SMARTMETER AREA and SMART CLOCK, this company (a gas production manufacturing company) was selected as the case study.

On August 4, 2022, the authors visited the selected manufacturing company to conduct a semi-structured interview with a staff member responsible for energy management at the site (office and factory), including oversight of the EPCS. The interview aims to understand five main components: (i) an overview of the company's economic activities and trends, (ii) changes in electricity consumption, (iii) challenges related to electricity consumption before the introduction of the EPCS, (iv) the use and effects of the EPCS (including timing, locations of installed smart devices, and the extent of EPCS usage), and (v) energy conservation measures. The authors also contacted the company's president to explain the study's purpose, and the president granted permission for the research team to collect and analyze electricity consumption data on-site from May 2010 to December 2021 to assess the long-term effects of the EPCS. The target company has been using NT's eco-feedback service since May 2010.

Data on annual electricity consumption, contracted power, and annual gas production from 2011 to 2021 were collected from the target company. With the company's consent, the authors also obtained monthly electricity usage (kWh and contracted power) from NT. Additionally, information was collected from both the demand browsing service (including the number of logins) and the records of GIFT123 (including date and time information and content). These data were instrumental in analysing how the energy manager interacted with the EPCS and extracting insights from the service.

4. RESULTS

4.1. Overview of the target manufacturing company and their energy conservation measures before the EPCS

The target company for the EPCS is a gas production manufacturing company headquartered in Fukuoka prefecture, Japan. The company specializes in providing medical gases such as oxygen, nitrogen, and carbonic acid, as well as producing industrial gases for construction and food industries. The total area of the targeted site is 513 m^2, comprising one office building and one factory. While the factory is equipped with high-pressure gas filling equipment and inspection machines, the manufacturing company does not own tank trucks for transporting gas to industries.

The manufacturing company acquired ISO 14001 certification in December 2003, marking the initiation of systematic and continuous efforts toward energy conservation following the PDCA cycle. According to the semi-structured interview, the manufacturing company made attempts to reduce electricity usage by minimizing standby power consumption from personal computers and turning off unnecessary lights in the office. However, no energy conservation measures were implemented in the gas production process at the factory, resulting in a higher electricity consumption rate of 65% in the factory compared to 35% in the office.

4.2. Changes in electricity usage

The total amount of gas production in the manufacturing factory increased by 4.2% in 2019 compared to 2011, indicating a higher energy consumption requirement for industrial gas production. Figure 3 illustrates the changes in annual electricity usage from 2011 to 2021. Annual electricity consumption reached its peak in 2012, but has been on a declining trend since then. Although there was a slight increase from 2015 to 2018, the overall data still showed a 10.6% decrease in 2018 compared to 2012. Figure 4 illustrates the changes in energy efficiency (gas production per kWh). The manufacturing company achieved a significant increase in energy efficiency from 2012 to 2015. The decrease in gas production in 2020 is attributed to reduced demand for carbonic acid, which accounts for approximately 60% of the company's total gas production, due to the prevalence of COVID-19.

As shown in Figure 3, the peak contracted power reached a maximum of 52 kW in both 2011 and 2014, and a minimum of 46 kW in 2016. When a Pearson's product-moment correlation coefficient was calculated to examine the relationship between electricity consumption and contracted power, the correlation coefficient was not statistically significant (r=.34, p>.05). In 2014 and 2015, contracted power increased while electricity consumption reached its lowest point in 2015. This suggests that the manufacturing company succeeded in reducing the total amount of electricity consumption over the entire period but struggled to control the instantaneous demand value during specific time intervals. In response to this challenge, efforts to implement demand-based strategies using the EPCS were made in the following year. Consequently, contracted power reached its lowest point in 2016, even though gas production remained almost unchanged from the previous year (approximately -0.01%), and annual electricity consumption increased slightly (approximately 0.03%).

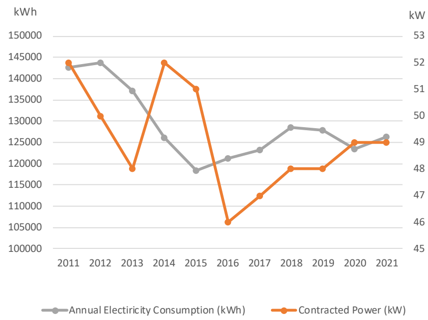

Figure 3 Changes in electricity use

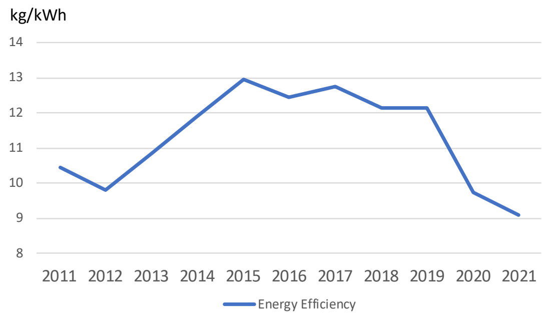

Figure 4 Changes in energy efficiency

4.3. Energy conservation measures using the EPCS

The EPCS was introduced at the targeted site in May 2010. The SMARTMETER ERIA was installed in the management division located on the second floor of the office building, which employs eight individuals. At the time of the interview, the demand value was set at 46 kW. Alerts from the device frequently occurred during the morning to noon period when the factory was in operation. The respondent responsible for energy management acknowledged the impact of the real-time feedback system, stating the following: "*When the alert sounds, we can reduce the demand value by one or two kW by turning off the air conditioners and lights*."

In March 2016, the manufacturing company also decided to introduce the SMART CLOCK as an optional addition to the SMARTMETER ERIA. The SMART CLOCK was installed on the first floor of the office building, where many employees work, with the goal of providing easily understandable real-time feedback about electricity usage. The introduction of the SMART CLOCK encouraged more employees to be involved in reducing energy consumption by turning off unnecessary air conditioners and lights when the color changes from green to yellow or red, or when the device emitted a voice alert. In this regard, the respondent mentioned that adjustments were made to the demand target-setting value. As the alerts occurred frequently, the novelty effect on employees diminished. To strike the right balance between not too being strict and not being too lenient, a trial-and-error approach was taken, finally settling on a setting of 46 kW, which remains in use. The approach was determined with active use of both the demand browsing service and the GIFT123.

The manufacturing company took further steps to implement four distinct actions for energy conservation: adjusting the timing of gas filling for tank trucks (2012), changing the cooling time in a carbonate tank (2013), introducing eco-time (2015), and implementing power button sealing (2016). The former two actions primarily align with demand-based strategies employed within the factory. The first action targeted tank trucks. During the gas filling process for these trucks, a significant amount of power was consumed for approximately 45 minutes until the filling was completed. Since the contracted power amount is determined by the highest value (demand peak value) of maximum power demand within a 30-minute interval slot (between 0 minutes and 30 minutes past every hour, or between 30 minutes and 60 minutes past the hour), the manufacturing company decided to avoid the operation of the motor pump in the full 30-minute slot. Instead, the start time for the motor pump's operation was set between 10 minutes and 20 minutes, or between 40 minutes and 50 minutes. Additionally, the filling schedule was adjusted to avoid peak morning electricity usage resulting from factory operations. The second action involved changing the cooling time for a carbonate tank from daytime to nighttime. The EPCS enabled the energy manager to understand the electricity usage and identify the issue: when the cooling system operates during the daytime, the demand value rises.

The latter two are energy conservation measures in both the office and factory. Eco-time is an initiative to thoroughly turn off lights in area not in use from 16:00 to 17:00 in summer and after 17:00 in winter. The initiative is communicated to employees via groupware designed to facilitate collaboration and communication among employees. The groupware is effectively used not only for disseminating eco-time but also for sharing information, such as summaries of electricity consumption using the demand browsing service and GIFT123. In 2016, further elaborations were made to seal power buttons. Like the SMART CLOCK's traffic light, seals with three colors (red, orange, and blue) were placed on each power buttons, such as air-conditioners and lights. After implementation, employees are encouraged to gradually reduce electricity consumption in response to the eco-feedback system, rather than by turning off all power buttons simultaneously.

4.4. User interactions with the demand browsing service and GIFT123

The NT provides information and consulting necessary for contracted companies to develop a better understanding of electricity usage through the services of the demand browsing service and GIFT123. In the former, the total number of logins for the demand browsing service was analysed to understand how users interacted with the web-based eco-feedback system. The study found that there were 345 logins in total from 2010 to 2021 (Figure 5). Among them, there was a remarkably high number of logins, 149 times (43.2%), from February to September 2011. During this period, the respondent actively used the service to monitor electricity usage patterns to identify both energy conservation measures and demand-based strategies. However, the number of interactions significantly decreased year by year since then. In particular, the number of logins has been less than once a month since 2017. Over time, the respondent may have felt that there was nothing new to learn from the provided eco-feedback system, eliminating the need for frequent checks. A majority of interactions with the demand browsing service (59.7%) occurred in the morning, peaking at 11:00 (Figure 6). During the noon period, demand alerts increased. Hence, it is likely that the energy manger responded to the alarms, resulting in a higher number of logins during that time.

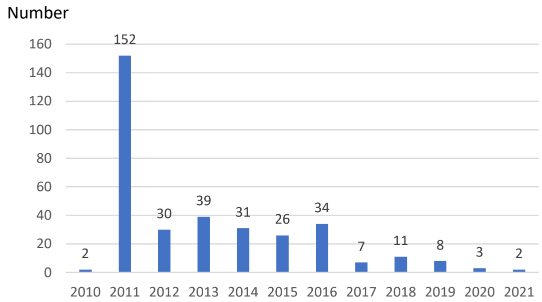

Figure 5. Trends of number of logins to the demand browsing service

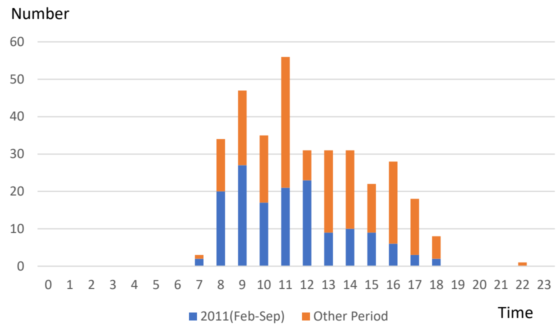

Figure 6. Number of logins to the demand browsing service by hour of the day

The GIFT123 was conducted 34 times from 2010 to 2021, averaging 2.8 times a year (Figure 7a). There are three ways to respond to the energy diagnoses depending on the contracted company's preference: in-person visits, phone consultations, and fax. In the target manufacturing company, visits (61.8%) were the most frequent, particularly before 2017, followed by phone consultations (38.2%). By months, October (21%) saw the highest frequency of interactions for the GIFT123, followed by April, August, and November, each accounting for 15% (Figure 7b). Typically, the energy diagnosis service is provided twice a year. Given that the fiscal year in Japan starts in April, it is assumed that the GIFT123 was first implemented in that month and then repeated in August to November at regular intervals. It is worth noting that the number of GIFT123 sessions was notably high in 2015 (5 times) and 2016 (7 times), indicating that contracted companies sought this service more frequently during those years to address energy-related challenges and collaborate with NT to find solutions.

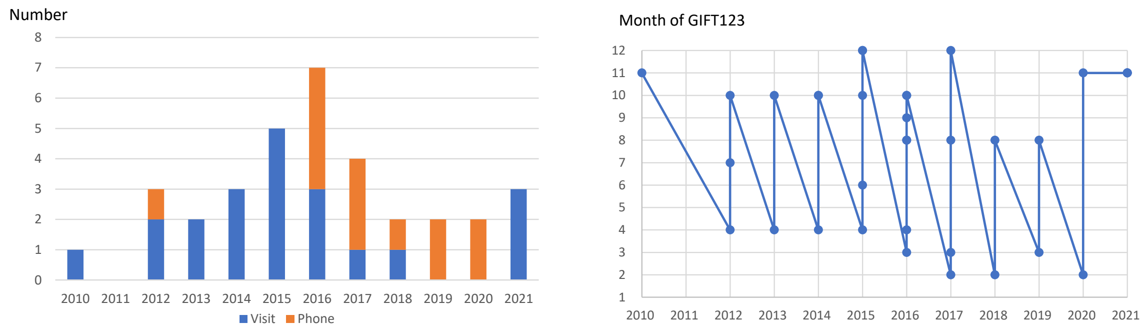

Figure 7 User interactions with GIFT123: Year-wise trend (left: 7a) and month-wise trend (right: 7b)

5. DISCUSSIONS AND CONCLUSIONS

In order to address the two research questions (RQ1 and RQ2), this paper aimed to assess the long-term effects of the EPCS and analyse how users interacted with it. Concerning RQ1, the study confirmed the long-term effects of the EPCS based on data from a selected manufacturing company, which showed reductions in electricity consumption and contracted power, as well as an increase in energy efficiency (gas production per kWh) from 2010 to 2021. Notably, this manufacturing company had already obtained ISO 14001 certification in December 2003 and had been actively pursuing energy conservation using the PDCA cycle even before implementing the EPCS. Furthermore, it is important to highlight that despite experiencing a 4.2% increase in gas production in 2019 compared to 2011, which typically results in higher electricity consumption and contracted power, the introduction of the EPCS led to reductions in both electricity consumption and contracted power over the long term. To understand the factors behind these long-term effects, we turn to RQ2.

The energy manger acknowledged the effective role of smart devices, namely SMARTMETER ERIA and SMART CLOCK, in encouraging both the energy manager and employees to adopt energy conservation measures. Of particular, SMART CLOCK, a wall clock smart device, was installed to engage employees in energy conservation efforts using a traffic light-based approach to prompt them to reduce energy consumption by turning off unnecessary air conditioners and lights. Furthermore, the energy manager made efforts to maintain the novelty effect of alerts from these devices by adjusting the demand target values, striking a balance between not being too strict and not being too lenient. Additionally, the introduction of sealing power buttons made it easy for employees to respond to alerts from these devices in the ‘Do’ stage. However, the study also revealed a decline in the number of logins to the demand browsing service, corresponding to the ‘Check’ stage, after 2012. Similar results were shown in earlier studies (Komatsu and Nishio, 2013; Pereira et al., 2013). Over the 120-month period from 2012 to 2021, there were 68 months (56.7%) in which the energy manager accessed the service at least once. Compared to the initial novelty-driven usage in 2011, it became evident that the novelty effect had waned. Nevertheless, the study found that when examining login records for the demand browsing service within 15 days before and after each GIFT123 session, 77.8% of the sessions had corresponding logins. This suggests that regular energy diagnoses in the ‘Act’ stage served as triggers, reminding the energy manager to access the service. Furthermore, the GIFT123 sessions provided valuable insights that helped the energy manager understand electricity usage patterns and identify potential energy conservation measures. Consequently, the energy manger remained motivated to use the demand browsing service in the long term.

It is worth noting the significant role played by GIFT123. Traditional energy diagnoses tend to be short-term, often limited to a single day or session, which can hinder dynamic assessments aimed at finding comprehensive energy conservation solutions (Kojima, 2000). To overcome this limitation, frequent energy diagnoses, such as those provided by GIFT123, are recommended. Previous studies, such as one conducted at the West Lothian Energy Estate in Scotland (Darby, 1999), have demonstrated energy conservation through frequent feedback by advisors. Similarly, the German energy advice center offered consultations that typically lasted

45 minutes for the initial consultation and were followed by additional sessions in many cases (Goepfert, 2006). Frequent energy diagnoses offer several advantages, including a better understanding of dynamic changes in electricity usage and the identification of potential energy conservation measures. It is worth highlighting that during a GIFT123 session in July 2012, the energy manager received advice regarding the peak power consumption during gas filling to tank trucks, which significantly contributed to high electricity usage. Consequently, the manufacturing company decided to adjust the timing of gas filling for tank trucks, resulting in a reduction in the peak value of contracted power. However, in the same year, the manufacturing company experienced higher energy consumption. In response to this, it is speculated that a change in the cooling time in a carbonate tank, accounting for 65% of total electricity consumption, was proposed through the GIFT123 in the following year, resulting in a long-term reduction of electricity usage compared to 2011.

In summary, this study confirmed that eco-feedback systems using the EPCS played a substantial role in achieving long-term energy conservation. Four distinct actions for energy conservation were implemented, aligning with the principles of the PDCA cycle. In the case study, smart devices were tailored to the specific local context, maintaining the novelty effect for employees. While the novelty effect of the demand browsing service diminished, regular energy diagnoses continued to engage the energy manager with the web-based service. Consequently, the introduction of eco-feedback systems aligned with the PDCA cycle, such as the EPCS, is highly recommended to promote long-term energy conservation in the industrial sector, including companies with existing certifications such as ISO 14001 and ISO 50001. However, it is important to note that this study represents a single case, and the findings may not necessarily apply universally. Future research should aim to verify the effectiveness of the EPCS based on larger sample sizes. Furthermore, the ability to generalize the results of this study could be limited by primarily using annual electricity consumption data to assess the effects of energy conservation measures. Therefore, conducting further case studies using data on 30-minute interval electricity usage would be desirable. Numerous research questions remain to be explored, including an examination of factors contributing to energy conservation failures by considering other contracted companies that have implemented the EPCS. Subsequent studies should continue to investigate user interactions with eco-feedback systems over the long term, following the PDCA cycle, building upon the lessons learned from this research.

REFERENCES

Darby, S., (1999). Energy advice – what is it worth? *The European Council for an Energy Efficient Economy Summer Study Proceedings*, 1999, Panel III.05.

Dobson, J. K., & Griffin, J. A. (1992). Conservation effect of immediate electricity cost feedback on residential consumption behavior. *The 7th ACEEE summer study on energy efficiency in buildings Proceedings*, *1992*, 33-35.

Gulbinas, R., & Taylor, J. E. (2014). Effects of real-time eco-feedback and organizational network dynamics on energy efficient behavior in commercial buildings. *Energy and buildings*, *84*, 493-500. https://doi.org/10.1016/j.enbuild.2014.08.017

Goepfert, C., (2006). *An evaluation of energy efficiency advice centers in Scotland*. MSc Thesis, University of Strathclyde, Scotland.

Holmes, T. G. (2007). Eco-visualization: combining art and technology to reduce energy consumption. *The 6th ACM SIGCHI conference on Creativity & cognition Proceedings, 2007*, 153-162. https://doi.org/10.1145/1254960.1254982

JASE-W. (2023). *Japanese energy-efficient technologies*. Japanese Business Alliance for Smart Energy Worldwide. Available at: https://www.jase-w.eccj.or.jp/technologies/pdf/Japanese_Energy_Efficient_Technologies.pdf, accessed September 14, 2023.

Kim, H., Bilionis, I., Karava, P., & Braun, J. E. (2023). Human decision making during eco-feedback intervention in smart and connected energy-aware communities. *Energy and Buildings*, *278*, 112627. https://doi.org/10.1016/j.enbuild.2022.112627

Kojima, T. (2000). A study on the diagnosis for saving energy around rational use of electric power. *Annual Report of Society of Business Diagnosis (Japan)*, *32*, 16-28. https://doi.org/10.11287/jmda1969.32.16

Komatsu, H., Nishio, K. (2013). *Applicability of 'Nudge' as information provision for energy and electricity conservation: energy reports for the US households as a case example*. Research Report Y12035, Central Research Institute of Electric Power Industry. Available at: https://criepi.denken.or.jp/hokokusho/pb/reportDetail?reportNoUkCode=Y12035, accessed September 14, 2023.

Ma, G., Lin, J., & Li, N. (2018). Longitudinal assessment of the behavior-changing effect of app-based eco-feedback in residential buildings. *Energy and Buildings*, *159*, 486-494. https://doi.org/10.1016/j.enbuild.2017.11.019

McCalley, L. T., & Midden, G. J. H. (1998). Computer based systems in household appliances: the study of eco-feedback as a tool for increasing conservation behavior. *3rd Asia Pacific Computer Human Interaction Proceedings*, *1998*, 344-349. https://doi.org/ 10.1109/APCHI.1998.704455.

METI. (2023). *The 2023 annual report on energy*. Ministry of Economy, Trade, and Industry, Japan. Available at: https://www.enecho.meti.go.jp/about/whitepaper/2023/pdf, accessed September 14, 2023

METI. (2023b). *Sougou energy toukei*. Ministry of Economy, Trade, and Industry, Japan. Available at: https://www.enecho.meti.go.jp/statistics/total_energy, accessed September 14, 2023

NT. (2023) *Demand etsuran service*. NIHON TECHNO CO., LTD. Available at: https://service.n-techno.co.jp/demand, accessed September 14, 2023

Pereira, L., Quintal, F., Barreto, M., & Nunes, N. J. (2013). Understanding the limitations of eco-feedback: a one-year long-term study. *Human-Computer Interaction and Knowledge Discovery in Complex, Unstructured, Big Data: Third International Workshop Proceedings*, *2013*, 237-255. https://doi.org/10.1007/978-3-642-39146-0_21

Sanguinetti, A., Dombrovski, K., & Sikand, S. (2018). Information, timing, and display: A design-behavior framework for improving the effectiveness of eco-feedback. *Energy Research & Social Science*, *39*, 55-68. https://doi.org/10.1016/j.erss.2017.10.001

UNFCCC. (2023). *Time series – Annex I*. United Nations Framework Convention on Climate Change. Available at: https://di.unfccc.int/time_series, accessed September 14, 2023.

BiBo: A SERIOUS BOARDGAME TO ACCELERATE URBAN INNOVATION IN GLOBAL-SOUTH

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Abstract: *Climate crisis is a complex topic, for practitioners, scientists, and policymakers alike. This is due to its interdisciplinarity, global scope, long-term effects, uncertainty and complexity of climate systems, and sociopolitical dimensions. Responsibly communicating climate emergency to a wide variety of stakeholders with varying intellectual abilities and professional competencies necessitates simple, hands-on interventions such as roleplay-based experiential games. In this article, we present a creative design-thinking process that aims to address climate crisis through (a) climate education (b) using serious experiential games as (c) simple yet creative social interventions to bring behavioural change at scale. We co-created and developed a new interactive board game called 'Building-in-a-Box' (aka. BiBo). This game is introduced as an interactive aid to communicate climate emergency in the building-scale. It serves as a simple yet creative artifact to stimulate thinking future alternatives leading to responsible design and behavioural change innovations within the complex urban systems. The article presents the comprehensive design of the BiBo board game, along with details to facilitate activity-based learning and reflection to stimulate critical-thinking and reasoning to address complex social issues (e.g. energy citizenship) in global-south. The discussions underline the imperative of proposed experiential game as not just an educational aid in schools or universities, but a powerful social-intervention to drive just transition (e.g., by minimizing risks to digital transformation, and low-carbon transition) within urban communities. The objective of BiBo is to accelerate responsible innovation in the global-south, by deepening the engagement among actors from policy, bureaucracy, administration, industry, and academia. In summary, this article exemplifies the eminent role of serios games in communicating complex problems and seeking innovative solutions in a simpler manner.*

1. INTRODUCTION

Urban innovation is a significant challenge globally, especially where rapid urbanization (UN-Habitat, 2016), limited resources, climate change (IPCC, 2014), poverty, and complex socioeconomic issues (UNDP, 2019) impede inclusive and sustainable urban development. Typically, the global-south nations are characterized by limited resources, funding, poor governance, environmental vulnerability, a lack of awareness and education, and the absence of data and evidence-based decision-making. This impedes an innovation-driven approach to urban problem solving. Various approaches have been devised to address these challenges, including top-down, bottom-up, participatory (Tarrow S, 2011), advocacy, and collaborative (Innes at al., 2004) (Sørensen at al., 2015). Traditional methods, such as community surveys, interviews, meetings, and assemblies, have proven to be less effective at extracting the ground truth and raising community awareness. Major approaches to problem-solving focus on comprehending and communicating the causes of a problem or presenting a specialized set of solutions. Neither of them account for crucial information buried in layers. Nonetheless, nations in this region of the world offers advantages such as youthful populations, technological leapfrogging, informal economies, cultural diversity, international knowledge exchange, and south-south cooperation for the efficient resolution of problems.

Gamifying the building design and construction lifecycle by explicating the underlying complexities creatively and clearly is identified as a critical knowledge gap based on our review. This manuscript is organized as follows: knowing—understanding the background of serious games and related works (section 1.1); sensing—the necessity of a gamification approach (section 1.2); doing—the design thinking process of game design (section 2); refining—remastering and evolving the game design for improved effectiveness (section 3). In addition, discussion on the various applications of proposed game, conclusions and future work is presented in section 4, 5, and 6 respectively.

1.1 Background to Serious Games

The serious games have emerged as an effective tool to address several aforementioned challenges by engaging stakeholders, enabling collaboration, and facilitating informed decision-making. Combining the engagement and intensity of gaming with educational and problem-solving components, these games effectively address community issues (DeFilippis J., 2017) (Fung A., 2015). Increased participation, experiential learning, collaboration, cooperation, data collection, and a safe environment for experimentation are all advantages offered by serious games. The original instructional and simplistic nature of serious games has evolved into a more engaging and interactive form. The theories of reasoned action (Fishbein et al., 2010) and social cognitive theory (Bandura A., 2004) has been applied to serious games for the purpose of community problem-solving to alter people's perspectives on issues or teach new skills. There is empirical support for the effectiveness of meaningful activities for community problem-solving. (Stanitsas et al. 2018) discovered an increase in serious games that teach sustainability and classified them according to the triple bottom line in their comprehensive literature review. However, their utility was limited (CRS, 2017), and a research strategy proposing the development of new, pertinent serious games to enhance holistic comprehension and educational foundations was presented. Serious games have evolved into effective engagement and negotiation tools. This includes, for instance, Friedemann Friese's *Power Grid* (Friedemann et al., 2009) and Ken Eklund's *World Without Oil* (Ken Eklund, 2007). These games and activities emphasize critical thinking, negotiation, and decision-making, which makes them appropriate for energy community issues, energy sustainability, resilience planning, public health, and community problem resolution. Other games such as *Fate of the World* (Greenwood C., 2012), *Flash Point: Fire Rescue* (Lanzing K., 2011), *Freedom: The Underground Railroad* (Arcade Games, 2012), the American Red Cross' *Climate Challenge* (Red Redemption, 2015), and *Community Inc.* (T4 Interactive, 2019) also encourage critical thinking, collaboration, and negotiation.

Serious games have matured into effective engagement and negotiation tools that encourage collaboration, problem-solving, and communication in a variety of contexts. The game development efforts should consider these principles and their pedagogical outcomes in order to increase the effectiveness of video games in addressing community issues. They can be powerful tools for raising awareness, facilitating dialogue, and empowering communities to resolve complex issues like climate change, public health, social justice, and urban development. A recent review of serious games conducted by (Wu, X., Liu, S. and Shukla, A., 2020) has identified that the concept of gamification in the field of *energy and built-environment* is gradually growing owing to the world of possibilities. However, all the eighteen serious games curated in this study are concerning energy-use and behaviour in the built-environment. In addition to the above, there are other creative experiential serious games/activities that are closely related to this thematic field of study (viz. urban design, sustainability, building industry). This includes the following:

1. *Technology Cards* (Ernstsen et al., 2023) **-** A novel dialogue-based design game that enables users to explore the impact of multiple technologies on their future business. The Technology Cards present 22 digital technologies that may create disruptive changes in the construction sector. These cards are used as (a) an information tool to get an overview of digital technologies entering construction; (b) a dialogue tool to imagine how the future of the sector will look like; and (c) as a strategic tool to prioritise technologies according to their perceived importance.
2. *'Kaun Hai MASTER? Kya Hai PLAN?'* (Shahdadpuri, A, 2021) is a participatory toolkit designed by the Social Design Colab in New Delhi. Used for Main Bhi Dilli campaign and workshops to help spread awareness within communities typically left out of planning processes on Delhi's upcoming Master Plan 2041; and with a vision to explore creative means to engage them in the design process. An interactive tool to spread awareness on Delhi's Master Planning process and share people's perspectives.
3. *GoGoals by United Nation* (Chen, F et al., 2022) is an interactive board game and an assessment toolkit to educate students about the 17 Sustainable Development Goals (SDGs) of the United Nations. Participants, acting as national leaders, completed tasks related to SDG implementation while balancing the environment, economy, and society. The game clarified common misunderstandings and helped students expand their perspectives from local to global issues. The study assessed the board game's fluidity, enjoyment, and interactivity, as well as its pedagogical value in understanding the relationship between SDGs.

1.2 Motivation and Contribution

According to the United Nations, the construction industry alone in 2018 accounted for approx. 39% of energy-related CO_2 emissions (UN Environment, 2018). The Architecture, Engineering, and Construction (AEC) and Facilities Management (FM) industries combined contribute considerably to global carbon emissions. On one hand, the operational phase of buildings alone is responsible for 28% of global carbon dioxide emissions. However, on the other hand, the embodied carbon emissions of buildings range between 11 and 40 percent of their entire lifecycle emissions. In 2018, 36% of the world's total energy consumption was contributed by the AEC and FM industries. The International Energy Agency (IEA) predicts that between 2010 and 2050, the building energy consumption will increase by fifty percent (International Energy Agency, 2019). Both these sectors are expected to adopt sustainable practices rapidly, reduce their energy consumption, and cut their carbon emissions considerably to contribute positively to climate action. As a result, the World Green Building Council aims to attain net-zero carbon emissions by 2050. In this effort, energy efficiency measures and renewable energy sources could reduce 30% of the building sector's energy demand by 2030 and reduce 80% of the CO_2 emissions by 2050 (International Energy Agency, 2019).

With climate-sensitive design targets on one hand and economic pressure on the other hand, both AEC and FM industries are embracing new design paradigms, innovative construction materials, techniques, and digital management practices. As a result, the built-environment is turning into a complex urban system globally. Arguably, the *energy and sustainability* are one of the wicked problems faced by the AEC and FM industry globally. Other wicked problems include among other challenges such as cyber resiliency, health and safety, and circularity. The poor governance, lack of far sight and foresight, weaker economy, lacks of collective social responsibility, etc. compounds the problem even more among developing nations in the global-south. Clearly, none of the existing serious games (presented in section 1.1) address this gap. Also, a recent study has underlined a long gap in the penetration of serious games in the AEC industry in Asia, particularly in this sector (Wu, X., Liu, S. and Shukla, A., 2020).

Understanding these global targets and translating them into action points, in order to reduce the energy demand and Green House Gas emissions by the target industry in the global-south nations require innovative suite of tools and approaches. Through this article, the authors introduce a design, development, and implementation of a new innovative serious game with an objective to bridge the gap in communicating such a complex/wicked problems (and seek innovative solutions). Gamifying wicked problems in the AEC industry (e.g., net-zero transitions, digital transformation, cyber resiliency) allows diverse stakeholders to collaborate and identify new value chains. To the best of our knowledge, there is no serious game that allows understanding the complex challenges surrounding building design, construction, and facilities management lifecycle intuitively. With this in mind, this article proposes the first of its kind serious game called *Building-in-a-Box (BiBo).* It is uniquely positioned as one of the first of its kind unique, modular, and flexible game that aims to advance innovation in the AEC industry sector across global-south nations (e.g., India).

2. BOARD GAME DESIGN AND CONTENT

Simple hands-on interventions that are serious and experiential in nature are required for the responsible communication of climate emergencies to a broad range of stakeholders with varying intellectual and professional abilities. This section describes the building's lifecycle centric board game's content, design thinking, guiding principles, rules or scenarios, game board overview, and cards.

2.1 Design thinking

The proposed BiBo boardgame is envisaged as an interactive, engaging visioning tool for communicating building-scale climate-related strategic design measures. It functions as a simple yet intuitive artifact to stimulate future-thinking, responsible design-thinking and behavioral change aid that leads to strategic innovation within complex urban ecosystem. The BiBo boardgame development procedure includes concept design, prototyping, development, and evaluation.

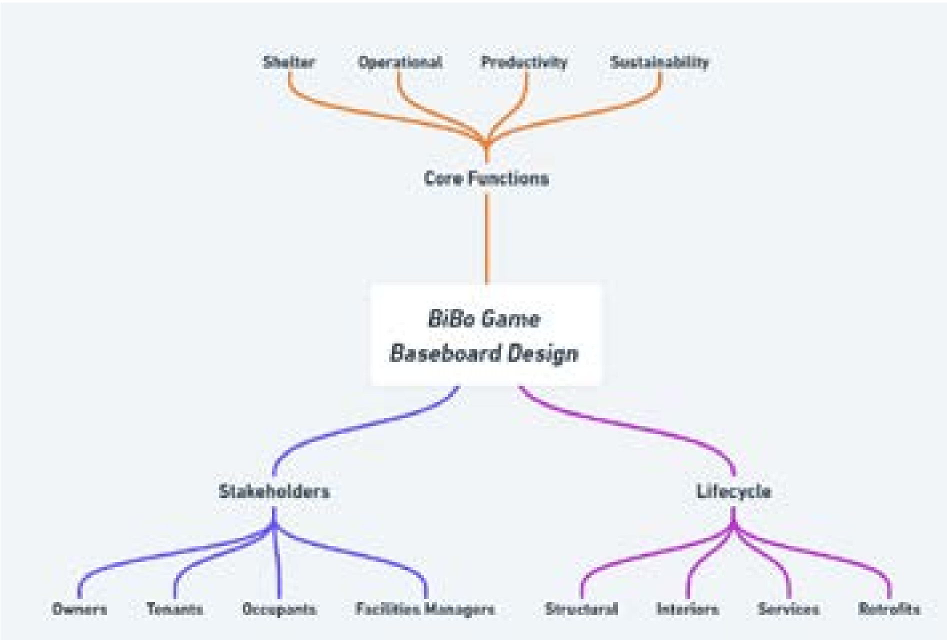

Figure 1: BiBo Design Thinking and Baseboard schema creation

The *concept design* of BiBo is inspired by one of the most well-known *Bingo* games in the market. Figure 1 describes the conceptual design-thinking underlying the four-level BiBo board game. The *four levels* in the board design represent four *core functions* (shelter, operation, productivity, and sustainability), *stakeholders* (owners, tenants, occupants, and facility manager), and *lifecycle stages* (structure, services, interiors, and retrofit) as mapped out in Figure 1. Unboxing urban innovation responsibly requires blending them creatively in the design of proposed serious game. Furthermore, this phase outlines creating game's overall structure, including the game's objectives (sustainability, resiliency, economics), team dynamics, components, and scenarios.

The focus of the *development phase* is on the creation of gameplay rules, content and graphical visuals, simple and concise rules. The prototype phase concentrates on creating a functional version of the game blending aforementioned concepts into components and rules of the gameplay, as well as a physical prototype for playtesting and revision. Visual design elements, such as artwork, illustrations, and layout are also considered during this stage to enhance the overall user-experience and engagement level of the target audience.

The evaluation phase consists of playtesting sessions with a diverse group of players, observing their interaction, level of engagement, and comprehension of the game team dynamics. Iterative enhancements are made to the game's components, rules, team dynamics, and overall gameplay based on player feedback. The final game incorporates feedback and enhancements, ensuring that all components are consistent with the objectives and themes.

Overall design of the BiBo board game aims to effectively accelerate urban innovation in the context of the global-south by engaging stakeholders in a dynamic and educational experience, fostering collaboration, decision-making, and strategic thinking in relation to building design, construction, urban planning, sustainability, and community development.

2.2 Game Design Principles

BiBo game is designed based on the following six principles, namely - modularity, scalability, intuitiveness, entertainment and education, experience, strategy, and complexity theory.

- *Modularity:* The modular design of BiBo enables flexibility and adaptability by dividing the game into smaller, easily rearrangeable components. This ensures gameplay is dynamic, relevant to a variety of player preferences and abilities, and facilitates goal-setting.
- *Scalability:* The game's scalability allows it to accommodate a range of player counts, making it appropriate for educational and enterprise workshop settings with smaller to medium sized groups.
- *Intuitiveness:* This principle emphasizes on the simplicity to understand the game, grasp the rules, goals and objectives. Thus, it makes the game accessible to both experienced and inexperienced players from varied technical backgrounds.
- *Edutaining:* The game also balances between *entertainment and educational value* it delivers. The gameplay allows players to have some degree to fun, and interaction, while catalysing creativity in players to think out of the box and drive urban innovation.
- *Experiential:* The gameplay parallels the challenging real-life scenarios and immerses players in a typical urban building design and development process. This provides players with a real-world understanding of a typical decision-making processes in a gamified way.
- *Strategic gameplay:* BiBo design fosters analytical thinking, foresight, systems reasoning and valorization in the minds of players required to drive innovation. The game embeds *complexity theory* underlying the intricate and interconnected nature of the complex urban systems (natural, social, technical, legal) which are typically non-linear, dynamic, and characterised by emergent behaviours.

By incorporating these fundamental concepts, BiBo aims to fosters critical and creative thinking.

2.3 Game Board and Cards

Through gamification, BiBo targets improving the understanding of the complexity across the building design, engineering, and construction lifecycle. Fundamentally, the game entails a baseboard with *4 levels and 6 slots under each level, a deck of cards*[1], and *rules* for K–12 and older audiences, making it ideal for academic institutions and engineering consulting firms among others target audiences.

Figure 2 presents the actual BiBo game design. On the left, it shows the graphical design of the baseboard. It depicts a four-level building under construction. As mentioned before, the four levels/stages in the gameplay correspond to the four typical phases in the lifecycle of buildings/facilities viz. *structural design*, *engineering services*, *interior design*, and *retrofits* (from bottom to top) respectively. Following the rules of the game, players are expected to pick/choose and place six cards (appropriate components) corresponding to each stage in the lifecycle to proceed to next level in the gameplay. Every time while selecting appropriate cards from the pack, players should administer strategic-thinking in the decision making keeping in mind increasing the value chain of all four major stakeholders, namely, facility managers, tenants, owners, and occupants. Finally, the four fundamental functions of every built environment. This includes providing shelter, a functional or operational facility, enhancing the productivity and well-being of occupants, and reducing their environmental impact in order to promote sustainability.

Figure 2: BiBo Game: Baseboard (on the left) and cards (on the right) (Source: Artistic Copyrights Reserved, Balaji Kalluri)

On the right, a sample palette of BiBo cards is shown. Each level has six card compartments that serve as placeholders for cards. The card design captures three essential characteristics of

[1] The first version of BiBo consist of *37 unique cards*

a building component, namely the title, visual icon, and cost (per unit area) of each component used to construct a larger complex system in the building scale. Together appropriate choice of cards at each level in the baseboard determines the design intent of the player in constructing a facility. The guiding arrow indicates that the dimensions of the cards allows players to easily pick and place cards of their choice into appropriate slots or placeholders on the baseboard.

3. GAME EXECUTION

3.1 Briefing the Game

Prior to the activity, it is essential to brief players on the rules, objectives, and limitations. This usually takes about 5 minutes. The briefing phase is the initial phase of a game, whereby players are introduced about the objectives, rules, and team dynamics of the game to all the participants. A game guidebook consists of an introduction, game objectives, rules and team dynamics, scenarios and challenges, team formation, and queries and clarifications. The facilitator introduces the game, explains its objectives, expected outcomes with a particular emphasis on the fostering urban innovation. The facilitator clarifies the rules of the game, and team dynamics, ensuring that all participants comprehend how to play a fair game. The facilitator presents one or more scenarios to challenge players by mimicking real world circumstances from the urban society. If team formation is required, the facilitator guides participants in forming teams, fostering collaboration, and working toward shared objectives. Before moving on to the next stage, the briefing phase permits players to ask questions and seek clarifications about the game's rules, objectives, or scenarios, ensuring a complete understanding.

3.2 Gameplay

This phase forms the crux of a game in which participants exercise their comprehension, complex problem-solving, and engage in the decision-making process. In a collaborative game format, BiBo is played in turns, one player at a time, in which players make decisions based on scenarios and challenges, considering objectives, resources, and hazards. Players analyse scenarios, evaluate options, and make well-informed decisions, cultivating strategic thought and teamwork. They manage resources judiciously, harmonizing project requirements with scenarios. Collaboration and networking opportunities promote teamwork and capitalize on one another's assets. As players encounter obstacles, they must engage in problem-solving and adapt their strategies, which requires critical thinking, creativity, and the capacity to analyse and adapt to shifting circumstances. The gameplay stage provides a dynamic environment for players to develop these skills, emulating the real-world difficulties of urban innovation. However, BiBo can also be played in a single player format (refer to the scenario description outlined below in italics). A few sample gameplay scenarios are highlighted to facilitate the adaptability of BiBo gameplay in order to increase player participation and instigate cross-functional and pragmatic dialogues, can facilitate many scenarios involving variety of stakeholders. Here is an example scenario. Figure 3 captures scenes during actual BiBo gameplay following the scenario.

"As a property owner, I (facilitator, playing the role of a building owner) provide two architectural firms (players in the role of contractors) with one set of BiBo each and request a design proposal for a four-story commercial building in a

10,000-square-meter plot of land. BiBo enables me (building owner) to comprehend architectural design provided by the players (contractors) and in turn intuitively analyse designs and make quick decision based on multiple objectives or criteria, such as environmental sustainability, economic viability, future-proof organizational resilience. Thus, in this instance, BiBo serves as a creative design aid that facilitates communicating complex system design (e.g., multi-objective decision-making) rapidly and intuitively between the stakeholders."

Figure 3: BiBo actual gameplay at FLAME University Summer School in July 2023

3.3 De-Briefing

Debriefing is a reflective activity conducted at the conclusion of the gameplay. Depending purely on the facilitators, a debriefing for a 30-minute gameplay session can typically last between 5 and 10 minutes. Debriefing is an essential component of this serious reflective game/activity. Each participant has two to three minutes to describe their building design strategy or intent (e.g., overall cost versus how it pledges to deliver the intended performance at each stage of the building's life to various stakeholders). Following this, the facilitator explains how decisions are typically made in the AEC projects, etc., for approximately two to three minutes.

3.4 Preliminary Outcomes and Findings

In this section, we present the preliminary outcomes of an experiential learning (EL) program involving seven participants which had BiBo game as one key component. The theme of EL program was '*buildings as a complex urban system*'. This was piloted in the FLAME University Summer School in July'23. The program combined (a) seminar; (b) BiBo gameplay; and (c) a guided walk to a net-zero energy facility in Pune, India as three key learning modules. A 10-question, multiple-choice questionnaire was administered to assess the efficacy of the combined EL approach. The findings showed that all respondents reported an increase in their comprehension of concepts, methods, and applications, including the systems, technological interventions underlying the operations of net-zero energy buildings with mean score = 8.875, and SD = 0.83 respectively. Specifically, 43% of the survey respondents felt that the guided walk alone provided the knowledge required to understand energy and sustainability concepts in buildings, whereas 57% of respondents felt seminar, BiBo gameplay, and guided walk combined provided them a greater understanding.

4. DISCUSSION

The discussion presented in this section exemplifies the potential application, outcomes and impact of BiBo under three broad categories, namely.

- **Environmental Impact:** BiBo *promotes broad knowledge about sustainable building design and construction* by emphasizing energy efficiency, circularity in construction, and the use of sustainable materials. It also serves *a strategic decision-making tool*, enabling players to make conscious design designs by subjecting them to present and future scenarios and providing them with multiple alternatives (in the form of cards) to choose from. It also functions as a *valuable data collection tool* for researchers in the building design and construction sector, by allowing players to contribute information on their design preferences, material selections, and energy consumption patterns among other key information.
- **Social Impact:** It serves as *a potential social intervention* tool in the building design by simulating various stakeholder requirements and preferences. It encourages players to create indoor environment that cater to the needs of the occupants/tenants, promote social well-being, and cultivate empathy. The gameplay promotes understanding the effects on building performance, responsible energy usage and informed decision-making. It functions as an effective *instrument for fostering collaboration* and *driving change* in the AEC industry by intuitively simulating the entire project lifecycle through a serious activity. Last but not the least, it can serve as the GoGoal game to promote *energy stewardship/citizenship* among communities in global-south nations. It is suitable for schools, learning institutes, and higher learning communities. Other examples include apartment complexes in urban India that use social games to spur innovation in energy efficiency, safety, comfort, and space utilization etc.
- **Educational Impact:** Broadly, BiBo gameplay fosters players with the knowledge about net-zero approaches, passive architectural design, integration of renewable energy, socio-environmental and socio-economic impact of design decisions. Furthermore, it also simplifies the complexity in comprehension of ‘design for net-zero’ or ‘low-carbon’ by combining a game/activity-based approach with scenario-based decision-making. Its modular design allows players to develop farsight, foresight, critical-thinking and problem-solving ability by presenting players with a variety of challenges using same boardgame. For instance, the suite-based design allows repurposing BiBo game to other *wicked problems* faced by the practitioners. This includes nation-wide building energy benchmarking, and enabling small and medium enterprises (SMEs) to support green transition by realigning their business strategies, creating green jobs and so forth.

5. CONCLUSION

In the 21st century, several challenges faced by developing nations in the global-south can be categorized as *wicked problems*. This study proposes a creative serious boardgame called BiBo. It bridges the existing gap in the innovation process by tapping the potential of serious games to drive socio-behavioural change. This is the key to unlock just transition among the urban global-south communities.

BiBo is uniquely positioned as one of the first serious games that aims to foster innovative-thinking within the AEC industry sector. It simulates real-world challenges (rapid urbanization, climate action, technological risks) and constraints (land-use limitations, climate emergencies, energy poverty, water security) encountered in typical decision making. The engaging nature of gameplay stimulates creativity, risk-free exploration of design decisions, and fosters collaboration within and beyond the AEC community. Moreover, BiBo shall serve as an *interactive visioning tool* to challenge the status quo (design practices, operations, maintenance, and best practices) prevalent in the industry, allowing players to reimagine the future design alternatives more holistically.

The preliminary findings from the pilot study involving serious roleplay games have shown favourable results, such as improved comprehensive of the complexity in urban building design and management discourse among players. Furthermore, it allowed players to think outside-the-box and explore creative/alternative solutions to complex and intractable (*wicked*) problems encountered by stakeholders in this industry. Overall, BiBo serious game contributes to the just and responsible urban innovation charter.

6. FUTURE WORK

The BiBo game is designed with multiple target audiences in mind, including children and young adults (agents of grassroots change), aspiring professionals, industry practitioners, citizens, and real estate and facilities management associations and organizations. The creators acknowledge that the success and full potential of the proposed game depends on the following - *acceptance*, *usability*, and *scalability*.

Although BiBo was piloted and tested at the FLAME Summer School (in July 2023), one of the immediate next steps is to roll it out to others schools and universities. The pilot study lacks substantial qualitative and quantitative evidence on the impact of serious games in comprehending complex urban challenges. For this purpose, the authors are planning a series of BiBo workshops, first among them is in the forthcoming EdTech conference on the theme *Technology for Education (T4E)* 2023 conference in IIT Bombay. Further research is required to design a structured questionnaire that allows capturing and evaluating the learning outcomes of such games.

The next step is to plan activity/game-base workshops involving practitioners and professional bodies such as Indian Green Building Council, Alliance for an Energy Efficient Economy in India, National Institute of Urban Affairs, Indian Society of Heating, Refrigerating and Air Conditioning Engineers to evaluate the efficacy of BiBo in fostering urban innovation (e.g. creating green jobs, identifying new business models, fostering new collaborations/partnerships) to drive just transition into the future. Furthermore, BiBo is thoughtfully designed to forge cross-sectoral, and cross-professional collaboration. For instance, the intuitive design and gameplay allow players from diverse professional backgrounds to collaborate with architects, engineers, cyber security experts, humanities scholars, lawmakers, sociologists, and community representatives. This will enable solving *'wicked'* problems beyond energy and sustainability, including cyber terrorism, biological warfare etc. Last but not least, subsequent research and development shall focus on upgrading BiBo game with more building components (e.g. introducing new cards), and turn it into a digital game in order to facilitate scalability and enriching experience.

6. REFERENCES:

Arcade Games- Freedom: The Underground Railroad (2012), https://boardgamegeek.com/boardgame/119506/freedom-underground-railroad

Bandura, A. (2004). Social cognitive theory for personal and social change by enabling media. In A. Singhal, M. J. Cody, E. M. Rogers, & M. Sabido (Eds.), Entertainment-education and social change: History, research, and practice (pp. 75-96). Lawrence Erlbaum Associates Publishers.

Chen, F.-H.; Ho, S.-J. Designing a Board Game about the United Nations' Sustainable Development Goals. Sustainability 2022, 14, 11197. https://doi.org/10.3390/su141811197

CRS. 2017. Games 4 Sustainability [Online]. Poland: Centre for system solutions. Available: https://games4sustainability.org/.

DeFilippis, J. (2017). Community Development and Public Administration Theory: Promoting Democratic Principles to Improve Communities. Public Administration Review, 77(4), 580-589.

Ernstsen, S. K., Thuesen, C., Mossing, C. H., Brinck, S., & Maier, A. (2023). Technology Cards: A Design Game for Navigating in a Future of Digital Technologies. International Journal of Design, 17(1), 37-53. https://doi.org/10.57698/v17i1.03

Fishbein, M., & Ajzen, I. (2010). Predicting and changing behavior: The reasoned action approach. Psychology Press.

Friedemann Friese & Kalusky, Maura & Kröpke, Henning & Tummelson, Jay & Rio Grande Games. (2012). Power grid / author: Friedemann Friese ; graphics & design: Maura Kalusky ; rules text: Friedemann Friese & Henning Kröpke (August 2009) ; translation & editing: Henning Kröpke & Jay Tummelson.

Fung, A. (2015). Putting the Public Back into Governance: The Challenges of Citizen Participation and Its Future. Public Administration Review, 75(4), 513-522.

Greenwood, Chris. (2012). Fate of The World: computer gaming for conservation?. Oryx. 46. 10.1017/S0030605311002158.

Innes, J. E., & Booher, D. E. (2004). Reframing Public Participation: Strategies for the 21st Century. Planning Theory & Practice, 5(4), 419-436.

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC.

Ken Eklund, 2007 http://writerguy.com/wwo/metahome.htm

Lanzing, Kevin. Flash Point : Fire Rescue. Oakland, CA: Lone Oak Games, 2011. Print.

Red Redemption. 2015. Climate Challenge. Game [browser]. Red Redemption, Oxford, UK.

Shahdadpuri, A. (2021). How can we plan a city with people, for the people? New Questions and reflections on "Urban Activism": Reinforcing Claims in the 21st Century planning of the

City [preprint]. The Evolving Scholar | IFoU 14th Edition. https://doi.org/10.24404/6160707e066476000850012f

Stanitsas M, Kirytopoulos K, Vareilles E, Facilitating sustainability transition through serious games: A systematic literature review, Journal of Cleaner Production (2018), doi: https://doi.org/10.1016/j.jclepro.2018.10.157.

Sørensen, E., & Torfing, J. (2015). Enhancing Collaborative Innovation in the Public Sector. Administration & Society, 47(6), 831-855.

Tarrow, S. (2011). Power in Movement: Social Movements and Contentious Politics. Cambridge University Press.

T4 Interactive, (2019), Community Inc, Game, tinyBuild Games, US

UN-Habitat. (2016). World Cities Report 2016: Urbanization and Development - Emerging Futures. United Nations Human Settlements Programme.

UNDP. (2019). Human Development Report 2019: Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. United Nations Development Programme.

Wu, X., Liu, S. and Shukla, A., 2020. Serious games as an engaging medium on building energy consumption: A review of trends, categories and approaches. Sustainability, 12(20), p.8508.

UrbanXL: A suite of experiential learning tools to accelerate urban innovation in global-south

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Abstract

The global challenges require global solutions. This study is deeply motivated by three most prominent challenges that pose existential threat to human race - nuclear war, ecological collapse, and technological disruption. Addressing sustainable, social, and digital challenges of the real world ethically, humanistically, and critically requires developing the 21st century competencies through creative and experiential education. In this article, Urban eXperiential Learning (UrbanXL) - a new suite of experiential learning cum visioning tools that fosters analytical thinking and innovation, active learning and learning strategies, and complex problem-solving skills is presented. They are identified as the top-3 future skills by the World Economic Forum. The specific aim of UrbanXL is to stimulate reimagining 'The Future of Urban X' with a goal to lead urban innovation in the global-south. The article further elaborates on the underlying philosophy and design-thinking that led the design and co-creation of UrbanXL. The article presents a brief discussion drawn from piloting it in a foundational trans-disciplinary undergraduate course in a global-south university with an intent to communicate global and national emergencies. The course entails thematic topics including urban design and liveable cities, building design and construction, policy and urban governance, and cyber resiliency. The course entails more than ten experiential learning activities and serious games to develop 21st century skills and competencies. The proposed suite stimulates thinking future alternatives systematically, guiding the just transition at the nexus of complex urban systems, behavioural change, and policy making.

1. INTRODUCTION

'The global challenges require global solutions' ~ Harari, Y. N. (2018)

This study is deeply motivated by three most prominent challenges that pose existential threat to human race - nuclear war, ecological collapse, and technological disruption (Harari, Y.N., 2018). Addressing sustainable, social, and digital challenges of the real world ethically, humanistically, and critically requires developing the 21st century competencies through creative and experiential education. In this article, Urban eXperiential Learning (UrbanXL) - a new suite of experiential learning cum visioning tools is introduced to systematically guide the acceleration of responsible urban innovation pathways among the global-south nations (e.g., India).

2. PROPOSED SUITE

2.1. UrbanXL

UrbanXL is a new, first of its kind edutainment suite comprising of experiential learning aid and visioning tools that aims to systematically guide urban innovation across a broad range of 21st century global challenges. In turn, it enables developing creative-thinking, active and collaborative strategies, and complex problem-solving skills. These are identified as the top-3 future skills by the World Economic Forum (see Fig. 1).

Fig. 1 Top-10 skills of 2025 (Source: Zahidi, S. et al. 2020)

The specific aim of UrbanXL is to provide a creative and stimulating environment in the forms of serious games and visioning activities that are structured to facilitate reimagining *'The Future of Urban X'* with a goal to lead urban innovation in the global-south. Broadly, the current version of UrbanXL entails 5 modules and 11 experiential activities. In particular, it comes with 4 serious thematic games, one each for urban design, built-environment, resilience, and policy/governance as shown in fig. 2. More details of each game is presented in Section 2.3.

Fig. 2: Serious Thematic Games packaged within UrbanXL suite

2.2. Game Design Principles

The foundational design-thinking of UrbanXL lies in the following principles, namely:

1. *Modularity:* purposeful games/activities to suit to the wide range of target audience (e.g., educational institutions, knowledge consultants, executives, policy makers)
2. *Intuitive and Scalable:* globally relevant and no pre-requisites are required
3. *Fun and Engaging:* individual and/or teamplay
4. *Experiential:* embedded real-world scenarios, and sense of competition
5. *Strategic:* games and activities are designed to facilitate developing both far sights and foresights to help future-proof institutions and organizations.
6. *Complexity theory:* gameplay embeds complex aspects ecological collapse, and technology-led disruption in urban environment

2.2. Serious Games in UrbanXL

The current version of UrbanXL consists of a suite of four serious games. This includes the following:

- *Prospera:* a boardgame used as interactive and collaborative visioning tool to design future cities. Based on Pune Metropolis (a city in India), this game allows experiencing and better understanding concepts such as urbanization, urban agglomeration, and urban sprawl (see Fig. 3).

Fig. 3: Prospera game design consists of baseboard, scenario cards, and wooden blocks (Copyrights reserved, Balaji Kalluri)

- *BiBo:* Also known as Building-in-a-Box. It gamifies the lifecycle of the architectural design, engineering, building construction (AEC) and facilities management (FM) industry which contributes approx. 30% of global GHG emissions (see Fig. 4).

Fig. 4: BiBo game consists of baseboard & cards (Copyrights reserved, Balaji Kalluri)

- *City Runner:* a serious boardgame that gamifies the complexity encompassing urban governance. Again, based on Pune Metropolis, this game allows experiencing concepts such as participatory governance, fiscal health, nature of urban challenges, livability and quality-of-life (see fig. 5)

Fig. 5: City Runner game design consists of baseboard, various cards, ledger book, and a fortune wheel (Copyrights reserved, Balaji Kalluri)

- *Cyb Flash:* A flashcard based creative aid that facilitates carrying out activities central to evaluating the understanding and readiness of cyber resiliency in the context of digital systems amongst a wide range of target audiences. Typically used as an ice-breaker game (see fig. 6).

Fig. 6: CybFlash consists of pack of flashcards printed on both sides (Copyrights reserved, Balaji Kalluri)

2.3. Target audience

This is designed modularly keeping in mind various end-users. As a suite, the entire UrbanXL is ideal for tertiary educational institutions who want to teach urban innovation blending multiple disciplines. However, on the other hand, individual modules can be also used as a visioning and strategic planning tool in an interactive workshop setting by various institutions working in architectural and engineering sectors, management consulting, policy making and governance sectors.

3. URBANXL IMPLEMENTATION PLAN

3.1. Program Design

The proposed UrbanXL is first piloted in a recently concluded FLAME Summer School[i] in a liberal university based in India. The course is designed to offer rich insights and develop 21st century skills and competencies through experiential learning mechanisms at the foundational level. This will enable understanding the role of multi-disciplinary education in addressing challenges that pose existential threat to human race in the 21st century. The thematic topics are drawn from environmental studies (sustainable development goals, climate-change, architectural/civil engineering, building science), technology, policy and governance (societal transition, urbanism, digital urban governance, public administration, and cyber resiliency). Table 1 outlines design of 3-week long summer program titled *'Technology and Economics of Complex Urban Systems'*. The goal is to foster responsible urban innovation facilitated through a suite of serious games and creative learning tools offered by UrbanXL.

[i] https://www.flame.edu.in/academics/flame-summer-school/courses/technology-and-economics-of-complex-urban-systems

Table 1: Outline experiential learning program on urban innovation using UrbanXL

WEEK 1	
DAY 1	Intro to 21st century grand challenges & skills
	Activity 1: Ice-breaker: United Nations SDGs Go Goals Boardgame[ii]
DAY 2	Introduction to Economics of Urban Systems
DAY 2	**Module 1: Urban Design**
	Activity 2: United Nations - Climate-Change Board Game
DAY 4	Activity 3: PROSPERA - A Game on Spatial Design of Pune Metropolis
DAY 5	Activity 4: Guided tour of KUDOS[iii] and AVASARA Academy[iv]
WEEK 2	
DAY 1	**Module 2: Built-environment**
DAY 2	Activity 5: Building-in-a-Box
DAY 3	**Module 3: Resiliency (Safety & Security in Urban systems)**
	Intro to Cyber Resiliency
	Activity 6: Cyber-security Ice-breaker
DAY 4	Activity 7: Risk assessment in Critical Urban Infrastructures
	Activity 8: Decoding Stuxnet
DAY 5	Activity 9: Hands-on Cybersecurity
WEEK 3	
DAY 1	**Module 4: Public Policy Making**
DAY 2	Case Study: Decoding Mission 2070 Net-Zero Carbon India
DAY 3	**Module 5: Policy Implementation / Governance**
	Urban Governance
DAY 4	Activity 11: City Runner board game
DAY 5	Capstone Project Demo

[ii] UN-SDG Go Goals https://go-goals.org/
[iii] An Urban Innovation Studio in Pune (India) https://www.linkedin.com/company/kudosflame/about/
[iv] A net-zero energy campus in Pune (India) https://nzeb.in/webinars/design/avasara-academy/

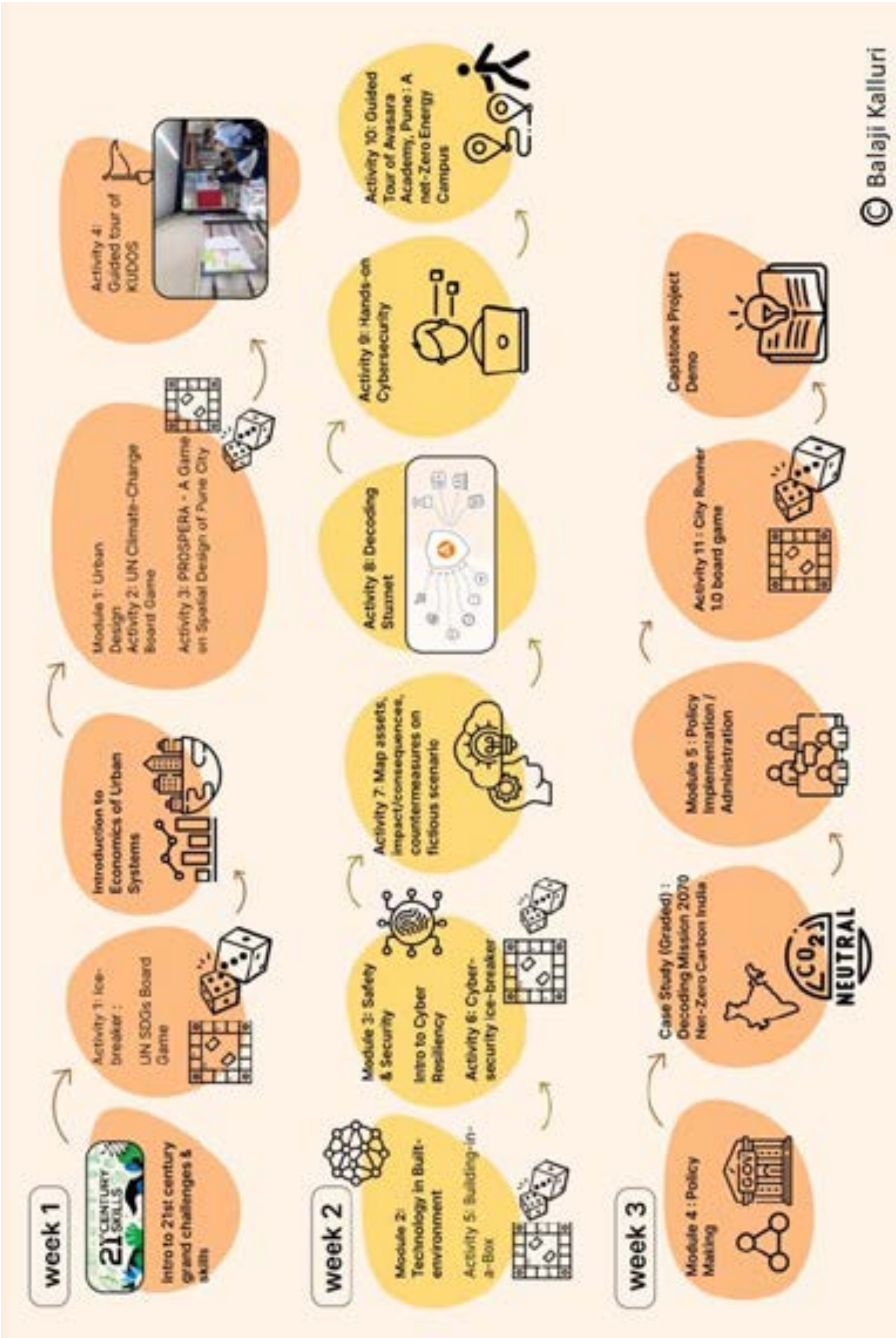

Fig. 7: UrbanXL – A Graphical Handout (Copyrights reserved, Balaji Kalluri)

4. CONCLUSIONS AND NEXT STEPS

This study introduces a first of such kind creative experiential learning suite of serious games and activities in the form of *UrbanXL*. It also discusses how can such tools enable educating the grand challenges faced by the 21st century, and experience the complexity encompassing it, and develop critical-thinking required to safely and responsibly navigate the societal transition. While I believe in the potential of the proposed experiential learning suite, I also acknowledge that the success and unleashing its full potential depends on the following - acceptance, usability, and scalability among the target communities. Although UrbanXL was piloted and tested at the FLAME Summer School in July 2023 (see Fig. 7), one of the immediate next steps is to roll it out to schools and universities with an objective to collect feedback (for evaluation and further development) and also assess the impact.

5. REFERENCES

Harari, Y. N. (2018). *21 Lessons for the 21st Century:'Truly mind-expanding... Ultra-topical'Guardian*. Random House.

Zahidi, S., Ratcheva, V., Hingel, G., & Brown, S. The Future of Jobs Report 2020| World Economic Forum. Futur Jobs Rep [Internet]. 2020;(October): 1163.

https://www.springer.com/journal/12053/submission-guidelines#Instructions%20for%20Authors%20Part%20I_References

Sustainability from the Top: How Leadership and Responsibility predict Corporate Sustainability

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Keywords: Corporate Sustainability Index, Sustainable Leadership, Individual Pro-environmental Behaviour, Perceived Corporate Sustainability, Hierarchical Linear Regression

Abstract *Addressing climate change requires both individual behavioural change and cor-porate transformation, as organizations play a crucial role in a sustainable society. How sustainability in organizations is perceived and implemented, depends on diverse factors such as management practices, communication, individual attitudes, and behaviours of leaders and employees. However, current research only investigates factors that affect the implementation of sustainable development and practices separately. Hence, holistic ap-proaches are required to provide insight into how they affect a company's sustainability efforts. A quantitative online survey with n = 87 employees was conducted in Germany in 2023. The Corporate Sustainability Index (CSI) was developed to indicate the extent to which organizations implement sustainability into their policies and concrete practices. To investigate which factors predict corporate sustainability, we analysed employee-, manage-ment-, and organization-related factors using multiple linear regression analysis. Trans-parent accountability for sustainability was the strongest predictor of the CSI, along with a top-down approach to implement corporate sustainability. In contrast, employees' envi-ronmental awareness and their organizational citizenship behaviour towards the environ-ment were not related with CSI. Our results stress the importance of leaders with an envi-ronmental focus as role models who can drive the transformation toward effective sustain-ability management in companies. This study offers important insights into the prerequisites for leaders to foster an environmentally responsible culture in their organizations.*

1. INTRODUCTION

The challenges of climate change mitigation have urged both governments and organizations to adopt effective sustainability measures (Fawehinmi et al., 2020) . Ensuring sustainability is not merely an option but a necessity for companies to remain competitive, as demanded by all stakeholders (Yue et al., 2023) . While many companies have recognized its importance, the implementation of sustainable practices is often hindered by several factors such as financial constraints, legal requirements, and internal organizational factors (Gawusu et al., 2022) . These obstacles underscore the importance of refining a company's internal strategies (Biswas et al., 2022) . The existing body of literature has primarily centered on personal characteristics and corporate culture as the most important drivers of sustainability attitudes and behaviours (Kiesnere & Baumgartner, 2019) . However, to provide a comprehensive understanding of the factors shaping corporate sustainability, this study analyses individual, behavioural as well as organizational factors in one frame of reference.

2. IMPACT FACTORS ON ORGANIZATIONAL SUSTAINABILITY

In this chapter, the main factors influencing corporate sustainability and the respective empirical state of the art are outlined.

2.1 Individual factors influencing sustainability

Environmental sustainability in organizations largely depends on the pro-environmental behaviour of its members, both employees and executives (Biswas et al., 2022) . The sustainable behaviour of employees is mostly conceptualized as Organizational Citizenship Behaviour for the Environment (OCBE) . The concept of OCBE comprises individual voluntary initiatives that are not rewarded by the organization (Boiral & Paillé, 2012) . Yue et al. (2023) highlight the positive association between OCBE and a company's sustainability performance. They suggest that OCBE acts as a mediator between the presence of an environmental management system and a company's sustainability performance. The impact of OCBE makes it relevant to consider management practices and other factors that promote OCBE for achieving sustainability goals. Several studies have highlighted the importance of leadership behaviour in promoting sustainable behaviour, which in turn has a positive impact on the company's overall sustainability performance (Foo et al., 2021) . Specifically, Environmental Transformational Leadership (ETL) has been identified as a catalyst of sustainable employee behaviour (Li et al., 2020) . Wang et al. (2018) posit that when leaders demonstrate sustainable behaviour, employees are more motivated to accept and adapt it. However, while leadership can foster sustainable behaviour, its direct association with a company's sustainability performance remains open (Foo et al., 2021) .
Apart from leadership, individual attitudes influence sustainable behaviour, and the effectiveness of sustainability measures in companies (Latif et al., 2022) . Sustainability attitude, subjective sustainability norms, perceived control of environmental behaviour, and the perception of corporate sustainability were found to positively affect employee sustainability behaviour (Alzaidi & Iyanna, 2021) . In contrast, the study by Foster et al. (2022) shows that the influence of environmental commitment, environmental consciousness, and green self-

efficacy on OCBE was insignificant.

2.2 Organizational factors shaping sustainability

Another aspect of implementing sustainability is the organizational culture. An eco-friendly company culture promotes the integration of sustainable practices into everyday working life, while a slow-changing organizational culture and lack of strong leadership can hinder its integration (Kiesnere & Baumgartner, 2019) . Moreover, Psychological Green Climate (PGC) has a positive impact on employees' sustainability behaviours (Biswas et al., 2022) . PGC reflects employees' collective perception of the company's policies and procedures promoting environmental sustainability and green values. Additionally, it has been identified as a mediator between leadership styles like ETL and OCBE (Liu & Yu, 2022) . Besides leadership styles, strong support from top management is crucial even if the main initiative for the implementation comes from employees (Gotsch et al., 2023; Kiesnere & Baumgartner, 2019) . Further, the company's size impacts corporate sustainability. Larger companies tend to focus more intensively on ecological change and are better equipped to implement internal sustainability strategies (Risius et al., 2023) .

2.3 Research aims and hypotheses

Despite the current insights, an understanding of the determinants of corporate sustainability necessitates an integrated perspective, encompassing both individual and organizational factors. Therefore, the present work aims to a) adopt a multifactorial approach to simultaneously investigate factors influencing corporate sustainability and b) develop a novel instrument for measuring corporate sustainability, which reflects its multifaceted nature and considers both, specific measures as well as the integration into corporate policies. Adequately, the following research questions were derived:
RQ1: Which attitudinal and behavioural factors influence corporate sustainability?
RQ2: Which organizational factors influence corporate sustainability?
RQ3: Which attitudinal, behavioural and organizational factors can be used to predict corporate sustainability?

3. METHODOLOGY

In the following chapter, we describe the operationalization of relevant factors, the acquired sample as well as the different steps and procedures of the statistical data analysis.

3.1 Survey structure and variables

To investigate our research questions, we conducted a quantitative online survey using Qualtrics software (Version March 2023; © 2023 Qualtrics, Provo, UT) . Since only a part of the collected data is relevant here and further data is processed in other publications, only the relevant variables for this paper will be presented. Employee-, management, and organization-related factors were either measured with validated scales or derived and qualified from a qualitative pre-study in which semi-structured interviews were conducted with employees and corporate sustainability experts. All multi-item constructs were measured on six-point Likert-scales (1 = strongly disagree, 6 = totally agree). The questionnaire consisted of the following parts:

a) Sociodemographics: Gender, age, education, job position (leadership, yes or no);

b) Individual attitudinal factors: *Eco-consciousness* (eight items by Geiger & Holzhauer, 2020), *general openness to change* (four items of the scale developed by Szebel, 2015);

c) Individual behavioural factors: To measure employees' sustainable behaviour we adapted the *Organizational Citizenship Behaviour for the Environment* (*OCBE*) scale by Boiral and Paillé (2012) and translated twelve of the originally 13 items into German. *Environmental Transformational Leadership* (*ETL*) was assessed with six items from Robertson and Barling (2000);

d) Organizational factors – Corporate demographics: Company size (up to 9, 49, 249 and more than 249 employees), company age (in years);

e) Organizational factors – Corporate sustainability: Here, participants were asked if sustainability in their organizations is approached in a *top-down* or *bottom-up* way (four items, e.g., "Regarding sustainability, our employees are pushing the issue more than management"), if there is transparent *accountability* for sustainability (four items, e.g., "Our company employs a sustainability expert") and if the company's *image* is perceived as sustainable (five items, e.g., "Sustainability is a guiding principle of our company"). Corporate actions regarding sustainability were measured with 13 items describing different possible areas of sustainable measures (e.g., energy management or mobility) as well as an adaptation of the *Corporate Environmental Policies* (CEP) scale (Ramus & Steger, 2000) extended to 15 items (e.g., "My Company has specific sustainability targets"). For all items of these constructs, the 6-point scales were expanded to include an "I don't know" option. Finally, we assessed the perceived *relevance* of sustainability once across the *overall* company, at the *management* level, and at the *employee* level each on a scale from 0 (irrelevant) to 100 (extremely relevant).

3.2. Sample

Data were collected in March 2023 in Germany. To ensure data quality, we discarded incomplete surveys, speeders (response time below 50% of the median, $Md = 29$ min.) , and non-differentiated data sets. As our focus lies on the employee perspective, we omitted 14 data sets from respondents in an executive position. The final sample ($n = 87$) comprised 72% female ($n = 24$) and 28% male ($n = 24$) participants. The mean age of participants was 28 years ($SD = 9.21$) , with an age range spanning from 18 to 56 years. With 61% the majority of participants exhibited high educational attainment ($n = 53$) , while 38% held medium levels ($n = 33$) and only one percent fell within the lower range of educational attainment ($n = 1$) . The determination of educational levels was based on the International Standard Classification of Education (ISCED) . Regarding employment relationships, most participants worked full-time (40.23%, $n = 35$), as student assistants or mini-jobbers (37.93%, $n = 33$). Other employment forms were part-time (18.39%, $n = 16$) and short-term employment or internships (3.35%, $n = 3$).

3.3 Statistical analysis

All analyses were computed using R Studio Version 2022.12.0+353. First, we performed descriptive analyses that included calculating measures of central tendencies and dispersions and checked the internal reliability constructs with Cronbach's Alpha. Increased or decreased construct means were statistically validated with one sample t-tests. When evaluating the sustainability measures and policies (s. 4.1), missing values ("I don't know") were not included. On average, there were eleven missing values for each measure and 20 for each policy. As shown in table 1, the sample exhibited an elevated environmental consciousness (M = 4.76, SD = 0.68) and openness to change (M = 4.35, SD = 0.7). Except for top-down, which was slightly decreased (M = 3.14, SD = 1.17), the mean values of all other factors were closely clustered around the scale means of 3.5 and 50 for the relevance factors.

Table 1: Descriptive analysis of attitudinal factors, behavioural factors, and corporate sustainability (n = 87)

		M	***SD***	**Cronbach's α**	**Scale**
Individual factors	Eco-consciousness	4.76	0.68	0.83	1-6
	Openness to change	4.35	0.7	0.7	1-6
	OCBE	3.38	0.92	0.9	1-6
	Leadership (ETL)	3.3	1.11	0.93	1-6
Organizational factors	Top-down	3.14	1.17	0.71	1-6
	Bottom-up	3.67	1.06	0.8	1-6
	Accountability	3.83	1.47	0.9	1-6
	Image	3.73	1.33	0.95	1-6
	Relevance Overall	55.37	26.53	-	1-100
	Relevance for employees	53.06	24.11	-	1-100
	Relevance for managers	48.82	29.02	-	1-100

Secondly, possible relations between variables were investigated by calculating bivariate correlations (Spearman's rank correlation) . Before performing the regression analysis, we tested the necessary assumptions. Bivariate correlation analysis indicated linearity, while the Breusch-Pagan test confirmed homoscedasticity and low variance inflation factors (VIFs in the range of 1.3-2.1) ruled out multicollinearity. The normal distribution of residuals was confirmed by both visual inspection and the Shapiro-Wilk test.

4. RESULTS

In this chapter, we first provide a descriptive overview of sustainability in the companies surveyed. We then introduce the newly devised Corporate Sustainability Index and present factors that are related to it and predict it. Furthermore, companies are considered separately according to different corporate factors, and preliminary insights into the influence of leadership on sustainability are displayed.

4.1 Descriptive analysis of corporate sustainability practices

In this section the descriptive results of measures that companies have already implemented to enhance their sustainability, as well as the policies employed to integrate sustainability into their corporate culture, are reported.

The most frequently implemented sustainability measures in companies pertained to energy management (*M* = 4.53, *SD* = 1.3), waste separation (*M* = 4.45, *SD* = 1.4), digitalization (*M* = 4.35, *SD* = 1.48), and mobility (*M* = 4.32, *SD* = 1.58). These initiatives were widely recognized with more than three-quarters of participants indicating their implementation in their respective organizations. Less prevalent sustainability measures were raising awareness about the current status of corporate sustainability (*M* = 6.62, *SD* = 1.58) – e.g., by collecting data on resource consumption –, acquiring knowledge (*M* = 3.41, *SD* = 1.64), and adapting their business model to promote sustainability (*M* = 2.78, *SD* = 1.69). The response distributions for all sustainability measures can be seen in figure 1.

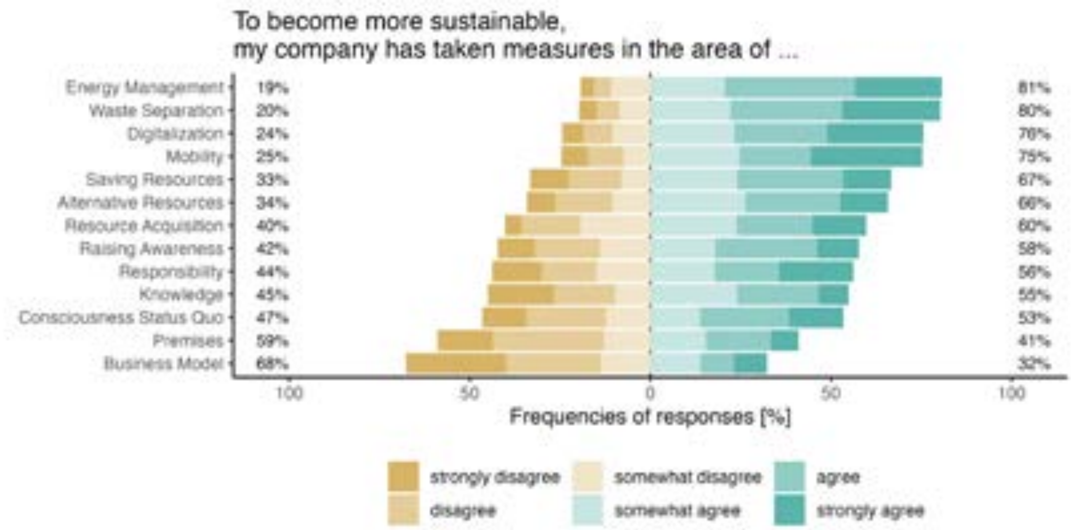

Figure 1: Response distributions for perceived sustainability measures in companies (missing values excluded)

Further, respondents were asked which environmental policies already affect their business activities. The predominant policy emphasized companies' commitment to environmental protection (*M* = 4.63, *SD* = 1.31), closely followed by dedication to becoming more eco-friendly (*M* = 4.47, *SD* = 1.27) and the pursuit of a sustainability-driven vision (*M* = 3.86, *SD* = 1.68). These three policies, in essence, describe overarching attitudes or orientations of companies towards sustainability. More tangible policies were less prevalent in respondents' ratings. Only about a third of the respondents stated that their companies offer employee trainings on sustainability (*M* = 2.83, *SD* = 1.86), enforce global environmental standards (*M* = 2.70, *SD* = 1.78), and use an environmental management system (*M* = 2.69, *SD* = 1.64). As leadership behaviour was identified as an important aspect influencing corporate sustainability, it is worth noting that 58% of respondents reported that their managers consider sustainability (*M* = 3.58, *SD* = 1.64). Again, response distributions for all policies can be seen in figure 2 below:

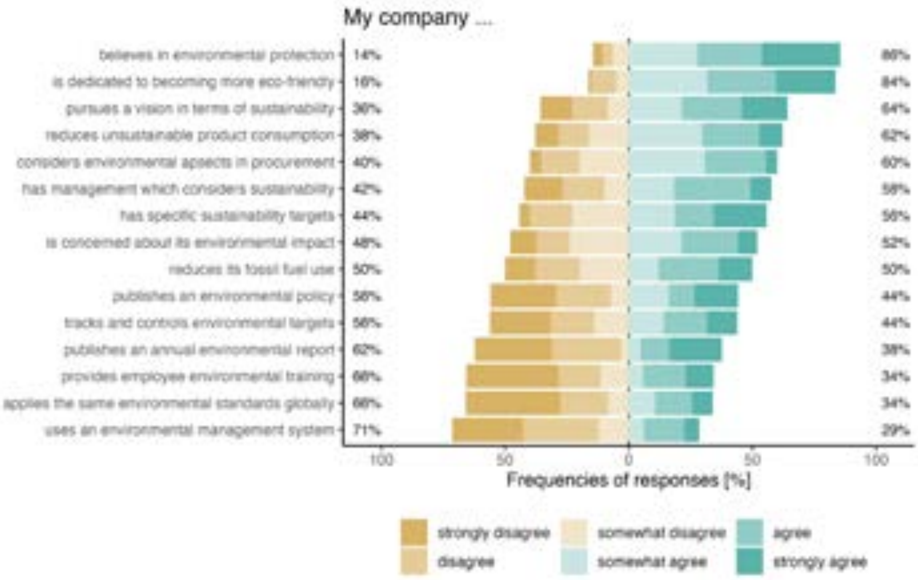

Figure 2: Response distributions for perceived corporate environmental policies (missing values excluded)

4.2 Corporate Sustainability Index (CSI)

As previously stated, various factors such as perceived corporate structures, individual attitudes, and behaviours of leaders and employees influence corporate sustainability. To investigate the interplay between those factors and corporate sustainability, its robust operationalization is a necessary initial step. Therefore, we composed an additive index that comprises sustainability measures and the corporate environmental policies (CEP scale) with 28 items in total. This Corporate Sustainability Index (CSI) reflects a holistic indicator and encompasses both tangible sustainability actions as well as the integration of sustainability into corporate strategy and culture. In the present study, CEP demonstrated a very high internal consistency ($\alpha = .96$) and was normally distributed ($M = 3.63$, $SD = 0.95$).

4.2.1 Factors correlated to CSI

Bivariate correlations were calculated to determine relations between individual attitudinal and behavioural factors and CSI. Neither the employees' eco-consciousness ($r_s = -.13$, $p = .223$, n.s.) nor their openness to change ($r_s = .07$, $p = .532$, n.s.) or their OCBE ($r_s = .21$, $p = .053$, n.s.) was related to their company's CSI. The only behavioural factor which was significantly correlated to CSI was the management behaviour measured in ETL ($r_s = .66$, $p < .001$). Hence, the more leaders act sustainably and encourage sustainable practices among their employees, the higher is a company's CSI score.

Bivariate correlations for CSI and the organizational factors were also calculated. While the approach of driving sustainability from the management in a top-down manner showed a strong positive association with CSI ($r_s = .70$, $p < .001$), it was not significantly related to a bottom-

up approach (r_s = -.07, n.s.), suggesting that higher CSI levels are not affected by such an approach. Among all evaluated factors, accountability ($r_s = 0.76$, $p < .001$) and a sustainable image ($r_s = 0.76$, $p < .001$) had the strongest associations with higher CSI levels. Thus, companies with distinct sustainability responsibility structures and a perceived sustainable image had elevated CSI levels. Regarding the perceived relevance of sustainability in the company, an increased overall relevance ($r_s = 0.65$, $p < .001$), a higher perceived relevance for employees ($r_s = 0.53$, $p < .001$) as well as for managers ($r_s = 0.69$, $p < .001$) was significantly related to higher CSI levels. Of these, the perception of how relevant sustainability appears to the management was most strongly correlated with CSI.
Summing up so far, the correlation analysis revealed significant associations between CSI and both leadership behaviour (specifically ETL) and several organizational factors, including top-down approach and accountability.

4.2.2 Predictors of corporate sustainability

In the next step, we conducted a hierarchical regression analysis to predict CSI. Image and the perceived relevancies were not included as predictors, as their relationship to CSI cannot be assumed as causal, e.g., while it is reasonable that more sustainable companies also would have a more sustainable image, this is not necessarily the reason for their sustainability.

Table 2: Results of hierarchical regression analysis on the prediction of the Corporate Sustainability Index

Variables	Model 1	Model 2	Model 3
ETL	0.65***	0.34**	0.15
Top-down		0.44***	0.35***
Accountability			0.54***
Adjusted R^2	0.41	0.51	0.74

Dependent Variable: Corporate Sustainability Index (CSI); Asterisks indicate level of significance (*p < 0.05, **p < 0.01 =, ***p < 0.001

Model 1 (with ETL as a predictor) accounted for 41% of the variability in CSI (adjusted $R^2 = 0.41$; $F(1, 85) = 61.4$, $p < .001$). Companies in which the participants evaluated their leaders as more environmentally transformational ($\beta = 0.65$, $p < .001$) scored higher on the CSI. In Model 2 (adjusted $R^2 = 0.51$; $F(2, 84) = 45.6$, $p < .001$) the predictor "top-down approach" was included, which significantly improved the explained variance from 41% to 51% ($F(1, 84) = 17.7$, $p < .001$). This suggests that a pronounced top-down approach to sustainability led to elevated CSI scores ($\beta = 0.44$, $p < .001$). ETL remained a significant predictor in Model 2. Lastly, adding accountability as a predictor led to the significant Model 3 (adjusted $R^2 = 0.74$; $F(3, 83) = 80.8$, $p < .001$), which increased the explained variance by 23% up to 74% ($F(1, 83) = 73.0$, $p < .001$). Higher levels of accountability as a newly added variable were strongly related to higher CSI levels ($\beta = 0.54$, $p < .001$). Whilst top-down remained a highly significant predictor in model 3, ETL became insignificant. In summary, accountability was the strongest predictor of CSI followed by a top-down approach when integrating sustainability. Although, ETL was strongly correlated with CSI and a significant predictor in the models 1 and 2, it became insignificant in model 3. This diminished significance may be attributed to the limited sample size or potential overlap among the factors. However, multicollinearity checks confirmed it was not a major concern.

4.2.3 Organizational Factors

In a subsequent step focusing on organizational factors, we built two groups regarding company size to analyse if there is a difference between small and medium-sized enterprises (SMEs) with up to 249 employees (n = 43) and large enterprises with 250 or more employees (n = 44) regarding their corporate sustainability. The results of Welsh's two-sample t-test ($t(84.6) = -3.29$, $p < .01$) indicated that large enterprises (M = 3.95, SD = 0.94) are more progressive in terms of sustainability and thus have a significantly higher CSI than SMEs (M = 3.31, SD = 0.86).
Due to the substantial disparity in group size based on company age, we describe them descriptively to highlight some interesting results. Both companies under five years old (n = 3, M = 3.89, SD = 0.26) and companies between five and ten (n = 8, M = 4.00, SD = 0.85) years old scored similarly to the scale mean of 3.5 in terms of CSI. Due to the small sample size of five participants working in companies between ten and 20 years old (n = 5, M = 2.64, SD = 0.94), and an outlier, no reliable conclusion can be drawn about the sustainability of companies in this age range. Companies over 20 years old (n = 61, M = 3.72, SD = 0.98) had similar scores to the first two groups but had more variability.

4.3 Initial insights: Leadership's role in sustainability

While this paper mainly discusses the effects of the employee sample on corporate sustainability, this section briefly explores individuals in leadership or management roles (n = 14), as our results imply a significant role of leaders in corporate sustainability. The sample comprised eight male and six female participants in leadership positions (age: M = 37.5, SD = 14.79, 24-62 years). Notably, leaders had a higher environmental consciousness (M = 4.86, SD = 0.9) and openness towards change (M = 5.02, SD = 0.66) in comparison to employees (s. 3.2). Additionally, leaders scored higher on the OCBE scale (M = 3.95, SD = 1.14). When comparing bivariate correlations, leaders' OCBE correlated highly significantly with CSI (r = 0.78, $p < 0.001$) – in contrast to the employee sample (n.s., s. 4.2.1). This indicates that higher OCBE levels among leaders are linked to greater sustainability within their organizations. When comparing the two samples, the leadership sample showed a higher variability (M = 4.03, SD = 1.32) in CSI.

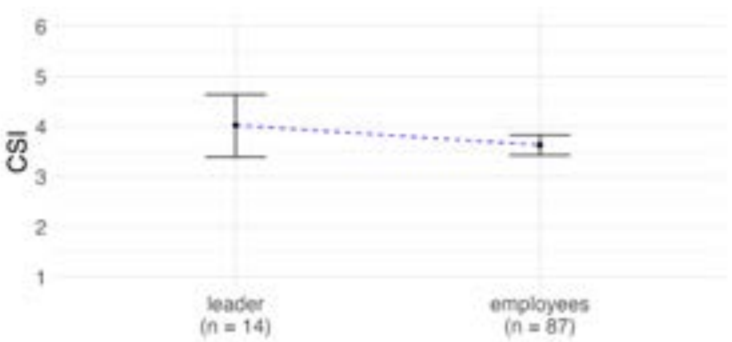

Figure 3: Mean CSI of leaders and employees (error bars indicate 95% confidence intervals based on bootstrap)

5. DISCUSSION

This study explored the factors influencing corporate sustainability, emphasizing the roles of both individual factors (attitudes and behaviours) and organizational structures. We conducted a quantitative online survey and developed the Corporate Sustainability Index (CSI). Our analysis highlighted the impact of leadership behaviour (ETL) on corporate sustainability. Organizational factors such as a top-down structure and clear accountability further acted as strong determinants of sustainability levels. Larger enterprises showed a greater inclination towards sustainable practices compared to SMEs. The exploratory observations on leaders highlighted their heightened environmental consciousness, environmental citizenship, and their potential to shape an organization's sustainability efforts. These results, methodological limitations, and future research steps are discussed according to the impact of individual factors (RQ1), organizational factors (RQ2), a nd their holistic impact on corporate sustainability (RQ3).

Prior research stressed the role of **individual** employee **factors** for corporate sustainability (e.g., Biswas et al., 2022). In contrast, our results challenge the notion that individual attitudinal factors such as eco-consciousness, openness to change as well as pro-environmental citizenship (OCBE) directly impact a company's sustainability. This discrepancy could arise from differences in measuring corporate sustainability or our approach of directly correlating individual factors with CSI, rather than considering OCBE as a moderating factor. Future research should take a closer look at these relationships in order to understand how companies' strategies for sustainability measures can be effectively promoted. Apart from employee behaviour, leadership behaviour appeared to significantly impact corporate sustainability. As a novelty, we examined the direct influence of ETL on corporate sustainability, whereas prior research mainly focused on ETL as a mediator, e.g., for OCBE (Foo et al., 2021). The strong impact of leader behaviours on corporate sustainability, in comparison to employees without leadership tasks, may lie in the managerial capacity to implement more extensive measures due to their hierarchical position, but also the effect of strong role models that influence employees' opinions, attitudes, and behaviours. Regardless of the importance of leadership behaviour, 42% of participants still stated that their management does not consider sustainability in their actions, yet. Furthermore, managers' OCBE exceeded that of employees' and positively correlated with CSI, although these are preliminary findings due to the small sample size. The higher variances in the leadership sample may indicate the effect of differential factors. To validate these findings and contribute to the limited research on sustainability leaders' characteristics, further research should focus on sustainability leaders as a target group. Building upon the results of Knight and Paterson (2018), who identified personal expertise and influencing skills as defining behaviours of sustainability leaders, we suggest investigating these individual factors as possible CSI predictors. Overall, our results underscore the relevance of individual leadership behaviour and the importance to train and sensitise leaders, who drive sustainability transformations in their respective companies. In the context of sustainability education, Haney et al. (2020) propose to focus on leaders' emotional engagement and moral obligation with respect to sustainability.

One of our aims was to develop a methodology for measuring corporate sustainability. The operationalization of our newly introduced **sustainability index** encompasses both specific sus-

tainability measures and corporate environmental policies, demonstrating strong internal consistency. To validate the CSI, it should be incorporated in future studies. To mitigate biases arising from participants choosing the "don't know" option when answering CSI items, we recommend focussing on leaders responsible for sustainability decisions in companies. The transparency of these measures might further be reduced by insufficient sustainability communication (Genç, 2017), w hose impact on CSI is another area for future research.
Clear accountability emerged as the most influential **organizational factor** predicting sustainability, indicating that companies with greater sustainability assign and communicate responsible persons for sustainability (e.g., Ludwig & Sassen, 2022) . As accountability has not been addressed in the literature so far, this study contributes to current research on the strategic approach to sustainability. The findings implicate that companies should recognize the need for diligently steering the accountability of corporate sustainability, e.g., by installing management-centric approaches. Given that only 56% of respondents recognize designated roles being responsible for sustainability within their companies, it is crucial for companies to clearly identify and communicate responsibilities (be it an individual, team or department). We suggest that accountability should be incentivized or become mandatory for companies above a certain size or annual turnover with the corresponding resources.
Another important finding is that companies with a top-down approach, with clear responsibilities for sustainability, ETL, and a sustainable image achieve a higher CSI value. This underscores the need to make sustainability an integral part of corporate culture (Siyal et al., 2022). Conversely, bottom-up approaches did not affect CSI, suggesting that such initiatives do not enhance corporate sustainability. We assume that bottom-up approaches are comparably small measures without visible impact on sustainability. In our sample, sustainability was approached rather bottom-up than top-down, which highlights the importance of management-driven approaches. Finally, larger companies (250 or more employees) demonstrated higher CSI values, highlighting the necessity of integrating sustainability as a foundational element and assigning responsibilities, even in smaller companies with fewer human and material resources available.

6. CONCLUSION

In this study, we investigated the factors influencing corporate sustainability. Our findings emphasize the pivotal role of leadership behaviour and transparent accountability. They underscore the need for a management-driven approach and for embedding sustainability in the corporate culture. For future research, we suggest focusing on the characteristics of "sustainability leaders" as they drive the corporate transformation supporting a more sustainable society. The complex interplay of factors highlights the challenges of promoting corporate sustainability (e.g., by leadership training) .

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REFERENCES

Alzaidi, S. M. & Iyanna, S. (2021). Developing a conceptual model for voluntary pro-environmental behavior of employees. *Social Responsibility Journal.* Vorab-Onlinepublikation. https://doi.org/10.1108/SRJ-11-2020-0477

Biswas, S. R., Uddin, M. A., Bhattacharjee, S., Dey, M. & Rana, T. (2022). Ecocentric leadership and voluntary environmental behavior for promoting sustainability strategy: The role of psychological green climate. *Business Strategy and the Environment*, *31*(4), 1705–1718. https://doi.org/10.1002/bse.2978

Boiral, O. & Paillé, P. (2012). Organizational Citizenship Behaviour for the Environment: Measurement and Validation. *Journal of Business Ethics*, *109*(4), 431–445. https://doi.org/10.1007/s10551-011-1138-9

Fawehinmi, O., Yusliza, M. Y [M. Y.], Wan Kasim, W. Z., Mohamad, Z. & Sofian Abdul Halim, M. A. (2020). Exploring the Interplay of Green Human Resource Management, Employee Green Behavior, and Personal Moral Norms. *SAGE Open*, *10*(4), 215824402098229. https://doi.org/10.1177/2158244020982292

Foo, P.-Y., Lee, V.-H., Ooi, K.-B., Tan, G. W.-H. & Sohal, A. (2021). Unfolding the impact of leadership and management on sustainability performance: Green and lean practices and guanxi as the dual mediators. *Business Strategy and the Environment*, *30*(8), 4136–4153. https://doi.org/10.1002/bse.2861

Foster, B., Muhammad, Z., Yusliza, M. Y [Mohd Yusoff], Faezah, J. N., Johansyah, M. D., Yong, J. Y., ul-Haque, A., Saputra, J., Ramayah, T. & Fawehinmi, O. (2022). Determinants of Pro-Environmental Behaviour in the Workplace. *Sustainability*, *14*(8), 4420. https://doi.org/10.3390/su14084420

Gawusu, S., Zhang, X., Jamatutu, S. A., Ahmed, A., Amadu, A. A. & Djam Miensah, E. (2022). The dynamics of green supply chain management within the framework of renewable energy. International Journal of Energy Research, 46(2), 684–711. https://doi.org/10.1002/er.7278

Geiger, S. M., & Holzhauer, B. (2020). Weiterentwicklung einer Skala zur Messung von zentralen Kenngrößen des Umweltbewusstseins[Development of a scale for measuring key indicators of environmental awareness].Umweltbundesamt Dessau-Roßlau.

Genç, R. (2017). The Importance of Communication in Sustainability & Sustainable Strategies. Procedia Manufacturing, 8, 511–516. https://doi.org/10.1016/j.promfg.2017.02.065

Gotsch, M., Gandenberger, C., Serafimov, L. & Miemiec, M. (2023). Top-down and bottom-up strategies for the implementation of corporate social responsibility: A qualitative survey of an international IT services company. *Corporate Social Responsibility and Environmental Management*, *30*(4), 1645–1663. https://doi.org/10.1002/csr.2441

Haney, A. B., Pope, J., & Arden, Z. (2020). Making It Personal: Developing Sustainability Leaders in Business. Organization & Environment, 33(2), 155–174. https://doi.org/10.1177/1086026618806201

Kiesnere, A. L. & Baumgartner, R. J. (2019). Sustainability management emergence and integration on different management levels in smaller large-sized companies in Austria. *Corporate Social Responsibility and Environmental Management*, *26*(6), 1607–1626. https://doi.org/10.1002/csr.1854

Knight, B., & Paterson, F. (2018). Behavioural competencies of sustainability leaders: An empirical investigation. Journal of Organizational Change Management, 31(3), 557–580. https://doi.org/10.1108/JOCM-02-2017-0035

Latif, B., Gunarathne, N., Gaskin, J., Ong, T. S. & Ali, M. (2022). Environmental corporate social responsibility and pro-environmental behavior: The effect of green shared vision and personal ties. *Resources, Conservation and Recycling*, *186*, 106572. https://doi.org/10.1016/j.resconrec.2022.106572

Li, Z., Xue, J., Li, R., Chen, H. & Wang, T. (2020). Environmentally Specific Transformational Leadership and Employee's Pro-environmental Behavior: The Mediating Roles of Environmental Passion and Autonomous Motivation. *Frontiers in Psychology*, *11*, 1408. https://doi.org/10.3389/fpsyg.2020.01408

Liu, X. & Yu, X. (2022). Green transformational leadership and employee organizational citizenship behavior for the environment in the manufacturing industry: A social information processing perspective. Frontiers in Psychology, 13, 1097655. https://doi.org/10.3389/fpsyg.2022.1097655

Ludwig, P. & Sassen, R. (2022). Which internal corporate governance mechanisms drive corporate sustainability? Journal of environmental management, 301, 113780. https://doi.org/10.1016/j.jenvman.2021.113780

Ramus, C. A., & Steger, U. (2000). The Roles of Supervisory Support Behaviors and Environmental Policy in Employee "Ecoinitiatives" at Leading-Edge European Companies. The Academy of Management Journal, 43(4), 605–626. https://doi.org/10.2307/1556357

Risius, P., Seyda, S., Wendland, F. A. & Monsef, R. P. (2023). Ökologische Nachhaltigkeit – Mit welchen Kompetenzbedarfen rechnen die Unternehmen? *Risius Gutachten*. https://www.iwkoeln.de/studien/paula-risius-susanne-seyda-finn-arnd-wendland-roschan-pourkhataei-monsef-mit-welchen-kompetenzbedarfen-rechnen-die-unternehmen.html

Robertson, J. & Barling, J. (2017). Contrasting the nature and effects of environmentally specific and general transformational leadership. *Leadership & Organization Development Journal*. https://www.semanticscholar.org/paper/Contrasting-the-nature-and-effects-of-specific-and-Robertson-Barling/da6eaaca3e4c4d8f6f56ca03d288727e3395293b

Siyal, S., Ahmad, R., Riaz, S., Xin, C., & Fangcheng, T. (2022). The Impact of Corporate Culture on Corporate Social Responsibility: Role of Reputation and Corporate Sustainability. Sustainability, 14(16). https://doi.org/10.3390/su141610105

Szebel, A. (2015). *Veränderungskompetenz von Mitarbeitern. Eine empirische Untersuchung zur differentiellen Konstrukterschließung der individuellen Veränderungskompetenz von Mitarbeitern unter besonderer Berücksichtigung des Einflusses dispositionaler Persönlichkeitsfaktoren*[Change competence of employees. An empirical study on the differential construct development of employees' individual change competence with special consideration of the influence of dispositional personality factors], Universität zu Köln.

Wang, X., Zhou, K. & Liu, W. (2018). Value Congruence: A Study of Green Transformational Leadership and Employee Green Behavior. *Frontiers in Psychology*, *9*, 1946. https://doi.org/10.3389/fpsyg.2018.01946

Yue, G., Wei, H., Khan, N. U., Saufi, R. A., Yaziz, M. F. A. & Bazkiaei, H. A. (2023). Does the Environmental Management System Predict TBL Performance of Manufacturers? The Role of Green HRM Practices and OCBE as Serial Mediators. *Sustainability*, *15*(3), 2436. https://doi.org/10.3390/su15032436

REGIONAL CHALLENGES OF THE ENERGY TRANSFORMATION – TOP-DOWN ACCELERATION VERSUS BOTTOM-UP DEMANDS

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Abstract: *The urgent need for a transition to renewable energy is often met with local or regional resistance, which hinders effective implementation. Although there is widespread societal support for the energy transition, attitudes towards renewable energy (RE) installations remain controversial among those potentially affected. Thus, a generally positive view of RE doesn't automatically translate into actual support for local RE projects. Different attitudes and behaviours towards local RE implementation can be attributed to different socio-cultural and historical experiences and imprints, as well as to modalities of participation in implementation processes. The tightened RE targets of European and national legislation in Germany in the interest of accelerated planning procedures create further top-down pressure on community level. However, as the energy transition relies heavily on local actors, planning policies need to encourage commitment to RE. Drawing on literature and a case study in north-west Germany (Steinburg district in Schleswig-Holstein), it is argued for a place-sensitive energy transition governance approach for "co-transformation" (Kelly/Mbah, 2024, forthcoming). This paper elaborates how transdisciplinary elements of 'co-visioning' and 'co-narration' can contribute to an inclusive energy transition and foster acceptability of RE plants, through the integration of desirable regional energy futures and historically informed co-narratives into regional transformation biographies.*

1. INTRODUCTION AND BACKGROUND

The energy crisis underscores the urgency of a sustainable energy transition (Hosseini, 2022), one consequence of which is the acceleration of renewable energy (RE) deployment. For example, the European Union has set the ambitious target of becoming carbon neutral by 2050, and Germany by 2045. The necessary energy transition decentralises power generation, resulting in the spatial transformation of predominantly rural areas into future energy infrastructure hotspots. This alters the roles and attributes of these rural regions, also opening opportunities for future regional development (Benedek et al., 2018). However, this may lead to landscape changes and shifts in regional identities, potentially causing dissent or support, depending on the strength of place attachment, opportunities to participate, and the extent and speed of transformation (Clarke et al., 2018; Devine-Wright & Batel, 2017). Place attachment refers to the value people attach to a place; this value is constructed by the meanings, perceptions, memories, and relations people attach to or have at a specific place (cf. Brown et al., 2015; Mbah & Kuppler, forthcoming).

Furthermore, social research underlines the general significance of political trust, distributive justice, and siting issues for RE project acceptability (cf. Carley & Konisky, 2020; Segreto et al., 2020). While more behavioural approaches show that higher levels of perceived self and collective efficacy have a positive impact on sustainable behaviour (cf. Peng et al., 2020; Doran et al., 2015). Contrary to these findings, current legislation sacrifices environmental impact assessment, participation, and legal protection rights to expedite planning for RE projects (Kelly & Schmidt, 2019). This top-down approach intensifies pressure on European energy regions. In synthesising these conflicting developments, three central dilemmas of the energy transition have been identified, (Kelly & Mbah, 2024, forthcoming)[i], namely (1) a 'coordination dilemma' (cf. Mattes et al., 2015), (2) a 'distribution dilemma' (cf. Lennon et al., 2019), and (3) an 'imagination dilemma' (cf. High & Smith, 2019). Starting from these dilemmas, an energy transition governance approach for “co-transformation” has been proposed. It is based on the observation that firstly local resistance stems mainly from insufficient participation lacking an inclusion of historically grown meanings and identities. Secondly, a perceived unfair distribution of benefits and burdens, and thirdly a lack of a common vision or supportive narratives at the regional level. Of particular interest within the associated processes of spatial transformation is the collaborative development of visions and narratives of desirable energy futures in shaping regional identity, when integrated into locally adapted participatory frameworks (cf. Chateau et al., 2021; Standal & Feenstra, 2022).

Based on a literature review and an empirical case study in the ENSURE[ii] energy region of Steinburg, this paper elaborates on the governance approach for co-transformation (cf. Kelly & Mbah, 2024, forthcoming) by posing the research question: ‘How can collaborative

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[i] Parts of this paper build on a manuscript entitled "Regional energy transition governance for the co-transformation of sustainable energy infrastructures as services of general interest in rural areas", which is currently under review for a special issue of Spatial Research and Planning (Kelly & Mbah 202, forthcoming).

[ii] This paper is based on the "Kopernikus Joint Project ENSURE II: New Energy Grid Structures for the Energy Turnaround - Öko-Institut Subproject", which was funded by the German Federal Ministry of Education and Research (funding code 03SFK1T0-2). The authors are responsible for the content of this publication.

co-visioning and co-narration promote acceptance and supportive behaviour for local RE expansion?'. It is argued that all three dilemmas also reflect different socio-spatial expressions of the 'attitude-behaviour gap' (Shaw et al., 2016) concerning procedural, distributional, and temporal aspects. The aim of this exploratory qualitative study is to show how local and regional socio-spatial aspects can be integrated in planning through co-visioning and co-narration; this is considered key to an acceptable transition process (Brown et al., 2019). The overview of the framework of the co-transformation approach is provided first. Following this, elements of a place sensitive RE governance are presented, by giving examples of co-developing visions and narratives and argue how this might can incentivise behavioural change towards proactive RE engagement. The discussion of the case study highlights the necessary policy shift from managing acceptance ('top-down') to promoting ownership and empowerment, fostering a sense of agency among prosumers and local actors ('bottom-up').

2. METHODS AND TRANSDISCIPLINARY DESIGN

The case study was conducted in the energy transition region of the ENSURE-project in the northern German state of Schleswig-Holstein. To investigate acceptability and participatory requirements in a collaborative and place-sensitive way, a transdisciplinary approach was pursued. It is important to stress that this qualitative exploratory design does not claim to be representative or attempt to validate empirical correlations. In sum, 13 guideline-based interviews were conducted (cf. Table 1) along with four workshops involving local stakeholders (n=12-20) as well as one reflexive workshop with researchers (n=8) to reflect and further develop the methods used. The stakeholders were interviewed not only in their professional roles, but also in terms of their personal experiences as individuals deeply rooted in the region. But here, the focus is mainly on findings from the workshops. The interviews were recorded, transcribed in the form of 'denaturalised transcripts' (Oliver et al., 2005) and analysed according to the principles of 'content-structuring' qualitative content analysis using MaxQDA software (Kuckartz, 2016). Following Kuckartz (2016), major categories were identified deductively from theory, with the individual subcategories then deduced inductively from the transcripts. The focus here is on the analysis according to the identified narratives (cf. Table 1). The literature review as well as the interviews and workshops conducted revealed the particular importance of the socio-technical conflict between the directly experienced regional burdens today (e.g., visibility, emissions, landscape change) and the future indirect benefits of energy transition measures (e.g., climate protection, independence from energy imports, resilience). Accordingly, a second in-depth phase focused on integrating participatory visioning and narrative development into the energy transition governance approach. For the purposes of this paper, mainly three workshops on co-visioning and narrative have been analysed. In addition, sporadic reference is made to findings from the content analysis of the 13 guideline-based interviews and the two workshops conducted on participatory requirements and aspects of acceptability.

Table 1: Characteristics of local actors interviewed and main themes supporting co-developed narratives

ID	Functional area	Residence in Steinburg	Gender	Main themes	Dominant narrative
1	Administration / local politics	yes	w	Land pressure, planning process, value creation, monument protection, community	Narrative 1
2	NGO	yes	m	Visibility of RE, fair distribution, historical wind region, regional identity, autonomy	Narrative 2
3	Politics (district)	yes	m	Nuclear experiences, land conflicts, local benefits, financial share, energy cycle region	Narrative 3
4	Administration (municipality)	yes	w	Structural change, wind energy acceptance, communication, locality, emotionality	Narrative 2
5	Administration (district)	no	m	Community spirit, law, informal participation, value creation, collective narratives	Narrative 3
6	Administration (district)	yes	m	Cultural markers, place attachment, cultural-historical identity, cultural landscape	Narrative 2
7	Culture and Art	yes	w	Monument protection, structural change, agriculture, regional identity, transformation	Narrative 1
8	Administration (state)	no	m	Regional identity, cultural markers, historical wind region, landscapes, local networks	Narrative 1
9	Regional development	yes	m	Structural change, spatiality, land pressure, agriculture, collective visions and narratives	Narrative 3
10	Regional development	no	m	Locality, engagement and empowerment, collective visions and narratives, knowledge	Narrative 3
11	Science	no	m	Cultural markers, place attachment, cultural-historical identity, monument protection	Narrative 2
12	Science/ Culture and Art	no	w	Community spirit, cultural markers, collective visions and narratives, emotionality, locality	Narrative 1
13	Politics (municipality)	yes	w	Autonomy, empowerment and ownership, landowners, place attachment, local benefits	Narrative 3

As a culmination of the workshops, a ‘Spatial and Energy Vision 2040 for Steinburg’ was developed together with local stakeholders (n=12) using the ‘Back- and Forecasting’ methodology (Vergragt & Quist, 2011). Based on this vision of a regionally desired future, the aim of the last collaborative workshop with key stakeholders was to identify supporting culturally and historically grown and future-oriented energy transition narratives in Steinburg as success stories of regional energy transition (n=10). The additional reflection workshop with researchers helped to adapt the methodology and to compare energy visions and narratives ‘from’ and ‘about’ the region.

3. RESULTS: PARTICIPATORY VISIONING AND NARRATION

The focus here on participatory visioning and narration picks up on approaches to co-visioning of liveable futures and regional spatial energy visions to be derived from them (Lingua & Balz, 2020). In this perspective, the imaginative space of possible regional energy futures is inevitably intertwined with the transformative power of discourses on socio-technical and geographical visions (Späth & Rohracher, 2010). Energy landscapes as socially constituted spaces are thus not only created through historical and contemporary practices but can also evolve and transform through a collective imaginative practice

(Chateau et al., 2021). Landscape and "(...) spatial identity [have] to do with becoming and having become, i.e. also historical atonement and an 'emotional we'" [ID 8], but also with visions of desirable futures (Walker et al. 2010). For the co-visioning of such desired energy futures, the collaborative development of narratives plays a crucial role [ID 12, ID 7].

First, a conceptual distinction needs to be made between visions and narratives, as the two concepts serve different purposes, with visions focusing on future goals and narratives focusing on storytelling and interpretation.

A 'vision' here is understood as a forward-looking, aspirational target that outlines a desired future state or outcome in terms of 'goal orientation' (David et al., 2013). The central contents of the co-visioned spatial energy future of the Steinburg energy region in 2040 with reference to energy transition are: (1.) the regional development of a photovoltaic (PV) register to further promote the leasing and expansion of rooftop PV systems, (2.) the modernisation of the digital distribution grids into flexible smart grids, and (3.) the further development from an energy production region to an energy cycle region in increasing the regional consumption of the generated renewable electricity by the settlement of energy-intensive sustainable industries. Especially this last aspiration is linked with the need for a future-oriented role and identity of the region in the new energy system.

A 'narrative', in contrast, is understood as a narrative pattern that provides a contextual and often chronological description of events, thereby constructing social reality as a basis for 'transformative action'. Narratives combine historical and contemporary aspects of a region with visions for the future and can therefore make an important contribution to transformation. Central characteristics of narratives have already been described in the literature (Espinosa et al., 2017; cf. Fina & Georgakopoulou, 2011), namely that a narrative refers to collective identities, is purposeful, transferable (for a variety of individual stories) and functions in an evaluative and emotional way through the social construction of a so to speak 'larger us'. Furthermore, the co-development of shared narratives can have various effects on the attitudes and behaviour of stakeholders. These effects range from cognitive prioritization to the formation of socio-spatial identities, increased motivation, action guidance and reduced complexity (Chabay et al., 2019; David & Schönborn, 2018). As a working definition, narratives are understood as fundamental communicative structures of social interaction that shape social action and socio-spatial developments, consequently defining social reality (Bushell et al., 2017, p. 41). Moreover, especially in view of the socio-technical transformations accompanying the energy transition, narratives support conveying and transferring knowledge.

Following Chabay et al. (2019) narratives of visions and identities influence and reflect social dynamics of movements towards sustainable futures in different ways. First, narrative expressions of visions of sustainable futures provide insights into desirable futures envisioned and expressed by individuals and collectives as targets and incentives for reaching a more desirable future. Second, the motivations of individuals and groups for acting in support of, or opposition to, the expressions of vision are strongly influenced and may be inferred from narrative expressions of identity (e.g., place attachments), culture, and contexts (Chabay et al., 2019). Furthermore, strategic narratives can integrate "the complex range of actors who need to be engaged, provide a coherent explanation for government strategy, and harness the drivers of behavioural change needed to meet the challenge" (Bushell et al., 2017, p. 39). Moreover, co-constructing strategic narratives can lead to reduced cognitive dissonance by providing a sense of purpose and owning a problem, building on existing cultural barriers and social norms and a strategic dialogue between stakeholders involved (Bushell et al., 2017, p. 47). In doing so, they enable the linking of spaces, places, and scales of transition processes, thereby providing a sense of local agency (Feola & Nunes, 2014). Especially when narrative development follows a green shared vision, self-efficacy of individuals and organisations can be influenced positively (Chen et al., 2015). The narratives jointly identified in the interviews and workshops can therefore be understood as underlying structures for various individual stories of regional history and the development of the cultural landscape and regional identity towards the "Spatial and Energy Vision 2040 for Steinburg".

4.1 Narrative 1 "Hand in hand for the preservation of the cultural landscape"

One of the main narratives articulated is based on a strong sense of an 'emotional we' in the Steinburg district. This is a result of the cultural history of the region, in which historically consolidated communities of support were necessary for the provision of public services within the framework of collective landscape maintenance. The peripheral settlement structures in the district of Steinburg are characterised by a high degree of federal heterogeneity between small autonomous communities and former manors, some of which are still in existence today. Along with this, voluntary work and mutual neighbourly support have established themselves as an important social resource. The region has the lowest topographical point in Germany and lies almost entirely below sea level. It has been made habitable and agriculturally usable via developed coats, dikes, and an extensive network of drainage structures (ditches, hollows, etc.), which means it is a anthropogenically cultivated landscape starting with historical land reclamation. This leads to a widely shared collective attribution of value to an intact cultural landscape and emotional attachments to the cultural landscape as part of a collective place attachment. Local actors refer to it also as the "below 0 mentality", meaning the social structures of trust and responsibility in respect of hazard prevention. One interviewee reported, for example, that "landscape and (...) spatial identity has to do with 'becoming' and 'having become', i.e., also [in terms of] historical recollection and an 'emotional we'" [ID 8]. Therefore, it is also a "problem if new inhabitants are not part of landscape care practices; caring for each other is key to living together (all pump houses must work and all drainage ditches must drain, otherwise the cellars will fill up)" [ID 8, cf. ID 3]. This narrative is also used in political communication on the energy transition, e.g., during the 3rd Infrastructure Forum of the state-funded "Regional Cooperation West Coast". The district administrator of Dithmarschen, Stefan Mohrbeck, is cited: "The energy transition needs space. But neither the population nor nature should suffer" (Energiekueste, 2023). This statement refers to the high value of community coexistence and consideration of the needs of the local population as well as the importance of landscape conservation. At the same time, it raises awareness of the space required for energy transition. There is an ambivalent connotation of this narrative. On the one hand, the professionalised management and successful implementation of citizen energy projects in many places in the region, including cooperatively operated large wind power and PV plants, can be explained, among other things, by the mentioned “we-feeling”. On the other hand, the high sensitivity of Steinburg citizens for spatial changes and the preservation of existing landscapes can also lead to the rejection of RE infrastructures. This can be seen, for example, in the bad experiences reported for some municipalities with large-scale projects for ground-mounted PV plants by external developers or investors that are not adapted to the local requirements of the municipality. Consequently, this basic narrative pattern in the region can both, promote and hinder the energy transition, depending on how participation approaches incorporate the narrative.

4.2 Narrative 2 “Energy region from past, present to future”

Another popular narrative identified in Steinburg is based on the high importance of energy use and production for the economic progress of the region, in past, present and in the future. Wind power in particular functions as an important energy resource in the region. The long regional tradition of wind power use manifests itself in historical windmills and modern wind turbines for power generation and has thus become an important part of the regional identity. Higher buildings such as wind turbines are widely visible as cultural land markers in an almost totally flat landscape. They contribute significantly to a landscape-based place definition as a factor of place attachment and thus create cultural value in the region (cf. Knaps & Herrmann, 2018). Whereas the historical windmills and scoop mills were primarily used to drain farmland and produce food, today the focus is on electricity generation. Although the appearance of the historical turbines differs significantly in both quality and quantity from today's large wind turbines for electricity generation, the basic mode of operation and placement in windy locations in the region are culturally and historically connectable. In the workshops and interviews, a historically grown and still present wind farmer culture was reported as a central special feature of this region, which is referred to with pride. An interviewee described that “the expansion of wind power in the district of Steinburg is already historically 'settled' and less conflictual than other projects” [ID 4]. The reason for this is seen in the fact that “wind is a cultural-historical component and an identity marker here, so there is no categorical rejection” [ID 6]. In contrast, other RE projects are reported by interviewees and workshop participants to be controversial, for example in relation to electricity grids or land-intensive PV installations. It is also reported that “windmills are not a bad thing, (...) there is no big opposition in the region so far, (expansion) is wanted and the wind is there. The critical point, however, is (...) the fair distribution” [ID 2]. This also illustrates the observation-based finding that there is hardly any fundamental opposition in the region to the ‘if’, but only local negotiation processes about the ‘how’ of wind power development. In the district of Steinburg, the success of RE projects depends on credible communication and participation about the technological requirements and associated benefits of using local resources such as wind power and biomass from dairy farming and grassland management. Empowering governance must involve citizens and stakeholders to develop narratives that link necessary infrastructure projects (e.g., grid modernisation, as envisaged in ENSURE) with local demands.

4.3 Narrative 3 "From the Region for the Region"

Finally, the third co-developed narrative refers mainly to the importance of the creation of added value locally. For some of the interviewees and workshop participants, the regionality of energy transition projects as a value, is of particular importance. Historically, the Steinburg region has been and still is an energy production and transmission region not only because of wind power plants, but also due to its recently decommissioned nuclear power plants in Brunsbüttel and Brokdorf on the river Elbe. Furthermore, its integration into the European grid as an important grid hub, and its geographical location on the North Sea as a connection point for offshore wind farms and currently also the LNG hubs in Brunsbüttel are important aspects of this specific energy production and transmission role. In other words, the district of Steinburg produces a significant surplus of electricity (primarily from renewable energies) and exports this to the Hamburg metropolitan region and via large transmission grids to the southern parts of Germany. According to the interviewees and workshop participants, it is a major challenge to change the prevailing narrative of an energy production region to a more holistic economic, industrial and energy region by taking more benefit of the local RE infrastructure. To achieve this, the region aims to develop economically, socio-technically, but also to communicatively change the image of the region from an energy production region to an energy cycle region. In addition to the expansion of climate-neutral industry as employers and taxpayers in the region, great importance is also attributed to the return of revenues from the RE plants to the community and to social services of general interest. Thus, the symbolic of this narrative emphasises the relevance of local commitment and regional anchoring of project developers and utilities. According to the assessment of an interviewee, the following applies to the successful implementation of regional RE projects "for companies (...): (the) analysis of the regional specifics on site, obtain experience in the community (...) and engage in local value creation; local benefits must be transparent" [ID 13]. Furthermore, it was reported that "in addition to participation and being heard in the process, influence (ownership idea and empowerment of citizens) is also very important" [ID 13]. However, not only the local benefit as well as the empowerment and ownership claim of the citizens, but also in particular the location of the project developers in the region are emphasised within the narrative pattern; because the "regional anchoring of (energy transition) actors is very important, as these companies receive a leap of faith and contribute to regional value creation (trade tax, employers), (...) they have their hearts and ears in the right place (...)" [ID 5]. In the context of empowering participation in the energy transition in the district of Steinburg, the special demand for the realisation of local benefits, the employment of local specialists and the appreciation of regional expertise in the process must be considered. Regulations on, for example, regionally unevenly distributed grid fees, which additionally burden regions such as the Steinburg district with higher electricity prices, contrasts with this narrative and are therefore an obstacle to a socially supported citizens' energy transition in rural areas.

4. DISCUSSION: A SPATIAL-NARRATIVE TURN FOR CO-TRANSFORMATION

The narratives discussed above, as well as the participatory process of co-developing them, provide valuable insights into the dynamics of energy transition in Steinburg district and give examples of how co-visioning and -narration can influence supportive behaviour for local RE. While the narratives differ in their specific connotations, they share a common core in emphasizing the importance of socio-spatial relations. Narrative 1 underscores the significance of a collective sense of attachment to the cultural landscape, with a focus on community coexistence and the preservation of cultural heritage. In contrast, Narrative 2 highlights the historical importance of wind power in shaping regional identity, which contributes to local acceptance, particularly in the case of wind energy. Narrative 3 emphasizes the value of local benefits, economic growth, and community involvement in energy projects, emphasizing a shift from being solely an energy production region to a comprehensive energy cycle region. Reflecting all three narratives, it became clear that, the following aspects need to be integrated in a future-oriented transition narrative, which could be read as 'shaping innovation and tradition together for the future': (1.) intensive participation of regional and local actors, (2.) regional added value creation, i.e., through the settlement of climate-friendly industries, (3.) narrative combination of modernity with regional traditions, (4.) further development of pioneer regions of successful energy transition and (5.) orientation towards a sustainable future. Exploring these narratives reveals that place attachment, as facilitated by co-visioning and -narration, plays a crucial role in an acceptable transition process.

While both the spatial (cf. Warf & Arias, 2008) and the narrative turn (cf. Goodson & Gill, 2011) have been discussed in the literature, a mutually referential integration of both perspectives in governance is lacking. Considering this, regional energy transition governance needs a reorientation that brings together both spatial and narrative aspects, a so-called 'spatial-narrative turn', to enable co-transformation. Successful co-transformation in that sense necessitates, first and foremost, place-sensitive approaches to participation and, consequently, co-regulatory participation spaces for citizens. This requires the facilitation of collaborative spaces that are responsive to regional identities and local needs to contribute to procedural justice and hence acceptability (Walker & Baxter, 2017). Relevant stakeholders as well as citizens need to be involved early and openly in all phases of the planning process (Langer et al., 2017). This also includes the need for flexibility to integrate or adapt locally appropriate forms of 'co-regulation' through regulatory experimentation or regulatory sandboxes (Bauknecht et al., 2019; van der Waal et al., 2020). Second, regionally adapted forms of 'co-allocation' of spatially related burdens and benefits of RE projects are needed to ensure distributive justice among stakeholders (Knauf, 2022). This includes joint negotiations on RE compensation measures, participatory formulation of local guidelines for tendering procedures and sustainable value creation in the interest of social services and public goods, as well as effective participation models for municipalities or citizens in RE infrastructure projects (Mundaca et al., 2018). For RE operators and investors, this means proactively following local guidelines for RE tendering, actively participating in local value creation and transferring commercial revenues locally, and, for example, allocating further financial resources to projects in the public interest. Finally, as shown in greater detail,
co-

visioning an -narration in participatory processes can help to negotiate and jointly develop energy futures. It is therefore important to offer collective narratives within the framework of RE participation processes to make future regional roles and identities of “energy transition regions" conceivable and thus plannable. This can contribute to the intergenerational justice of future generations by addressing the cognitive dissonance between current burdens and long-term benefits in climate friendly RE infrastructure projects, thus visualising future liberty interests (Bushell et al., 2017; Chabay et al., 2019).

5. CONCLUSION

Energy landscapes are the result of spatial transformations and individual and collective narratives associated with them. In interest of the sketched spatial-narrative turn in transition governance, on the one hand, research in narrative studies needs to experiment with a more place-sensitive approach, respecting socio-spatial aspects as a crucial part of the narrative construction of a region; on the other hand, spatial approaches need to broaden their perspective and methods towards this narrative construction of spatiality. Participatory visioning and narrative development play a key role in such a transdisciplinary approach for an acceptable energy transition. The co-development of culturally and historically compatible, yet future-oriented narratives can contribute to the realisation of desirable energy futures (Chabay et al., 2019; Chateau et al., 2021). It is important to consider local values by the establishment of a green industry linked to regional RE expansion. Furthermore, narratives should aim at unfolding socio-spatial identity offers that link traditions with transformative future visions. Therefore, a place-sensitive governance approach needs to foster a culture of co-transformation in the regional energy transition. Participatory visioning and narrative development can contribute through a shared understanding of a green vision (‘goal orientation’) and through co-producing empowering narratives for collective action towards this vision (‘transformative action’). Perceived self- and collective efficacy are crucial in this context, as Bandura argues “people do not take upon themselves what they firmly believe is not within their power to do” (Bandura, 1997, p. 484). Future research should focus on how participatory visioning and narrative development can affect factors of place attachment and how this can be addressed adequately in the of participation to promote a place-sensitive energy transition governance. This study provides a conceptual framework for this task.

REFERENCES

Bandura, A. (1997). *Self-efficacy: The exercise of control*. Freemann.

Bauknecht, D., Bischoff, T., Bizer, K., Heyen, D. A., Führ, M., Gailhofer, P., Proeger, T., & Leyen, K. von der. (2019). *Exploring the pathways: Regulatory experiments for Sustainable Development - An interdisciplinary approach* (ifh Working Paper 22/2019).

Benedek, J., Sebestyén, T.-T., & Bartók, B. (2018). Evaluation of renewable energy sources in peripheral areas and renewable energy-based rural development. *Renewable and Sustainable Energy Reviews*, *90*, 516–535. https://doi.org/10.1016/j.rser.2018.03.020

Brown, G., Raymond, C. M., & Corcoran, J. (2015). Mapping and measuring place attachment.

Applied Geography, *57*, 42–53. https://doi.org/10.1016/j.apgeog.2014.12.011
Brown, K., Adger, W. N., Devine-Wright, P., Anderies, J. M., Barr, S., Bousquet, F., Butler, C., Evans, L., Marshall, N., & Quinn, T. (2019). Empathy, place and identity interactions for sustainability. *Global Environmental Change*, *56*, 11–17.
Bushell, S., Buisson, G. S., Workman, M., & Colley, T. (2017). Strategic narratives in climate change: Towards a unifying narrative to address the action gap on climate change. *Energy Research & Social Science*, *28*, 39–49.
Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy*, *5*(8), 569–577. https://doi.org/10.1038/s41560-020-0641-6
Chabay, I., Koch, L., Martinez, G., & Scholz, G. (2019). Influence of Narratives of Vision and Identity on Collective Behavior Change. *Sustainability*, *11*(20), 5680.
Chateau, Z., Devine-Wright, P., & Wills, J. (2021). Integrating sociotechnical and spatial imaginaries in researching energy futures. *Energy Research & Social Science*, *80*, 102207. https://doi.org/10.1016/j.erss.2021.102207
Chen, Y.-S., Chang, C.-H., Yeh, S.-L., & Cheng, H.-I. (2015). Green shared vision and green creativity: The mediation roles of green mindfulness and green self-efficacy. *Quality & Quantity*, *49*(3), 1169–1184. https://doi.org/10.1007/s11135-014-0041-8
Clarke, D., Murphy, C., & Lorenzoni, I. (2018). Place attachment, disruption and transformative adaptation. *Journal of Environmental Psychology*, *55*, 81–89.
David, M., & Schönborn, S. (2018). Bottom-Up Energy Transition Narratives: Linking the Global with the Local? A Comparison of Three German Renewable Co-Ops. *Sustainability*, *10*(4), 924. https://doi.org/10.3390/su10040924
David, S., Clutterbuck, D. & Megginson, D. (Eds.). (2013). *Beyond Goals: Effective Strategies for Coaching and Mentoring*. Routledge. https://doi.org/10.4324/9781315569208
Devine-Wright, P., & Batel, S. (2017). My neighbourhood, my country or my planet? The influence of multiple place attachments and climate change concern on social acceptance of energy infrastructure. *Global Environmental Change*, *Volume 47*, 110–120.
Doran, R., Hanss, D., & Larsen, S. (2015). Attitudes, efficacy beliefs, and willingness to pay for environmental protection when travelling. *Tourism and Hospitality Research*, *15*(4), 281–292. https://doi.org/10.1177/1467358415580360
Energiekueste. (2023). *Press release: the 3rd Energieküste Infrastructure Forum focuses on the energy pipeline network of the future*. https://energiekueste.eu/presse/press-releases/single-view/the-3rd-energiekueste-infrastructure-forum
Espinosa, C., Pregernig, M., & Fischer, C. (2017). *Narrative und Diskurse in der Umweltpolitik: Möglichkeiten und Grenzen ihrer strategischen Nutzung*. Berlin.
Feola, G., & Nunes, R. (2014). Success and failure of grassroots innovations for addressing climate change: The case of the Transition Movement. *Global Environmental Change*, *24*, 232–250. https://doi.org/10.1016/j.gloenvcha.2013.11.011
Fina, A. de, & Georgakopoulou, A. (2011). *Analyzing Narrative: Discourse and Sociolinguistic Perspectives*. Cambridge University Press. https://doi.org/10.1017/CBO9781139051255
Goodson, I. F., & Gill, S. R. (2011). The Narrative Turn in Social Research. *Counterpoints*,

386, 17–33. http://www.jstor.org/stable/42981362

High, M. M., & Smith, J. M. (2019). Introduction: The ethical constitution of energy dilemmas. *Journal of the Royal Anthropological Institute*, *25*(S1), 9–28. https://doi.org/10.1111/1467-9655.13012

Hosseini, S. E. (2022). Transition away from fossil fuels toward renewables: Lessons from Russia-Ukraine crisis. *Future Energy*, *1*(1). https://fupubco.com/fuen/article/view/8

Kelly, R., & Mbah, M. (2024, forthcoming). Regional energy transition governance for the co-transformation of sustainable energy infrastructure as a public service in rural areas. *Spatial Research and Planning, Special Issue*.

Kelly, R., & Schmidt, K. (2019). Energieleitungsausbau auf der infrastrukturrechtlichen Überholspur. *Archiv des Öffentlichen Rechts*, *144*(4), 577. https://doi.org/10.1628/aoer-2019-0037

Knaps, F., & Herrmann, S. (2018). Analyzing Cultural Markers to Characterize Regional Identity for Rural Planning. *Rural Landscapes: Society, Environment, History*, *5*(1), 1. https://doi.org/10.16993/rl.41

Knauf, J. (2022). Can't buy me acceptance? Financial benefits for wind energy projects in Germany. *Energy Policy*, *165*, 112924. https://doi.org/10.1016/j.enpol.2022.112924

Kuckartz, U. (Ed.). (2016). *Typenbildung und typenbildende Inhaltsanalyse in der empirischen Sozialforschung.* Springer VS, Wiesbaden.

Langer, K., Decker, T., & Menrad, K. (2017). Public participation in wind energy projects located in Germany: Which form of participation is the key to acceptance? *Renewable Energy*, *112*, 63–73. https://doi.org/10.1016/j.renene.2017.05.021

Lennon, B., Dunphy, N. P., & Sanvicente, E. (2019). Community acceptability and the energy transition: a citizens' perspective. *Energy, Sustainability and Society*, *9*(1), 1–18.

Lingua, V., & Balz, V. (Eds.). (2020). *Shaping Regional Futures: Designing and Visioning in Governance Rescaling*. Springer. https://doi.org/10.1007/978-3-030-23573-4

Mattes, J., Huber, A., & Koehrsen, J. (2015). Energy transitions in small-scale regions: What we can learn from a regional innovation systems perspective. *Energy Policy*, *78*, 255–264. https://doi.org/10.1016/j.enpol.2014.12.011

Mbah, M., & Kuppler, S. (forthcoming). Governing nuclear waste in the long-term: on the role of place. *Historical Social Research Journal.*

Mundaca, L., Busch, H., & Schwer, S. (2018). 'Successful' low-carbon energy transitions at the community level? An energy justice perspective. *Applied Energy*, *218*, 292–303.

Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005). Constraints and Opportunities with Interview Transcription: Towards Reflection in Qualitative Research. *Social Forces, 84*(2), 1273–1289. https://doi.org/10.1353/sof.2006.0023

Peng, L., Tan, J., Deng, W., & Liu, Y. (2020). Farmers' participation in community-based disaster management: The role of trust, place attachment and self-efficacy. *International Journal of Disaster Risk Reduction*, *51*, 101895.

Segreto, M., Principe, L., Desormeaux, A., Torre, M., Tomassetti, L., Tratzi, P., Paolini, V., & Petracchini, F. (2020). Trends in Social Acceptance of Renewable Energy Across Europe—A Literature Review. *International Journal of Environmental Research and Public Health*, *17*(24), 9161. https://doi.org/10.3390/ijerph17249161

Shaw, D., McMaster, R., & Newholm, T. (2016). Care and Commitment in Ethical Consumption: An Exploration of the 'Attitude–Behaviour Gap'. *Journal of Business Ethics*, *136*(2), 251–265. https://doi.org/10.1007/s10551-014-2442-y

Späth, P., & Rohracher, H. (2010). 'Energy regions': The transformative power of regional discourses on socio-technical futures. *Research Policy*, *39*(4), 449–458.

Standal, K., & Feenstra, M. (2022). Engaging the public for citizen energy production in Norway: Energy narratives, opportunities and barriers for an inclusive energy transition. In F. Karimi & M. Rodi (Eds.), *Energy transition in the Baltic Sea region: Understanding Stakeholder Engagement and Community Acceptance* (pp. 135–154).

van der Waal, E. C., Das, A. M., & van der Schoor, T. (2020). Participatory Experimentation with Energy Law: Digging in a 'Regulatory Sandbox' for Local Energy Initiatives in the Netherlands. *Energies*, *13*(2), 458. https://doi.org/10.3390/en13020458

Vergragt, P. J., & Quist, J. (2011). Backcasting for sustainability: Introduction to the special issue. *Technological Forecasting and Social Change*, *78*(5), 747–755.

Walker, C., & Baxter, J. (2017). Procedural justice in Canadian wind energy development: A comparison of community-based and technocratic siting processes. *Energy Research & Social Science*, *29*, 160–169. https://doi.org/10.1016/j.erss.2017.05.016

Warf, B., & Arias, S. (2009). *The spatial turn: interdisciplinary perspectives.* London: Routledge.

Slashing the surplus – how prosumers with smart metering respond to regulatory restrictions on self-consumption in Croatia

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Keywords: Smart Metering, Home Energy Management System, Photovoltaic Curtailment, Prosumers, Self-Consumption

Abstract: *Smart metering and home energy management systems (HEMS) support households with roof-top photovoltaic (PV) to optimize self-consumption. These HEMS can convey subtle guidance for consumption shifts that address intuitive consumption routines. However, the efficacy of the guidance depends on the regulation of self-consumption. This presentation provides experimental evidence on the interplay between both for the case of Croatia, where households that produce more electricity than they consume over the year are automatically re-classified as renewable traders and have additional administrative duties, as well as less favorable tax treatment. This creates perverse incentives to reduce PV generation or increase energy consumption. We document strong behavioral reactions within a real-life field experiment, which was conducted as part of the larger Horizon 2020 project NUDGE. The project collected both survey and smart meter data, which allows for a comprehensive picture of the behavioral reaction. According to the survey wave before the end of the year, almost half of the participants considered curtailing their PV output. According to the smart meter data, a sizable share did indeed take action by shutting down production or by powering additional devices to reduce the surplus near the end of the calendar year. In the final survey wave, prosumers provide ex-post insights on the specific measures taken to reduce surplus. Finally, we discuss insights from the experiment regarding the transparency and control offered by the HEMS, as well as how this can influence household behavior regarding the regulatory framework.*

1. INTRODUCTION

Prosumers are increasingly recognized as players in the energy transition (European Environment Agency, 2022). Through digital tools like smart metering and Home Energy Management Systems (HEMS), they have the tools to optimize self-consumption by actively managing production and consumption (see Cappa et al., 2020). However, whether prosumers actually adopt such behavior depends heavily on the overarching regulatory frameworks. Policy makers must strike a balance between encouraging microgeneration in the residential sector through awareness measures and policy support, while also preventing the exploitation of tax systems by commercial agents. A key question is then how to treat "surplus" (European Commission, 2017): if prosumers feed in more energy than they consume, they are net producers and sell a (taxable) good in a market. Many policy frameworks therefore set boundaries on prosumers' regulatory status through limits on plant size, surplus, or output thresholds (e.g., Inês et al., 2020; Clastres et al., 2019). However, there is little empirical evidence to date on the behavioral reaction of prosumers with regard to these limits.

We study the interplay between information provision and prosumer regulation for the case of Croatia. Under the current net billing system, the regulatory status depends on whether prosumers produce more energy than they consume on an annual basis. If prosumers have a surplus at year-end, they are automatically re-classified to a less favorable regulatory status with larger administrative burden. Hence, prosumers have incentive to reduce any surplus, which in practice can be done in two ways. Either by powering down their PV plants, or by increasing their consumption. Both options run counter to the core objectives of energy policy to promote microgeneration and reduce energy consumption. We provide experimental evidence highlighting that prosumers make drastic short-term adjustments to reduce the surplus. The experiment was conducted as part of the larger Horizon 2020 project NUDGE, which mainly focused on information provision through a mobile app. Yet the policy framework emerged as a key factor shaping behavior, and the purpose of this paper is to document these effects. We use survey data on the awareness and self-reported action, both before and after the turn of the year. This is complemented with smart meter data, which reveal that participants did indeed take action to manage their surplus. Selected case studies show how some participants increased consumption, while others reduced production. To the best of our knowledge, we are the first to provide evidence of a voluntary curtailment – where prosumers shut down microgeneration due to incentives in the policy system rather than grid constraints. Our work also provides novel insights on the interplay between information incentives and regulatory incentives – which are typically studied in isolation by scholars in behavioral science and public economics.

While we document a specifically Croatian case study, we believe that the insights are highly policy-relevant and timely beyond the example. In public economics, it has long been recognized that notches – i.e. discrete jumps in the tax treatment – create strong incentives to distort behavior, and that such distortions imply high economic costs (for a review see Slemrod (2013)). Given that many countries have notches in energy policy and that most legislative entities are still in the process of formulating the regulatory frameworks for prosumers, there are many potential areas of transfer. The experience and example of Croatia can serve as an alert for other countries and other policies.

2. INSTITUTIONS & DATA

2.1. Policy Framework

From 2021 until the end of 2023, the Croatian legal framework consisted of two distinct regulatory models: the "self-consumption" model, which applied to households and public institutions, and the "final customer with own production" model, which encompassed all other customer categories, but can also include households. These models were established by the Law on Renewable Energy Sources and High-Efficiency Cogeneration (Article 51). For household PV systems, a household transitioned to the "final customer with own production" model if they exported more energy to the grid than they imported in a given year. Under this billing approach, surplus energy not self-consumed on-site is bought by suppliers at a minimum of 90% of the user's average electricity price. Unlike the "self-consumption" model, which allows netting within a month, this model does not offer any netting. This significantly impacts investment returns, typically resulting in a 30% decrease. Additionally, the status switch comes with increased compliance burden that also makes it undesirable from a non-monetary perspective. Surplus in the regulation is defined as grid-in minus grid-out. In practice, the policy leaves prosumers two margins of adjustment: increase energy consumption (i.e. increase grid-in) or reduce the PV plants' production (i.e. grid-out). Accordingly, those are the two main hypotheses for the empirical analysis.

However, amendments to the Law on the Electricity Market and Renewable Energy Sources were accepted in July 2023. The transitional period starting in 2024 allows prosumers to retain the simpler regulatory model, and the Ministry aims to formulate a new system by March 31, 2025, initiating its application on January 1, 2026.

2.2. Data

The data were collected as part of the Horizon 2020 project NUDGE. The main aim of the project was to study nudging, i.e. non-monetary incentives altering a subject's choice architecture, through the medium of an online application. In the Croatian pilot, the sample consisted of 82 participating households with rooftop PV in three cities, who all received information about their photovoltaic production, self-consumption and overall energy consumption through the *Sunči mobile app*. We focus here on the second intervention period, which was a feedback nudge implemented in the fall of 2022 and provided participants with timely information regarding their surplus, including accumulated values on a monthly and annual basis. The information delivered in the nudge project therefore created a new level of transparency and easier control over the regulatory status for each participant. This feature was made available to the participants from November 2022. To analyze the behavioral reaction, we use two data types: survey and smart meter (i.e. sensor) data.

We conducted two online surveys – one with 54 participants (running end of October 2022 to mid-December 2022) and another one with 80 participants (in April 2023). The surveys cover both socio-demographic and energy-related questions. Specifically, our analysis focuses on (i) behavior regarding the regulatory status (e.g. shut down PV plant, turn on other electricity appliances, change the heating system), (ii) the self-assessed energy consciousness of the

participants, and (iii) electricity consumption and self-consumption (intention and future behavior). In the second survey, the sample consisted mainly of men (93%, n = 76) and six female participants (7%) aged between 32 and 73 years (M_{age} = 48 years, SD = 12.35). All survey respondents owned their home (84% single-family detached houses) and had a PV panel installed as a pre-requisite for participation. The average household of the responding participants consisted of two adults aged between 20 and 64 years and one child under the age of 14 living in a home with 172m² (living space ranging from 64 to 630m²).
Smart meter data were collected continuously throughout the study period, for the analysis of the policy effects, we focus on the period from 1 June 2022 to 28 February 2023. The high-frequency data are aggregated to daily values and focus on two outcome variables. Production is the energy generated by the rooftop PV. Consumption is total household consumption, including self-consumption and energy drawn from the grid. All values are reported in kWh and refer to the mean of daily values within a 24-hour period. We exclude participants with long gaps in data transmission, but do not require a fully balanced panel.

2.3. Strategy for Data Analysis

We provide a descriptive analysis of the data that is motivated by the small sample and the expected heterogeneity in the individual reactions. The results are organized chronologically. We begin with the first survey wave to examine the prosumers awareness and intention with regard to the policy. Second, we compare these self-reported adjustments to the sensor data. We first look at the full sample, and subsequently choose 10 participants for case studies on the individual behavioral reaction in a time-series plot.[i] The results conclude with the final survey wave and a comparison across waves. Most questions are congruent across the survey waves, but we added questions on ex-post experiences in the final wave.
Unfortunately, not all participants answered each survey wave, and there were data transmission problems with some participants in the sensor data. This leaves a discrepancy between the survey sample and the sensor sample. We do not want to restrict the sample any further given the limited sample and proceed with all survey respondents in each wave. We then examine each participant's smart meter data and select prototypical cases for each type of reaction. The analysis sample is therefore inconsistent across the data types, but this was a conscious choice to give comprehensive insights on the policy given the data constraints.
We discuss five prototypical reactions to the regulatory policy, illustrating each reaction with the production and consumption patterns of two exemplary participants as case studies. Considering the very diverging reactions and small initial sample, we only focused on those participants where the reaction is tied to the intervention timing, in order to avoid spurious correlations. The figures in Section 3.2 give electricity produced by the participant's PV panel and electricity consumed by the participant (provided from the PV panel or from the grid) in kWh. Metered daily averages are converted to seven-day rolling means in order to correct for variance from weather conditions, household events or similar. Color-coding distinguishes the

[i] None of the households selected as case studies underwent any changes in their living situation that could be confounded with their observed changes in electricity production and consumption.

different phases: Blue for pre-intervention, black during intervention, red after intervention and green for the new calendar year of 2023. As the timing of the intervention varies between participants, vertical dashed lines indicate when the intervention took place for the respective participant. Additional information from the survey data is used to interpret the observed production and consumption trends in each case study participant.

3. EMPIRICAL RESULTS

3.1. Results from Survey Wave 1 on Policy-Related Behavior

Participants were asked to report their policy-related behavior by implementing five variables (all single items). Specifically, we asked participants about their self-consumption, whether they turned on additional appliances to buffer PV over-production and whether they shut down the PV plant to avoid the status change. Only in wave 2, we asked whether participants changed their heating system, as this may also drive up electricity consumption (system-dependent), and whether their regulatory status actually changed in 2023. The descriptive statistics for the common questions in both waves are displayed in Table 1.

Table 1: Descriptive statistics for survey wave 1 and 2 on policy-related behavior

	Survey wave 1 (n = 54)			Survey wave 2 (n = 80)		
Increased self-consumption -2 = decreased a lot, 2 = increased a lot	M (SD) = 0.53 (0.94) n = 49	Min, Max = -2, 2 (range = -2, 2)	“I am not sure”: 6% (n = 5)	M (SD) = 0.38 (0.97) n = 78	Min, Max = -2, 2 (range = -2, 2)	“I am not sure”: 2% (n = 2)
Turning on additional electrical appliances	Yes: 61% (n = 33)	No: 26% (n = 17)	Other: 13% (n = 7)	Yes: 63% (n = 50)	No: 23% (n = 18)	Other: 15% (n = 12)
Shutting down the PV plant	Yes: 44% (n = 24)	No: 41% (n = 22)	Other: 15% (n = 8)	Yes: 43% (n = 34)	No: 50% (n = 40)	Other: 8% (n = 6)

During the fall (wave 1), the results indicate no or only a little increase of self-reported PV energy use. This is out of line with the initial objective of the app to nudge self-consumption. By contrast, most participants reported to turn on additional electrical appliances during hours of high PV generation. This serves both a direct financial benefit and the alignment of consumption patterns to the regulatory incentive. The survey also reveals high awareness of the policy. Almost half of the participants considered shutting down their production, and only 15% did not have a clear opinion. In this context, it is noteworthy that the dimensioning of the PV plant during installation is a key determinant on whether participants will be at risk of running a surplus, so it is not surprising that a substantial fraction answered “No”. The category *Other* includes the option “I did not think about it” to distinguish. The sample is rather evenly split on whether they consider self-curtailment, which indicates that the policy creates segmentation depending on the households' PV installation and equipment.

3.2. Results from Sensor Data on Prototypical Reactions

For each of the five prototypical reactions, we present the two case studies side-by-side. The dashed lines indicate the intervention start (double line if activation occurred over two days), and the break from red to green marks the end of the year.

Temporary shutdown of the PV plant until year-end —. Participants 2 and 14, as can be seen from the drop in the red production line, temporarily shut down their PV system, a step they had mentioned in the survey. During the shutdown, participant 2 strived to increase electricity consumption by installing an electric boiler to substitute for gas in hot water heating and by switching on additional appliances at times when the PV system produced more electricity than the household could consume. Participant 2 also strongly disagreed that they had made any attempts to save electricity at home in the months after the intervention. By contrast, participant 14 shut down PV production and maintained consumption as before (apart from a short peak towards year-end). In both surveys, participant 14 emphasised that they intended to and tried to save electricity at home; moreover, they did not switch on any extra electrical appliances when the power plant was producing much more electricity. These responses stated by participant 14 do not correspond with their sensor data; however, electricity saving efforts might have been levelled out by participant 14's low overall consumption level. Eventually, in 2023, participant 14 received the "self-consumption" status.

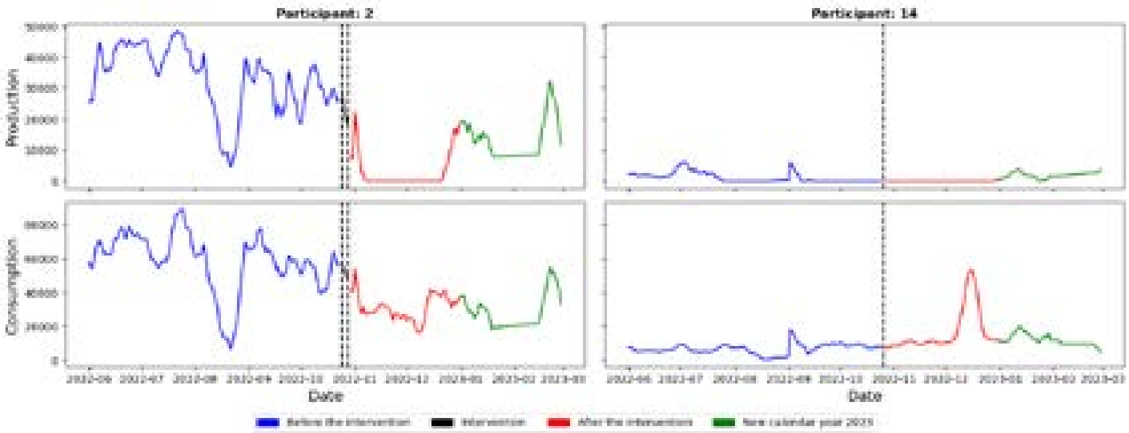

Figure 1. Temporary shut-down of PV plant in self-curtailment

Increase consumption until year-end —. Participants 19 and 43 showed a steep incline in electricity consumption immediately after the intervention, whereas their production remained unchanged or even decreased. After the turn of the year, their consumption returned to previous levels. Both participants expressed a strong intention to increase their own PV electricity consumption and strongly disagreed with trying to save more electricity at home in the three months following the intervention. They reported that they frequently used appliances when production exceeded consumption, with participant 19 using a washing machine, heat pump and clothes dryer, and participant 43 using air conditioning and electric heaters. Participant 43 explicitly stated that they did not consider the above reaction of shutting down the PV system temporarily, but instead decided to increase their consumption in order to balance their overall production-consumption ratio.

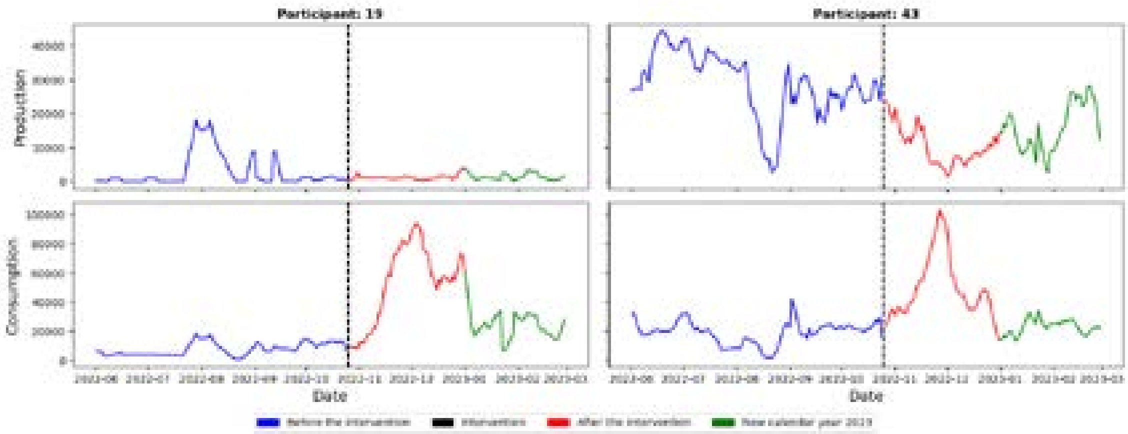

Figure 2. Increase consumption through additional appliances

Decrease consumption and maintain beyond year-end —. Participants 38 and 40 exemplified a persistent reduction in electricity consumption beyond the turn of the year. Participant 38 stopped using the electric boiler and opted for winter mode, i.e. a switch to an alternative heating method during the cold season. Both participants dismissed the option of turning on additional devices when production exceeded consumption; participant 40 even rejected this notion strongly. The electricity saving efforts of participants 38 and 40 as observed in the sensor data were consistent with their survey responses: both intended to save more electricity and use more PV energy after the intervention; both stated that saving energy made them feel good; and both described themselves as rather energy-aware households.

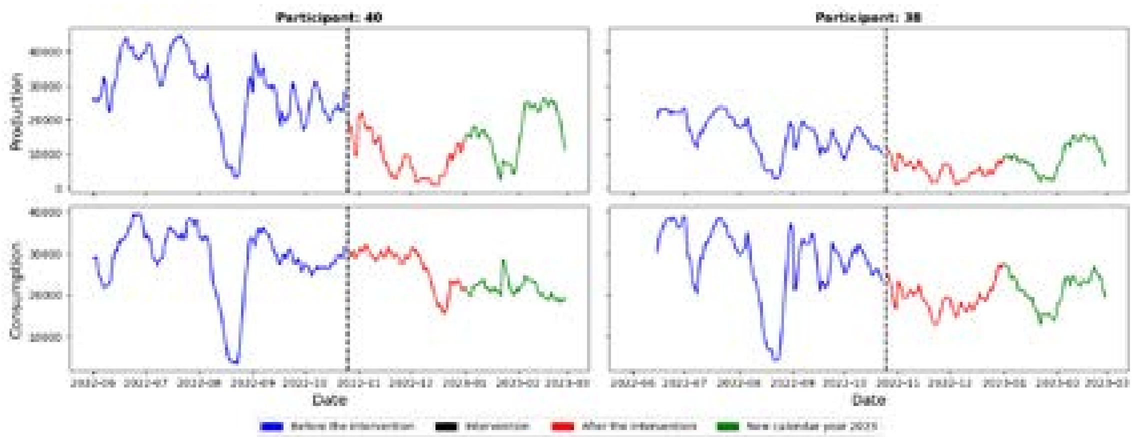

Figure 3. Continued decrease into the new year

Decrease consumption but bounce back with the new year —. Participants 46 and 48 decreased or at least maintained their electricity consumption after the intervention, but by the turn of the year, their consumption increased remarkably, even exceeding their previous levels and partly mirroring their production pattern. At the time of the intervention, participants 46 and 48 stated strong intentions for saving electricity in the next three months, but rather for reducing energy costs than for avoiding feelings of guilt. At the subsequent survey, participant 48 had abandoned their intentions for further saving energy. Both participants aimed for self-consuming more PV electricity instead and leveraging eventual production surplus; to this end, participant 46 planned to use less gas and to charge an electric vehicle, and to consequently reduce carbon emissions.

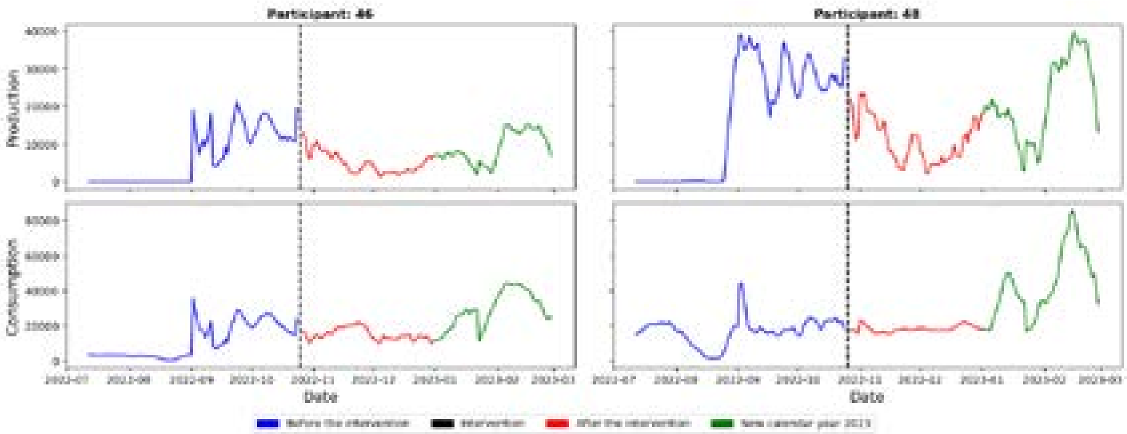

Figure 4 Decrease consumption only temporarily until year end

No reaction —.Participants 44 and 45 served as examples for a lack of visible reaction to the policy. This does not ascertain that they were not aware, random fluctuations in production and consumption might mask subtle underlying reactions. Both participants did not commit to electricity saving intentions or attitudes in either survey: They neither agreed nor disagreed with the statement on guilt about not saving energy. At the time of the intervention, they neither agreed nor disagreed with statements on trying to save or having already saved electricity. Participant 44 stated neutral intentions towards saving electricity in the three months after the intervention. Both participants replied “I am not sure” in their self-assessment whether their carbon emissions had decreased in the last three months.

There are several other participants with similar time series plots in the overall sample, while for other households there are only weak tendencies, which does not allow proper categorization. We deliberately chose two cases for each type to characterize the range of identified reactions and underscore the heterogeneity.

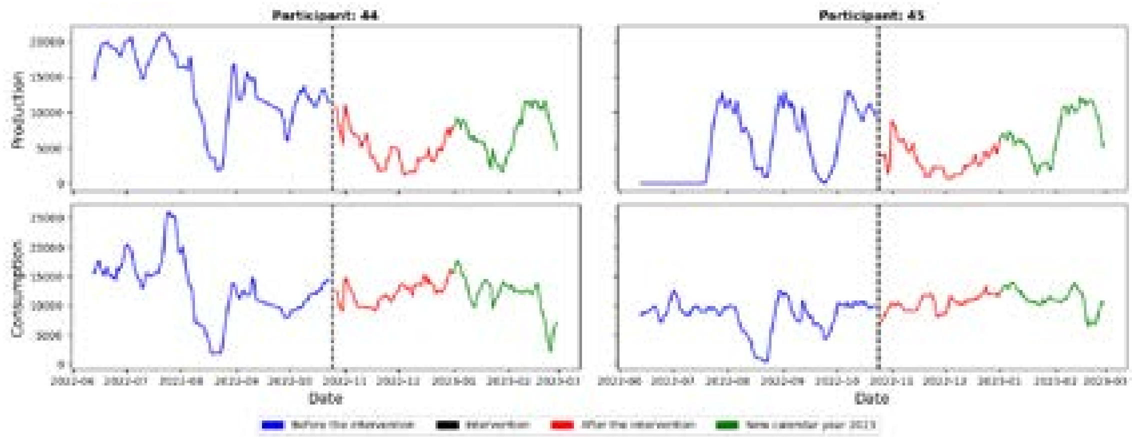

Figure 5. No visible reaction during the intervention period

3.3. Results from Ex-Post Survey Analysis

In spring 2023, we asked participants in a second survey wave the same questions as in wave 1 to assess potential differences and provide a policy evaluation.

3.3.1. Results from Survey Wave 2

For the self-curtailment behavior, the descriptive statistics for survey wave 2 show that participants perceive their self-consumption to be unchanged or increased a little over the first quarter of 2023 (see Table 1 in 3.1). Even in the spring, a large proportion of the participants (43%) stated that they considered shutting down the PV plant to avoid the status change. Moreover, the majority (61%) reported to have turned on additional appliances to achieve savings despite the over-production of their PV power plant. Similarly, only 28% of participants in wave 2 stated to have *not* changed their heating system. 50% ($n = 40$) reported that they started to occasionally heat with electricity (air conditioner or electricity heaters), 14% ($n = 11$) reported to use a heat pump since the installation of the PV plant, 5% ($n = 4$) replaced the gas boiler with an electric one, and 4% ($n = 3$) chose “Other”. These results fit with the other self-curtailment variables and indicate an increase in electricity consumption by most participants after the installation of the PV plant, which points to rebound effects that are indeed incentivized by the policy.

Notably, the responses for increasing consumption and shutting down the plant are on par with those from the fall. Applying a paired t-test as an inference statistical comparison of the self-consumption variable (with $n = 48$) shows no significant difference. However, the small sample size may limit the comparative analysis. Examining the cross-tables (automatically excluding participants who did not answer the same question in both surveys), it emerges descriptively that only eleven participants (26%) changed their answers across time regarding the shut-down of their PV plant (from yes to no or vice versa, $n = 43$). The same pattern results for the question to turn on an additional appliance ($n = 44$): 12 participants (27%) changed their response between survey wave 1 and 2.

Finally, in wave 2 we asked whether participants' status had changed at year-end and why (question is omitted from table, multi-response was possible). Only 3 participants (4%) experienced a status change – one participant reported having over-dimensioned the plant in the installation, the others attributed the status change to not using the PV plant enough. The most common response (46%, n = 37) was that participants felt they avoided the switch thanks to the correct dimensioning of their plant. The distribution of responses fits with the sensor data, where not all individual participants show strong reaction, but those that react do so drastically. While 9% (n = 7) of participants reported that they had actually engaged in self-curtailment (turned off PV plant), 19% (n = 15) reported that changing the heating source to electricity helped them avoid the switch. 4% (n = 3) bought an electric vehicle.

3.3.2. Before-After Comparison of Electricity Consumption Questions

In both survey waves in fall 2022 and spring 2023, we also asked participants about their electricity consumption behavior. Specifically, for the electricity consumption and their PV self-consumption, we implemented questions on the intention to save electricity (three items, Cronbach's alpha = .92 and .90, in wave 1 and 2 respectively) and the intention to use more PV energy (three items, Cronbach's alpha = .90 and .93), as well as their expected increase in electricity consumption and self-consumption (one item each). The descriptive statistics of these variables for both waves are displayed in Table 2.

Table 2. Descriptive statistics for survey wave 1 and 2 on electricity consumption behavior

	Survey wave 1 (n = 54)			Survey wave 2 (n = 80)	
	M (SD)	Min, Max (range)	Scale interpretation: Higher values indicate ...	M (SD)	Min, Max (range)
Self-assessed energy consciousness	7.24 (1.32)	5, 9 (1, 9)	higher energy consciousness	7.34 (1.25)	4, 9 (1, 9)
Intention for electricity saving (electricity consumption)	3.56 (1.08)	1, 5 (1, 5)	higher intention to save electricity	3.60 (0.99)	1, 5 (1, 5)
Intention for PV energy use (self-consumption)	3.83 (1.10)	1, 5 (1, 5)	higher intention to use PV energy	3.85 (0.98)	1, 5 (1, 5)
Expected increase in electricity consumption	1.48 (2.44)	-4, 4 (-4, 4)	expectation of higher consumption	0.69 (2.43)	-4, 4 (-4, 4)
Expected increase in PV self-consumption	1.50 (2.15)	-4, 4 (-4, 4)	expectation of higher self-consumption	1.23 (2.30)	-4, 4 (-4, 4)

The first note is the high starting motivation (above mid-scale in wave 1). When conducting paired t-tests for the electricity behavior variables between waves (with $n = 54$), none of the five t-tests reaches the statistical level of significance. Thus, none of the described variables changed significantly over time. However, descriptively, we observe a trend over time in an electricity-conscious positive direction. There is a slight increase in the intention to save electricity and to use more own production. The energy consciousness increases slightly on average. There is a decrease both in the mean for expected increase in electricity consumption and in the expected PV self-consumption. The latter is not in line with the other descriptive developments. We also examined the correlations within each wave and found positive correlations between the intention to save electricity and the intention to use PV energy (wave 1: $r = .62$, $p <.001$ and wave 2: $r = .66$, $p <.001$), and between the expected increase of consumption and self-consumption (wave 1: $r = .84$, $p < .001$ and wave 2: $r = .71$, $p < .001$). In wave 2, the self-assessed energy consciousness and the intention to save electricity have a small correlation ($r = .25$, $p = .028$). All other correlations were not significant. Overall, there is no strong evidence for a significant effect of the policy on the underlying electricity consumption behaviour. We take this as indicative of a disconnect between short-term adjustment and long-term behavioral change. However, we acknowledge that the small sample size limits statistical inference and constrains the external validity of the results.

4. DISCUSSION & CONCLUSION

4.1. Policy Implications

The interventions in the NUDGE project were initially intended to provide intuitive guidance that leads consumers to adapt everyday choices (see Thaler and Sunstein, 2009). The Croatian case, however, reveals that the information provided through the nudge served a different purpose. The information in the app became a transparency and control mechanism that allowed prosumers to monitor the regulatory conditions. Reminders are known to be effective for tax compliance (e.g., Ericson, 2017), but the link is new for energy policy. On the one hand, this indicates that nudging and similar information schemes can have a positive co-benefit: transparency. Policy measures that are designed for the intuitive behavioral system can have positive linkages to the rational system. On the other hand, the lesson is that nudging interventions have limited efficacy for their original objective of intuitive guidance when the regulatory framework is dominant. The observed reactions do not reflect adjustments to everyday choices, but rather short-term adjustments to a regulatory notch. We discovered this interdependence in the course of the NUDGE project, but our experiment was not specifically designed for this purpose. This admittedly limits our analysis in terms of methodology and scope. For example, we focus on short-term adjustments that can be directly related to the nudge timing. The analysis cannot capture participants that adjusted gradually throughout the year without reliance on the additional nudge information, which is why we selected the 10 case studies. Similarly, the survey included questions related to the policy, but this was not the main focus initially. Future research will be needed to provide a better understanding of the channels and mechanisms through which nudging might provide co-benefits to regulation.

Prosumers' behavioral reactions reveal the nexus between rigid regulatory frameworks and "soft" measures aimed at consumer awareness. Our study depicts an example where these two approaches intersect. Importantly, it is only through this intersection that we observe substantial changes in behavior. The policy *notch* provides strong economic incentives to adjust production and consumption. The *nudge* subsequently made prosumers aware of their status at a crucial point in the timeline (end-of-year). The result is a swift and drastic reaction by those participants that had thus far underutilized their production. In order to avoid the status switch, prosumers increase energy consumption and curtail production as hypothesized, but there is more heterogeneity in the observed reaction than expected. Prosumers differ in their reaction in the sensor data, which is also reflected in the distribution of self-reported reaction strategies in the survey. Taken together, this suggests that there is no one-size-fits-all adjustment, as the individual behavioral reactions are influenced by technical equipment. With this background, it is important to emphasize that a large fraction of consumer avoided any repercussions because their PV plant was correctly sized. This puts importance to the pre-ceding investment decision, where private companies implicitly take on responsibility for setting a path to regulatory compliance, for which they may not have economic incentives.

In this context, it also appropriate to consider the policy effects from the perspective of the local collective. The project partner, Croatian energy cooperative ZEZ, has a general interest in building up energy communities. Yet with the policy reaction, the smart meter data collected from existing customers are potentially biased downward in their capacity to produce and share renewable energy. The distortion created by the adjustment to the policy hence prevents local organizations from effectively using the collected data as a building block for future business models, especially when the regulatory framework is subject to frequent revision and uncertainty as in the Croatian case.

4.2. Conclusion

In principle, both nudging and regulation could be used to support the overarching objective of energy policy for prosumers, namely increasing domestic PV generation and encouraging self-consumption. Yet, the outcome does not match the overall target in the Croatian policy framework. We hence encourage policy makers to consider the potential of nudging to be aligned with regulatory frameworks and tax systems, since our results suggest that there is opportunity to leverage the intersection to create synergies. This would allow individual prosumers to better utilize the very different types of incentives that are ultimately intended to promote distributed energy resources and private households' participation in the energy transition, which saves resources and expands renewables.

On the aggregate level, prosumers collectively contribute to economy-wide green priorities. We can only look at individual cases with our small sample, but the results suggest that the policy setting is likely to have substantial aggregate effects. If our findings are representative of the Croatian population, the policy results in lost renewable energy potential and excess energy consumption. If our results are *not* representative, i.e. prosumers without the app do not manage to avoid the status switch, there would be high economic costs from sub-optimal choices and excess compliance burden. Our study does not quantify the full economic cost, but both scenarios imply a substantial welfare loss. This is especially concerning regarding the observed self-curtailment. Curtailment has been studied mainly from a technical perspective, where the question is how grid constraints can be managed effectively and efficiently. Our results point to a different, paradoxical type of curtailment: prosumers who voluntarily shut off their production to comply with a regulatory system that is meant to promote precisely this production.

More broadly, our results are a warning sign that tax systems, regulatory frameworks, and energy policy are intertwined. When new actors and business models emerge in a transition period, existing and emerging legislation should be reviewed for alignment to avoid undesirable consequences. This is not only a task for policy makers, but also a general call to behavioral scholars to share knowledge: economists know notches, psychologists know nudges, and engineers know technology. In the Croatian case, these three sciences came together to analyze and understand the policy effects. Likewise, we believe the Croatian case can be informative across country boundaries, as European stakeholders scramble together to devise and evaluate the policy puzzle needed for the energy transition.

5. REFERENCES

Cappa, F., Rosso, F., Giustiniano, L., & Porfiri, M. (2020). Nudging and citizen science: The effectiveness of feedback in energy-demand management. *Journal of Environmental Management*, *269*, 110759.

Clastres, C., Percebois, J., Rebenaque, O., & Solier, B. (2019). Cross subsidies across electricity network users from renewable self-consumption. *Utilities Policy, 59*, 100925. DOI: 10.1016/j.jup.2019.100925.

Ericson, K. M. (2017). On the interaction of memory and procrastination: Implications for reminders, deadlines, and empirical estimation. *Journal of the European Economic Association*, *15*(3), 692-719.

European Commission (2017). Opinion of the European Economic and Social Committee on ‘Prosumer Energy and Prosumer Power Cooperatives’: opportunities and challenges in the EU countries. *Official Journal of the European Union, C34,* 44–52. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016IE1190.

European Environment Agency (2022). Energy prosumers in Europe. Citizen participation in the energy transition (EEA report, 01/2022). Publications Office of the European Union.

Inês, C., Guilherme, P. L., Esther, M. G., Swantje, G., Stephen, H., & Lars, H. (2020). Regulatory challenges and opportunities for collective renewable energy prosumers in the EU. *Energy Policy*, *138*, 111212. DOI: 10.1016/j.enpol.2019.111212.

Slemrod, J. (2013). Buenas notches: lines and notches in tax system design. *eJournal of Tax Research*, *11*, 259–283.

Thaler, R. H., & Sunstein, C. R. (2009). *Nudge: Improving decisions about health, wealth, and happiness*. Penguin.

EXPLORING PRO-ENVIRONMENTAL BEHAVIOUR SPILLING EFFECTS IN DUTCH HOMEOWNER ENERGY EFFICIENT RENOVATIONS

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Keywords: Behavioural Public Policy, Pro-environmental Behaviour, Energy Efficient Renovation, Spilling, Spillover Effect, Homeowner, Netherlands

Abstract

Energy efficient renovation (EER) of the owner-occupied building stock is identified as a key effort to pursue in order to mitigate climate change. However, current renovation rates continuously fall behind and a need to foster EER uptake is apparent. As homeowners' behaviour and decision-making are crucial in the context of EER, behavioural research holds vast potential for policy design and ultimately increasing EER uptake. So-called 'spilling effects' in the domain of pro-environmental behaviour (PEB) continuously catch the attention of researchers. Therefore, this article proposes a conceptual framework of 'spilling effects' in the context of homeowner EERs based on an integrative literature study, facilitating policy design.

1. INTRODUCTION

In 2019, the European Union (EU) presented the 'European Green Deal' (EGD) in accordance with the Paris Climate Agreement of 2015 (European Commission, 2019; United Nations, 2015). At the core of this effort lies the goal of climate neutrality until 2050 with a 55% reduction in greenhouse gas (GHG) emissions by 2030 (European Commission, 2019). A key initiative within the EGD is the 'Renovation Wave', aiming to "renovate 35 million inefficient buildings by 2030", as the EU expects 85-95% of the current building stock to still be standing in 2050 (European Commission, 2020). Among others, the Netherlands acknowledged the need for energy efficient renovation (EER) of its building stock and followed the EGD with their national climate agreement the 'Klimaatakkoord' (KA) in the same year (Rijksoverheid, 2019).

In addition to increasing climate awareness and its recognition in policymaking, the recognition of behavioural research in policymaking is also steadily increasing. With the emergence of behavioural public policy (BPP) and the establishment of behavioural insight teams in the Netherlands and abroad, governments anticipate policy improvements (Hallsworth, 2023; Kaufman et al., 2021). These approaches have been proven to hold considerable leverage among various climate-related, pro-environmental behaviours (PEBs) (Biely, 2022; Hallsworth, 2023; Kaufman et al., 2021; Maki et al., 2019).

However, besides the increasing efforts towards climate neutrality, and raising awareness of the importance of behavioural factors in that regard, such pro-environmental actions of climate mitigation are also inherently costly and Dutch national EER rates continuously remain below set goals (Ebrahimigharehbaghi et al., 2019, 2022). Kerr & Winskel (2020) argue that EER stands out as a unique low-carbon policy strategy due to its need for a cooperative effort between private households and public policy within the intimate setting of a home. The authors further add that there would exist a significant opportunity (and necessity) for private contributions towards potential retrofit investments (Kerr & Winskel, 2020). Accounting for these special circumstances and the growing application of BPP, the potential for its application in the context of EER becomes apparent.

However, due to the variety of behavioural concepts, aiming to investigate this conceptual plurality as a whole would exceed the scope of this study (Biely, 2022). Therefore, focusing on a specific concept in depth is deemed the most promising way by the authors to derive tangible results for research and policy. Thus, the concept of spillover effects (or broader: 'spilling effects') is promising. For the scope of this research, 'spilling effects' describe the relationship between two (usually subsequent) behaviours. This includes more specifically the influence of a certain behaviour [in t_{-1}] on the targeted behaviour [in t_0] (or vice versa), as well as the influence of the targeted behaviour [in t_0] on a non-targeted subsequent one [in t_{+1}] (or vice versa). The literature on spilling effects is manifold regarding scope of analysis and terminology alike (Dolan & Galizzi, 2015; Krpan et al., 2019; Nilsson et al., 2017; Truelove et al., 2014).

In the realm of PEBs, the existence of spilling effects (Maki et al., 2019; Nilsson et al., 2017) as well as in the specific context of EER (Egner & Klöckner, 2021; Irwin, 2021) is partially proven. However, in relation to the Dutch context, research is still lacking. Therefore, this study answers the following research question:

"What are possible spilling effects in the context of Dutch homeowner energy efficient renovations, and how can they be embedded in a model to facilitate systematic analyses through research and policy alike?"

To answer this question, the study has the following structure. The next chapter explains the study methodology and research approach. Following this, chapter three first defines the concepts of PEB and EER and argues why EER should be classified as such a PEB. Afterwards, the chapter examines the concept of spillover effects in PEB as a promising concept for BPP and further provides an argument for the use of the term 'spilling effects' (in PEB) instead. Finally, the chapter gives an overview of several proven cases of spilling in EER contexts and identifies determinants of spilling and general EER uptake. Subsequently, the fourth chapter provides the main results of this study as a conceptual framework of spilling effects in the context of EER. Finally, this study discusses the results and possible implications for research and policy in the fifth chapter and concludes with limitations and final remarks in the sixth.

2. METHODOLOGY

The vast range of concepts relating to spilling effects and their partial lack of conceptual clarity pose both a challenge as well as an opportunity to the analysis. Prior desk research revealed various publications across different backgrounds and fields of application. This study aligns with Torraco's (2005) concept of an integrative literature review, which is usually not systematic according to Snyder (2019). Therefore, this study does not claim a complete and holistic coverage of the phenomenon, but rather acts as exploratory research. However, this research integrates research from various sources, following the notion and recommendation of transdisciplinarity in this regard (Biely, 2022; Günther, 2009; Kaufman et al., 2021) and furthermore targets spilling effects in a broader sense (i.e. extending from intrapersonal phenomena to interpersonal ones).

Following Callahan's (2014) 'The Six W', the search for the data (more specifically the literature / articles in this case) was carried out by the first author and main researcher, myself (Who). Data collection began January 1st 2023 and continued until the 12th of September 2023 (When). Regarding the scope and method of data collection, relevant scholarly journal papers were reviewed, found on the online databases ScienceDirect, EBSCO, and Google Scholar, using multiple combinations and spellings of the following keywords (Where & hoW): *Adoption*, *Barriers*, *Behaviour*, *Behavioural Change*, *Behavioural Public Policy*, *Behavioural Spillover*, *Decision Making*, *Drivers*, *Energy*, *Energy Efficiency*, *Energy Efficient Renovation*, *Energy Retrofit*, *Energy Transition*, *Peer Effects*, *Photovoltaic*, *Policy*, *Policy Design*, *Policy Making*, *Pro-environmental Behaviour*, *Public Policy*, *Spillover, and Spillover Effect*. Only publications after 2010 were included, to guarantee the inclusion of the most recent developments in the field and the active disregard of possible outdated research. While trying to develop a conceptual framework for spilling effects in EERs, an important part were relevant reviews on spilling effects in the general context of PEB, like, for example, Dolan &

Galizzi (2015) or Maki et al. (2019), to form a theoretical foundation (Why). The main result of the research is the conceptual framework depicted in the fourth chapter (What).

3. LITERATURE REVIEW

The previously mentioned emergence of behavioural research in general and BPP in specific highlights global efforts to account for behaviour in research and policy. The need for this recognition is supported by Tian & Liu (2022), who follow Kaaronen (2017), and state human behaviour as the key driver of environmental problems. Although human behaviour seems to have such a leverage, it can be assumed that it has similar potential for climate mitigation as well. In this regard, the authors further give this as a reason that the field of PEB research also became an ever more emerging one over time, while attracting researchers across various disciplines (Qiu et al., 2014; Seebauer, 2018; Sun & Hong, 2017; Tian & Liu, 2022). As the field is still considered to be in early development, one can observe an unintentional variety and fuzziness in labels, names, and concepts relating to PEB (Tian & Liu, 2022). A situation very similar to 'spilling effects'. Therefore, this study follows Tian & Liu's (2022) extended definition of PEB as a behaviour "that consciously protects the environment and improves its sustainability" (p. 2). Baum & Gross (2017) hereby add, that besides being pro-environmental, such a behaviour "must bring about a reduction in an individual's environmental impact, both overall and over the long run" (p. 56) to also be environmentally significant. This study argues that EER fulfils the requirements for both general PEB and environmental significance, as described in the following subsection and explained along the general aim and different depths of EER.

3.1 Energy Efficient Renovation as Pro-environmental Behaviour

The main reason why EER meets the above-mentioned requirements is due to the fact that EER can drastically reduce a household's energy demand over a long period of time while at the same time improving the household's living conditions (Dolšak, 2023). In more detail, specific EER measures include but are not limited to improved insulation (e.g. floor, wall, and roof insulation, doors and window frames, as well as glazing) and switching from fossil fuel powered to sustainable heat and electricity generation (e.g. solar heaters, photovoltaic (PV) and heat pump installations) (Kerr & Winskel, 2020). Hereby, the European Commission gives six categories of EER measures in a report to provide technical guidance for such renovation measures published in 2014, namely 'Building envelope and thermal insulation', 'Space heating', 'Space cooling', 'Domestic hot water', 'Ventilation systems' and 'Lighting' (European Commission. Directorate General for Energy. et al., 2014).
However, Filippidou et al. (2017) state that the term energy (efficient) renovation lacks a common definition and refer to the European Commission report for classification.
According to Filippidou et al. (2017) and the referred report, one can roughly differentiate four levels of EERs. Thus, the first level constitutes a so called 'low-hanging fruit'. This refers to EER strategies that are highly cost-effective, minimally intrusive, and typically offer a fast return on investment, sometimes leading to energy savings of up to 20-25%. Such strategies can encompass operational and maintenance improvements, change in the inhabitants' behaviour

as well as lighting enhancements (European Commission. Directorate General for Energy. et al., 2014). The second level of is termed ‘standard renovation’ and entails the concurrent and cohesive execution of several individual EER measures (European Commission. Directorate General for Energy. et al., 2014). The third level refers to ‘deep renovation’ following the European Commission’s Energy Efficiency Directive, as economically viable extensive overhauls that can markedly lower a building's energy consumption compared to its levels before the renovation. This results in exceptionally high levels of energy efficiency. Such thorough makeovers can be done incrementally and result in high levels of energy efficiency, commonly yielding energy savings exceeding 60% (European Commission. Directorate General for Energy. et al., 2014). The fourth and last level constitutes a (transition to a) ‘Nearly Zero-Energy Building’ (NZEB), referring to a highly energy efficient building which meets its remaining energy demands to a significant extent with renewable energy, ideally produced through the building itself (European Commission. Directorate General for Energy. et al., 2014). Such a differentiation can provide more specific insight, as it results in varying implications for the planning of EERs and related policymaking processes. It further highlights the lasting nature of such EERs compared to other rather day-to-day PEBs. Consequently, this specificity has implications on the nature of ‘spilling effects’ in this domain, as elaborated in the following subchapter.

3.2 Spilling Effects in Pro-environmental Behaviour

Regarding insights from behavioural research, the so-called ‘spillover effect’ (or broader: spilling effects) continuously catches the attention of researchers and policymakers alike. However, research associated with spilling effects regarding PEB is considered to be “still in its infancy” (Ye et al., 2022, p. 1), reflecting the early stage of PEB research mentioned above.

The spillover effect traditionally acts as an umbrella term for the influence of a person’s specific behaviour on a subsequent behaviour of this person, which are interlinked by a certain motive (in this context PEB), as a result of an intervention (Dolan & Galizzi, 2015). However, the use and interpretation of the term broadened over time (Nilsson et al., 2017). An example of these developments is the concept of ‘behavioural spillunders’ introduced by Krpan et al. (2019), referring to the valuation of the targeted behaviour influencing the precedent one (Krpan et al., 2019, p. 1), rather than the other way around (spillover).

Within the context of PEB, scholars currently define various types of spillovers, different directions of spillovers, and explore factors moderating spillover relationships, while at the same time using different names for similar concepts (Dolan & Galizzi, 2015; Irwin, 2021; Krpan et al., 2019; Maki et al., 2019; Nilsson et al., 2017; Truelove et al., 2014). Furthermore, a parallel stream of literature exists examining so called ‘peer-effects’ (or, for example, also ‘spatial spillovers’) (Irwin, 2021). Therefore, this study proposes a new terminology, due to the diversity of concepts and labels, but also their partial overlaps (i.e. fuzziness), as well as the early stage of the research field itself. The aim is to provide conceptual clarity, foster understanding, and facilitate research and application. Following this argument, we introduce the term of ‘spilling effects’, summarising concepts generally used to investigate intrapersonal behaviour (such as spillover and spillunder) as well as interpersonal behaviour (such as spatial spillover or peer effects).

Although the concept of PEB reaches far beyond energy conservation and efficiency improvements (e.g. EER), it can be assumed that when the engagement in EER is defined as an environmentally significant PEB, spilling effects can be present. This assumption is confirmed by several studies across different national contexts for different types of spilling effects regarding homeowner EERs (Egner & Klöckner, 2021; Irwin, 2021; Serra-Coch et al., 2023). Thus, it is possible to differentiate between four types of such effects, which themselves are moderated by various factors. The figure in section four (*Figure 1*) depicts these findings and maps them along a timescale.

The first type of these spilling effects are effects related to temporal spillover, defined by Nilsson et al. (2017) as "[conducting] behavior A in time 1 affects the probability of conducting behavior A in time 2" (p. 574). Therefore, these spillings would relate to a former EER increasing/decreasing the likelihood of another EER and were proven by (Egner & Klöckner, 2021) in the context of Norway through a quantitative analysis of two surveys among homeowners (combined n = 6402). Thus, the authors prominently state that, according to their results, "respondents who completed energy retrofits in the past three years are significantly more likely to undertake new energy retrofit" (Egner & Klöckner, 2021, p. 1).

A second and more complicated, although more intensively researched, type of spilling effects are those referred to as behavioural. These spilling effects occur from a specific first behaviour to a different second behaviour (Nilsson et al., 2017). In the context of EER, such behaviours would, for example, be other PEBs. However, Egner & Klöckner (2021) state that EERs have very little similarity to other PEBs and therefore could even not be perceived as PEB by individuals. This point is supported by Wilson et al. (2018), arguing that EERs are rarely perceived as a distinct action, but are part of larger efforts of individuals improving their home. Ebrahimigharehbaghi et al. (2022) also support this point by proposing to bundle EER efforts together with general efforts for home maintenance. Although maintenance could be such a similar behaviour leading to an EER through spilling, the proposition of bundling both behaviours rather than conducting them sequentially (hereby maintenance being the first) rather confirms the earlier statements. These circumstances raise the question of whether an EER could also be triggered by other (not necessarily pro-environmental but) highly impactful or life-changing behaviours (LCB), directly influencing/changing people's needs regarding their home (e.g. birth of a child or marriage/divorce).

The third category mentioned by Nilsson et al. (2017) is spilling across contexts. When investigating EER, this would refer to an individual who conducted an EER in one context (e.g. a first house) engaging in a second EER in another context (e.g. a second house). Therefore, Egner & Klöckner (2021) "judge contextual [spilling] to be nonexistent in most countries, as the vast majority of individuals only have one home to retrofit. Retrofitting of subsequent homes when moving house could be said to be defined as temporal spillover" (p. 3). According to the authors, such contextual spilling would rather likely be present in countries where large shares of the population own second homes (e.g. Norway) (Egner & Klöckner, 2021). Regarding the Netherlands, this is not the case. When including landlords, such contextual spilling effects could also be present (e.g. from their private to their rental homes), according to the authors (Egner & Klöckner, 2021).

The last category of spilling effects observed in the context of EER is the phenomena of interpersonal spilling. In the literature, this concept is largely referred to as 'peer-effects', 'contagion' or 'spatial spillover' targeting the influences of the individual's surroundings on the individual (Irwin, 2021; Mundaca & Samahita, 2020; Noonan et al., 2013; Serra-Coch et al., 2023). In the context of EER, such spilling effects seem to be present for the installation of photovoltaic (PV) (Irwin, 2021; Mundaca & Samahita, 2020; Serra-Coch et al., 2023), as well as heating, cooling, and air conditioning (HVAC) systems (Noonan et al., 2013), since both of these measures can be related to the EER levels two to four mentioned above. These effects were identified throughout several national contexts (e.g. USA, Norway, Switzerland) (Egner & Klöckner, 2021; Irwin, 2021; Serra-Coch et al., 2023). Although the investigated studies would generally refer to positive interpersonal spilling, Noonan et al. (2013) note that the adoption of an inefficient HVAC system due to interpersonal spilling could occur as well. This could then be understood as a negative interpersonal spilling effect in the case of EER. In this regard, Serra-Coch et al. (2023) differentiate between active and inactive effects. The first refers to the active transfer of information from peers who experienced an EER to the individual (e.g. through word-of-mouth). The latter refers to a passive spilling, for example through the individual visibly noticing its peer's PV adoption without actively getting informed (Serra-Coch et al., 2023). As PV can be perceived as a comparably visible EER measure, the question remains whether inactive interpersonal spilling effects are also present for other types of EER measures.

Regarding environmental significance, Baum & Gross (2017) state that it is necessary to include the context of a certain behaviour and its relationship with the environment to derive meaningful results. They identify four levels of determinants of environmental significant behaviour, namely, *Internal factors*, the *Individual-level context*, the *Social-cultural context*, and the *Techno-economic context* (Baum & Gross, 2017). In the case of EER, Dolšak (2023) defines five key determining factors for the uptake of EERs, described as 'barriers and drivers' (a phrase commonly used to describe such phenomena (Kaufman et al., 2021)). These are namely *Information and policy measures*, *Economic factors*, *Socio-economic characteristics of households*, *Technical – buildings characteristics*, and *Behavioural factors*. Looking at these two categorisations of determinants, it becomes apparent that accounting for all these factors is necessary when looking at EERs as environmentally significant PEBs and the related spilling effects in this regard.

4. RESULTS

Taking the above-mentioned literature into account, the following conceptual framework is presented, as depicted in the figure (Figure 1) below. This model accounts for the different types of intrapersonal and interpersonal spilling and shows different possible ways in which the uptake of EER as the targeted behaviour could be influenced by other behaviours as well as influence other behaviours itself. The framework further emphasises the context of the specific behaviour and lists important factors that can influence the strength of the spilling effect, its direction, as well as its general occurrence. Therefore, the different layers and their proximity to the behaviour highlight the level of influence of the homeowner on these layers (motivated by (Baum & Gross, 2017)).

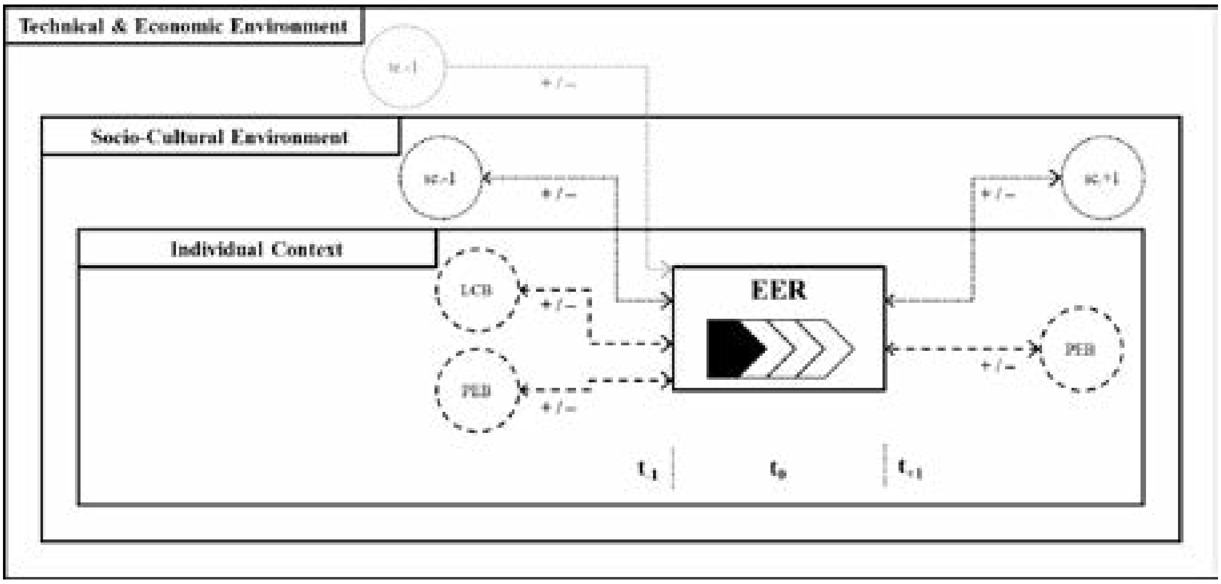

Figure 1: Conceptual framework of spilling effects in EER (own illustration)

Complementing the figure above, the following table (Table 1) provides an extended explanation and further adds relevant factors for EERs per layer. In this sense, the term ‘promoting’ refers to a positive influence (+) of one behaviour on another (in terms of likelihood of engaging in the latter), while the terms ‘permitting’ and ‘purging’ refer to the contrary (–) effect (Dolan & Galizzi, 2015). The arrows follow a similar logic, the right-sided depicting spillovers, while the left-sided depicting spillunders.
Following Egner & Klöckner's (2021) and Wilson et al.'s (2018) rational and due to an EER’s possible magnitude as well as socio-demographic determinants, we assume that LCBs in addition to PEBs could also lead to spilling. An example of such an LCB would be the birth of a first child and the family’s changing needs regarding their current living environment. PEB in this figure refers to any PEBs including prior/future EERs.
Time (t_{-1}, t_0, t_{+1}) has been added as a dimension to facilitate understanding and accounting for the specific nature of EERs compared to other PEBs (e.g. possible time-horizons of EERs of weeks or months).

5. DISCUSSION

Spilling effects can be identified as leverage points for BPP (Biely, 2022; Noonan et al., 2013). However, policymakers must pay particular attention and also account for possible negative effects of spilling. Research indicates that the likelihood of EER uptake decreases when individuals previously engage in PEBs of lower complexity (Maki et al., 2019; Truelove et al., 2014). On the other hand, the likelihood of spilling increases when tasks share higher degrees of similarity (Maki et al., 2019; Truelove et al., 2014). In the context of EER, these findings could imply that homeowner involvement in home maintenance (similar but not necessarily PEB) could increase their likelihood of engaging in EER. However, incentivising people through policy to behave very environmentally conscious could counteract policies aimed at incentivising people to engage in EER. Furthermore, Kerr & Winskel (2020) point out that the scope of the public contribution remains uncertain and is dependent on political priorities and the attractiveness of EERs compared to other low-carbon transition options.

Table 1: Types of spilling effects in EER & influential factors
based on Dolan & Galizzi (2015), Dolšak (2023), Egner & Klöckner (2021), Krpan et al. (2019), Maki et al. (2019), Nilsson et al. (2017) and Truelove et al. (2014)

Spilling Effects in Relation to the Environment + : promoting – : permitting/purging	**Influential Factors** *exemplary excerpt*
Technical & Economic Environment	
+ / – Environment t_{-1} → EER t_0	*Energy prices, Fiscal support, Information, Infrastructure, Institutional framework, Policies and regulations, Retrofit costs, Time horizon*
Socio-Cultural Environment	
+ / – Environment t_{-1} → EER t_0 spatial / peer-effects	*Social norms, Status considerations*
+ / – EER t_0 → Environment t_{+1} spatial / peer-effects	
Individual Context	
+ / – Prior PEB t_{-1} → EER t_0 behavioural, contextual, (temporal)	*Attitudes, Awareness, Identity & Self-image, Intentions, Knowledge, Lifestyle, Preferences, Socio-demographics (e.g. age, education, gender, geographic location, household size, income, marriage status, presence of children), Values*
+ / – Prior LCB t_{-1} → EER t_0 behavioural, contextual, (temporal)	
+ / – EER t_0 → Following PEB t_{+1} behavioural, contextual, (temporal)	

These simple examples highlight the complexity of the topic at hand and the caution policymakers need, not only when designing policies using spilling effects, but when designing policies in general.

6. CONCLUSION

In the case of Dutch homeowner EERs, possibilities for different types of spilling effects can be identified. In this context, spilling could occur intra- and interpersonally and could be affected by other PEBs or even other life-changing events and behaviours. Furthermore, a

multitude of influential factors moderate these relationships and should act as a guideline when designing and evaluating policies, as they can provide key insight on whom, how, and what to design for. The proposed model provides possible directions for further research, as spilling effects in relation to EER are currently under-researched in the context of the Netherlands. As the model is based on international literature, it is yet to be determined which specific factors play what role in this relationship and to what extent. Furthermore, it is possible that not all types of spilling are present in every EER context (cf. second homes in Norway). Therefore, this study has certain limitations, due to its scope and methodology.
The study calls for a qualitative and quantitative exploration of the identified factors and interrelationships. It follows former scholars' calls for inter- & transdisciplinarity, especially when investigating highly complex topics like EER. Finally, it calls for a much needed refinement of the concept of spilling effects, as briefly attempted in this work.

7. REFERENCES

Baum, C. M., & Gross, C. (2017). Sustainability policy as if people mattered: Developing a framework for environmentally significant behavioral change. *Journal of Bioeconomics*, *19*(1), 53–95. https://doi.org/10.1007/s10818-016-9238-3

Biely, K. (2022). Guidance through the jungle of behavioral science theories, models, and concepts for non-behavioral scientists. *Urban, Planning and Transport Research*, *10*(1), 2145350. https://doi.org/10.1080/21650020.2022.2145350

Callahan, J. L. (2014). Writing Literature Reviews: A Reprise and Update. *Human Resource Development Review*, *13*(3), 271–275. https://doi.org/10.1177/1534484314536705

Dolan, P., & Galizzi, M. M. (2015). Like ripples on a pond: Behavioral spillovers and their implications for research and policy. *Journal of Economic Psychology*, *47*, 1–16. https://doi.org/10.1016/j.joep.2014.12.003

Dolšak, J. (2023). Determinants of energy efficient retrofits in residential sector: A comprehensive analysis. *Energy and Buildings*, *282*, 112801. https://doi.org/10.1016/j.enbuild.2023.112801

Ebrahimigharehbaghi, S., Filippidou, F., van den Brom, P., Qian, Q. k., & Visscher, H. J. (2019). Analysing the Energy Efficiency Renovation Rates in the Dutch Residential Sector. *E3S Web of Conferences*, *111*, 03019. https://doi.org/10.1051/e3sconf/201911103019

Ebrahimigharehbaghi, S., Qian, Q. K., de Vries, G., & Visscher, H. J. (2022). Municipal governance and energy retrofitting of owner-occupied homes in the Netherlands. *Energy and Buildings*, *274*, 112423. https://doi.org/10.1016/j.enbuild.2022.112423

Egner, L. E., & Klöckner, C. A. (2021). Temporal spillover of private housing energy retrofitting: Distribution of home energy retrofits and implications for subsidy policies. *Energy Policy*, *157*, 112451. https://doi.org/10.1016/j.enpol.2021.112451

European Commission. (2019). *The European Green Deal* (COM(2019) 640 final). European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1576150542719&uri=COM%3A2019%3A640%3AFIN

European Commission. (2020). *The European Green Deal—Renovation Wave*. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/FS_20_1844

European Commission. Directorate General for Energy., ICF International., Hinicio., & CE Delft. (2014). *Financing the energy renovation of buildings with Cohesion Policy funding: Technical guidance: final report.* Publications Office. https://data.europa.eu/doi/10.2833/18766

Filippidou, F., Nieboer, N., & Visscher, H. (2017). Are we moving fast enough? The energy renovation rate of the Dutch non-profit housing using the national energy labelling database. *Energy Policy*, *109*, 488–498. https://doi.org/10.1016/j.enpol.2017.07.025

Günther, H. (2009). The environmental psychology of research. *Journal of Environmental Psychology*, *29*(3), 358–365. https://doi.org/10.1016/j.jenvp.2009.02.004

Hallsworth, M. (2023). A manifesto for applying behavioural science. *Nature Human Behaviour*, *7*(3), 310–322. https://doi.org/10.1038/s41562-023-01555-3

Irwin, N. B. (2021). Sunny days: Spatial spillovers in photovoltaic system adoptions. *Energy Policy*, *151*, 112192. https://doi.org/10.1016/j.enpol.2021.112192

Kaaronen, R. O. (2017). Affording Sustainability: Adopting a Theory of Affordances as a Guiding Heuristic for Environmental Policy. *Frontiers in Psychology*, *8*, 1974. https://doi.org/10.3389/fpsyg.2017.01974

Kaufman, S., Saeri, A., Raven, R., Malekpour, S., & Smith, L. (2021). Behaviour in sustainability transitions: A mixed methods literature review. *Environmental Innovation and Societal Transitions*, *40*, 586–608. https://doi.org/10.1016/j.eist.2021.10.010

Kerr, N., & Winskel, M. (2020). Household investment in home energy retrofit: A review of the evidence on effective public policy design for privately owned homes. *Renewable and Sustainable Energy Reviews*, *123*, 109778. https://doi.org/10.1016/j.rser.2020.109778

Krpan, D., Galizzi, M. M., & Dolan, P. (2019). Looking at Spillovers in the Mirror: Making a Case for “Behavioral Spillunders”. *Frontiers in Psychology*, *10*, 1142. https://doi.org/10.3389/fpsyg.2019.01142

Maki, A., Carrico, A. R., Raimi, K. T., Truelove, H. B., Araujo, B., & Yeung, K. L. (2019). Meta-analysis of pro-environmental behaviour spillover. *Nature Sustainability*, *2*(4), 307–315. https://doi.org/10.1038/s41893-019-0263-9

Mundaca, L., & Samahita, M. (2020). What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden. *Energy Research & Social Science*, *60*, 101319. https://doi.org/10.1016/j.erss.2019.101319

Nilsson, A., Bergquist, M., & Schultz, W. P. (2017). Spillover effects in environmental behaviors, across time and context: A review and research agenda. *Environmental Education Research*, *23*(4), 573–589. https://doi.org/10.1080/13504622.2016.1250148

Noonan, D. S., Hsieh, L.-H. C., & Matisoff, D. (2013). Spatial Effects in Energy-Efficient Residential HVAC Technology Adoption. *Environment and Behavior*, *45*(4), 476–503. https://doi.org/10.1177/0013916511421664

Qiu, Y., Colson, G., & Grebitus, C. (2014). Risk preferences and purchase of energy-efficient technologies in the residential sector. *Ecological Economics*, *107*, 216–229.

https://doi.org/10.1016/j.ecolecon.2014.09.002
Rijksoverheid. (2019). *National Climate Agreement of the Netherlands* (p. 247). Rijksoverheid. https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands
Seebauer, S. (2018). The psychology of rebound effects: Explaining energy efficiency rebound behaviours with electric vehicles and building insulation in Austria. *Energy Research & Social Science*, *46*, 311–320. https://doi.org/10.1016/j.erss.2018.08.006
Serra-Coch, G., Wyss, R., & Binder, C. R. (2023). Geographic network effects to engage people in the energy transition: The case of PV in Switzerland. *Heliyon*, *9*(7), e17800. https://doi.org/10.1016/j.heliyon.2023.e17800
Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039
Sun, K., & Hong, T. (2017). A framework for quantifying the impact of occupant behavior on energy savings of energy conservation measures. *Energy and Buildings*, *146*, 383–396. https://doi.org/10.1016/j.enbuild.2017.04.065
Tian, H., & Liu, X. (2022). Pro-Environmental Behavior Research: Theoretical Progress and Future Directions. *International Journal of Environmental Research and Public Health*, *19*(11), 6721. https://doi.org/10.3390/ijerph19116721
Torraco, R. J. (2005). Writing Integrative Literature Reviews: Guidelines and Examples. *Human Resource Development Review*, *4*(3), 356–367. https://doi.org/10.1177/1534484305278283
Truelove, H. B., Carrico, A. R., Weber, E. U., Raimi, K. T., & Vandenbergh, M. P. (2014). Positive and negative spillover of pro-environmental behavior: An integrative review and theoretical framework. *Global Environmental Change*, *29*, 127–138. https://doi.org/10.1016/j.gloenvcha.2014.09.004
United Nations. (2015). *Paris Agreement* (p. 27). United Nations. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
Wilson, C., Pettifor, H., & Chryssochoidis, G. (2018). Quantitative modelling of why and how homeowners decide to renovate energy efficiently. *Applied Energy*, *212*, 1333–1344. https://doi.org/10.1016/j.apenergy.2017.11.099
Ye, J., Yao, Y., & Li, L. (2022). The more involved, the more willing to participate: An analysis of the internal mechanism of positive spillover effects of pro-environmental behaviors. *Journal of Cleaner Production*, *375*, 133959. https://doi.org/10.1016/j.jclepro.2022.133959

RENOVATE FOR TOMORROW: EXPLORING BARRIERS AND DRIVERS FOR DIFFERENT TYPES OF ENERGY-EFFICIENT RENOVATIONS

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Abstract *In Flanders, 23,3% of the housing stock is in a moderate to bad condition and needs to be renovated to meet the energy efficiency requirements stipulated in the Renovation Pact by 2050. However, since 72% of Flemish households own their home, the Flemish government must fall back on houseowners' motivation to improve their houses' energy efficiency. Depending on the type of energy-efficient renovation, other barriers and facilitators are at play that motivate (or prevent) a homeowner to take action. This research explores the relevant barriers and facilitators for three types of energy-efficient renovations. We conducted a survey among 603 homeowners with the intention to renovate (i.e. people planning to perform a renovation within the next 3 years), assessing 19 barriers and 13 facilitators in relation to three renovation categories: (1) insulation improvements, (2) energy efficiency installations, and (3) extensions of the home. We conducted a series of one-way ANOVAs to assess how barriers and facilitators differ between the three renovation categories. Our results show that some barriers and facilitators are universal across all three types of renovations (e.g., the prospect of more comfort), whereas others come into play for a particular renovation category (e.g., the driver 'this type of renovation reduces my energy costs' is more important for energy efficiency and insulation renovations than for extension renovations). Policy recommendations are provided to increase the motivation of renovators considering specific energy efficiency renovation categories.*

1. INTRODUCTION

Climate scientists across the world agree that a reduction in greenhouse gas emissions (GHGE) is indispensable to reduce global warming (Pörtner et al., 2023). One of the major sources responsible for GHGE is the energy use in buildings (through the emission of CO_2). Indeed, buildings are responsible for 25% of GHGE globally and for 36% in Europe (Artola et al., 2016; International Energy Agency, 2019). To combat a further increase in GHGE, Europe is drafting legislations and policies such as the Energy Performance of Buildings Directive (2010) and the Energy Efficiency Directive (2012). In Belgium specifically, the Flemish Climate Strategy aims to reduce the GHGE of the residential housing stock by 75% by 2050. Therefore, the Flemish Government set a long-term goal with the Renovation Pact aiming to upgrade the Flemish housing market to energy label A by 2050 (Vlaanderen, 2022). As a result, there is a renovation obligation for houses with an energy label D or worse.

However, to reach its renovation goals, the Flemish government is highly dependent on the motivation of individual homeowners, as environmental changes are often related to the behaviour of people (Nielsen, 2017). Currently, 72% of Flemish households own their dwelling (Statistiek Vlaanderen, 2019), while only 14% of single-family homes have an energy label of B or higher (A, A+), and 65% of single-family homes and 29% of apartments have an energy label D or lower (Statistiek Vlaanderen, 2023). Thus, there is a substantial group in Flanders with energy-efficient renovation (EER) potential.

Subsequently, understanding what drives or hinders homeowners in their decision to undertake an EER has been a prominent topic in recent literature (Broers et al., 2019; Du et al., 2022; Ebrahimigharehbaghi et al., 2019; Klöckner & Nayum, 2016). However, the majority of research either treats EERs as an overarching category or focuses on one specific type of EER (e.g., insulation of walls), without considering heterogeneity in facilitators and barriers between different types of EER. Moreover, to our knowledge, no similar studies have been conducted in the context of Flanders. The aim of this study is to gain knowledge of the facilitators and barriers that boost or impede EERs and to identify differences in barriers and facilitators for three specific categories of EER, i.e., insulation renovations, energy renovations and extension renovations.

2. LITERATURE AND RESEARCH FRAMEWORK

To make a selection of relevant barriers and facilitators of energy-efficiency renovations, we conducted an exploratory literature review. We were able to group the most commonly identified facilitators and barriers into three main themes of commonly identified facilitators and six main themes of commonly identified barriers.

For the facilitators we found the following themes: firstly, enhancing life quality (1) considers repairing or replacing equipment and thereby increasing comfort (Azizi et al., 2019; Du et al., 2022; Ebrahimigharehbaghi et al., 2019; Pérez-Navarro et al., 2023). Economic benefits (2) relate to increasing the market value of one's home or reducing costs e.g., by lowering energy bills (Azizi et al., 2020; Du et al., 2022; Ebrahimigharehbaghi et al., 2019; Pérez-Navarro et al., 2023), and preserving the environment (3) alludes to a person's attitude towards the environment and motivation to act in a sustainable manner (Du et al., 2022;

Ebrahimigharehbaghi et al., 2019). For the barriers, we identified the following themes: first of all, informational barriers (1) relate to the reliability, comprehensiveness and trustworthiness of information on EERs (Azizi et al., 2019; Du et al., 2022; Ebrahimigharehbaghi et al., 2019), while financial barriers (2) relate to the uncertainties of return on investment, cost-effectiveness and access to capital (Azizi et al., 2019; Du et al., 2022; Ebrahimigharehbaghi et al., 2019). Barriers related to inconvenience to routine (3) include the hassle of dirt, stress, and having other priorities (Azizi et al., 2019; Ebrahimigharehbaghi et al., 2019), while social barriers (4) are linked to e.g., a lack of support from family or friends (Ebrahimigharehbaghi et al., 2019). Lastly, institutional barriers (5) relate to building protection regulations and a lack of incentives or standards (Ebrahimigharehbaghi et al., 2019; Hesselink & Chappin, 2019), and technical barriers (6) refer to the limitations of dwellings or technological systems (Broers et al., 2019; Du et al., 2022).

To our knowledge, there is no study that covers all categories presented in this literature overview, nor takes into account the particularity of the Flemish context and the heterogeneity across different renovation categories. Since the study of Klöckner & Nayum (2017) on upgrading the energy standard of homes in Norway is the most comprehensive study to date, their list of 14 barriers and 10 facilitators serves as the basis for our study. Additionally, we extended this list with three facilitators and five barriers, which were uncovered in our literature review after the study by Klöckner & Nayum (2017).

Firstly, recent research on barriers shows that people who struggle with the maturity of technologies or struggle to adopt novel technologies, are less likely to install that technology (Azizi et al., 2019; Broers et al., 2019). Thus, we added two barriers, being '*the technology available for this type of renovation has yet to improve*' and '*starting to use energy efficient technologies is not that important to me*'. Subsequently, we found that people are often not aware of or have little interest in what causes energy loss in their home. Indeed, literature identifies unawareness of energy consumption as another barrier for energy renovations (Du et al., 2022; Pelenur, 2018). Therefore, we formulated two barriers: '*I don't really know how much energy I use*' and '*I don't really care how much energy I use'*. Lastly, as identified in the six main themes of barriers, structural limitations of the property can prevent people from starting an EER (Broers et al., 2019; Du et al., 2022). Thus, we formulate a fifth additional barrier: '*technical limitations of my home make it difficult to implement energy efficiency measures*'.

In terms of facilitators, our exploratory literature review showed that environmental concern could motivate people to undertake a renovation (Azizi et al., 2019; Du et al., 2022; Ebrahimigharehbaghi et al., 2019). Thus, an additional facilitator for environmental concern was added: '*this type of renovation reduces my carbon footprint*'. Additionally, social pressure and social norms were also identified as a possible driver for EERs (Du et al., 2022; Ebrahimigharehbaghi et al., 2019; Schleich et al., 2019). Thus, a second facilitator was added: '*I try to renovate as much as people in my neighbourhood*'. Lastly, Azizi et al. (2019, 2020) found that being interested in energy efficiency and technological novelties also motivates end-users to undertake an EER, resulting in a third facilitator: '*I am interested in energy-efficiency renovations'*. A complete overview of the 19 barriers and 13 facilitators is presented in Table 5 and Table 6.

3. METHODS

3.1 Procedure and measures

An online survey was administered among a total of 603 Dutch-speaking participants living in Flanders, the northern part of Belgium. Participants were recruited in March 2023. The survey consisted of three major themes: (1) person-related aspects (sociodemographic characteristics, user-building interactions), (2) contextual aspects (location, dwelling type) and (3) facilitators and barriers for energy-efficient renovations. Three types of energy-efficient renovations were included, namely (1) insulation renovations, (2) energy renovations and (3) extension renovations.
In the original study, we distinguished between renovators and non-renovators by asking participants to indicate whether 'I intend to carry out one or more renovations within three years (between 2023 and 2026)'. All persons who answered 'Agree' or 'Fully agree' were categorized as renovators, with the remaining participants being categorized as non-renovators. Given space limits within this paper, we only focus on the renovators for this study. Additionally, a filter was applied asking whether participants own or rent their dwelling. Only participants who own a dwelling (that they live in or sublet) were kept for the entirety of the survey.
Subsequently, participants that were identified as renovators had to select the types of renovations they intend to perform from a list of nine types of renovations. These nine types were divided into three renovation categories, which can be found in Table 1. Then, all participants were presented with a list of barriers and facilitators related to a selected renovation category. Participants were asked to indicate their level of agreement with the respective barrier or facilitator on a Likert scale (ranging from 1 'Strongly disagree' to 5 'Strongly agree'). A full list of all barriers and facilitators can be found in Table 5 and Table 6. Lastly, sociodemographic variables were gathered, i.e., gender, year of birth, education and occupation.

Renovation category	Renovation type
1. Insulation renovations	a. Additional quick post-insulation such as cavity wall, cellar ceiling or attic floor insulation
	b. Larger works such as exterior or interior insulation (façade insulation)
	c. Installing new windows (high-performance glass)
2. Energy renovations	a. Replacement heat delivery system (radiators, convectors, underfloor heating …)
	b. Replacement heat source (fuel oil boiler, gas boiler, heat pump, solar boiler ...)
	c. Installing a ventilation system
	d. Installation of solar panels and/or solar collectors
3. Extension renovation	a. Extension of the house (for example at the back or by placing an extra floor)
	b. Thorough reorganization of interior spaces, including making attics habitable

Table 1: Renovation categories and types

3.2 Sample

The survey was started by 2178 respondents, with 1065 respondents completing the survey and fulfilling all quality criteria (i.e., agreed informed consent, owner of a dwelling, correct quality control questions, quota of max. 60% renovators). As noted earlier, for this study we only withheld homeowners with an intention to renovate, resulting in a final sample of 603 participants. An overview of distributions per renovation category of our final sample can be found in Table 2.

Renovation category	Frequency	Percent
Insulation	224	37.15%
EE installation	292	48.42%
Extension	87	14.43%

Table 2: Frequencies for renovation categories (*n*=603)

3.3 Analysis strategy

To assess differences between barriers and facilitators on the level of renovation categories, a series of one-way ANOVAs was performed with the barriers and facilitators as dependent variables using the three renovation categories as fixed factors. Tukey post hoc tests were performed to identify which categories differed significantly from one another. Given the sufficiently large size of our sample, we set our level of statistical significance at $p < 0.01$.

4. RESULTS

4.1 Preliminary analysis and sample description

Variable	Category	*n* (total *n*=1065)	Percent
Age	Mean = 44.39, Median = 44		
Gender			
	Male	263	43.62%
	Female	339	56.30%
Education			
	Lower secondary education or lower	63	10.45%
	Higher secondary education	224	37.15%
	Bachelor	203	33.66%
	Master or higher	113	18.74%
Occupation			
	Fulltime employee	356	59.04%
	Parttime employee	68	11.28%
	Student/intern	27	4.48%
	Incapacitated	19	3.15%
	Retired	71	11.77%
	Other	62	10.28%

Table 3: Sociodemographic variables, i.e., age, gender, education, occupation

The final sample of our study, as can be seen in Table 3, consists of a larger share of women (56.30%) than men (43.62%). Nearly half the sample has obtained higher secondary education, and more than 30% has obtained a bachelor's degree or equivalent. A large share (70.32%) of our sample is a fulltime or parttime employee.

Looking at the mean values of all facilitators and barriers, as shown in Table 4, it can be noted that the facilitators structurally score higher than the barriers for all renovation categories, with insulation having the highest facilitators' mean value. One-way ANOVAs were conducted to compare the mean value scores of facilitators and barriers between renovation categories. The facilitators are scored significantly different depending on the considered renovation category ($F(2, 600) = 19.724$, $p < 0.01$). A Tukey post hoc test revealed that the mean value of facilitators in the insulation category ($M = 3.671$, $SD = 0.484$) is significantly higher than the mean value of facilitators in the energy efficiency ($M = 3.515$, $SD = 0.437$) and extension ($M = 3.312$, $SD = 0.494$) category.

Category	**Mean value barriers**	**Mean value facilitators**
Energy-efficiency	2.299	3.515
Insulation	2.407	3.671
Extension	2.494	3.312

Table 4: Mean scores of facilitators and barriers per renovation category

In general, the highest rated facilitators are mostly linked to economic benefits and quality of life. The top two facilitators, i.e., '*this type of renovation increases the market value of my home*' and '*this type of renovation reduces my energy cost'*, both relate to gaining financial benefits, either through increasing the value of the home (with the aim of selling the home in the future) or reducing the financial costs of energy consumption through home optimisation. Additionally, two of the top five facilitators relate to the quality of life within the home, i.e., '*this type of renovation makes my house more pleasant to live in*' and '*this type of renovation offers more comfort*'. Thus, renovators across the three renovation categories are generally motivated by the prospect of improving their daily comfort and the domesticity of their homes. In terms of barriers, the top five relates mostly to a sense of uncertainty. '*The right time to do this type of renovation is yet to come'* embodies uncertainty about timing, while '*I am unsure about the savings in energy costs after this type of renovation'* and '*it's hard to know if I can trust the information I find about this type of information'* are related to uncertainty about the return of investments and the trustworthiness of information on EERs. In addition, the high ranking of '*the technology available for this type of renovation has yet to improve*' confirms that technological maturity is a barrier for people when deciding to renovate. Lastly, '*this type of renovation requires a lot of supervision from contractors'* also scores quite high, showing that disturbance of the daily routine is a considerable impediment.

	Facilitator Description	**Mean value**	**Source**
fac_2	This type of renovation increases the market value of my home	4.023	Klöckner & Nayum
fac_1	This type of renovation reduces my energy costs	3.934	Klöckner & Nayum
fac_13	I am interested in energy efficient renovations	3.927	New
fac_6	This type of renovation makes my house more pleasant to live in	3.851	Klöckner & Nayum
fac_7	This type of renovation offers more comfort	3.765	Klöckner & Nayum
fac_11	This type of renovation reduces my carbon footprint	3.741	New
fac_3	The investment in this type of renovation pays for itself within a reasonable time	3.493	Klöckner & Nayum

fac_8	I can quickly and easily find information about the practical approach to this type of renovation	3.444	Klöckner & Nayum
fac_4	This type of renovation has positive health effects	3.415	Klöckner & Nayum
fac_10	Subsidies are available for this type of renovation	3.380	Klöckner & Nayum
fac_9	I trust the information about this type of renovation that I get from officials	3.373	Klöckner & Nayum
fac_5	My current insulation is not energy efficient	3.090	Klöckner & Nayum
fac_12	I try to renovate as much as people in my neighborhood	2.632	New

Table 5: Overview of facilitators, ranking based on mean values for all renovation categories

	Barrier Description	**Mean value**	**Source**
bar_5	The right time to do this type of renovation is yet to come	3.083	Klöckner & Nayum
bar_1	I am unsure about the savings in energy costs after this type of renovation	2.829	Klöckner & Nayum
bar_15	The technology available for this type of renovation has yet to improve	2.803	New
bar_13	This type of renovation requires a lot of supervision from contractors	2.801	Klöckner & Nayum
bar_10	It's hard to know if I can trust the information I find about this type of renovation	2.771	Klöckner & Nayum
bar_11	This type of renovation causes a lot of distractions in my life (e.g. dirt)	2.763	Klöckner & Nayum
bar_7	There are no financial resources (savings or loan) available to carry out this type of renovation	2.721	Klöckner & Nayum
bar_18	Technical limitations of my home make it difficult to implement energy efficiency measures	2.624	New
bar_3	I can't decide which type of energy efficient renovation to do first	2.602	Klöckner & Nayum
bar_12	It is difficult to find relevant information about this type of renovation	2.519	Klöckner & Nayum
bar_16	I don't really know how much energy I use	2.426	New
bar_17	Starting to use energy efficient technologies is not that important to me	2.307	New
bar_8	Contractors who could carry out this type of renovation are inexperienced or incompetent (lack of knowledge)	2.244	Klöckner & Nayum
bar_14	I have previous negative experiences with this type of renovation	2.113	Klöckner & Nayum
bar_19	I don't really care how much energy I use	1.798	New
bar_9	I depend on approval from my neighbors to do this type of renovation	1.793	Klöckner & Nayum
bar_6	Monument preservation guidelines prevent me from doing this type of renovation	1.662	Klöckner & Nayum
bar_2	I plan to move to another place soon, so there is no point in renovating my current home	1.604	Klöckner & Nayum
bar_4	I do not own the property, so I will not invest in this type of renovation	1.514	Klöckner & Nayum

Table 6: Overview of barriers, ranking based on mean values for all renovation categories

4.2 Differences in barriers and facilitators across renovation categories

To assess differences between barriers and facilitators across the three different renovation categories, a series of one-way ANOVAs was performed. The results, as can be seen in Table 7, show both the *F*-value and the *p*-value. We only report the statistically significant facilitators and barriers ($p < 0.01$).

	Variable description	***M(SD)*** **energy-efficiency**	***M(SD)*** **extension**	***M(SD)*** **insulation**	***F*** **Score (2, 600)**	***p*** **value**
fac_1	This type of renovation reduces my energy costs	4.021(0.812)	3.069(1.139)	4.156(0.744)	55.049	< 0.01
fac_11[1]	This type of renovation reduces my carbon footprint	3.808(0.856)	3.080(0.955)	3.911(0.826)	30.905	< 0.01
fac_5	My current insulation is not energy efficient	2.897(1.037)	2.655(1.170)	3.509(1.016)	30.251	< 0.01
fac_6	This type of renovation makes my house more pleasant to live in	3.599(0.878)	4.299(0.749)	4.004(0.801)	29.774	< 0.01
fac_10	Subsidies are available for this type of renovation	3.404(1.006)	2.724(1.042)	3.603(0.857)	26.410	< 0.01
bar_11	This type of renovation causes a lot of distractions in my life (e.g. dirt)	2.490(1.053)	3.207(1.069)	2.946(1.147)	19.515	< 0.01
fac_7	This type of renovation offers more comfort	3.568(0.865)	4.138(0.702)	3.875(0.880)	18.095	< 0.01
fac_3	The investment in this type of renovation pays for itself within a reasonable time	3.599(0.893)	3.080(1.014)	3.513(0.888)	10.996	< 0.01
bar_9	I depend on approval from my neighbours to do this type of renovation	1.682(0.955)	2.126(1.159)	1.808(1.126)	6.035	< 0.01
bar_17	Starting to use energy efficient technologies is not that important to me	2.229(0.930)	2.632(1.080)	2.281(0.955)	6.001	< 0.01
bar_5	The right time to do this type of renovation is yet to come	2.925(1.081)	3.195(1.150)	3.246(1.095)	5.962	< 0.01

Table 7: Statistical differences for barriers/facilitators across all renovation categories (One-way ANOVAs, threshold of statistical significance: $p < 0.01$)

Generally, it is notable that only four out of 19 barriers differ significantly between renovation categories, while seven out of 13 facilitators differ significantly between renovation categories. Thus, the majority of barriers are similar across renovation categories, while the majority of facilitators are of greater or lesser importance depending on the renovation category.

For the insulation category, we find that five of the seven significant facilitators have the highest score in this category. Interestingly, these facilitators are either linked to financial concerns (‘*this type of renovation reduces my energy costs*’ and ‘*subsidies are available for this type of renovation*’), environmental concerns (‘*this type of renovation reduces my carbon footprint’* and ‘*my current insulation is not energy efficient*), and an improvement of the quality of life (‘*this type of renovation offers more comfort’*). Moreover, most significant differences exist between the insulation category and the extension category, whereby facilitators in the insulation category have significantly higher scores than in the extension category. This is the case for ‘*this type of renovation reduces my energy costs*’, ‘*subsidies are available for this type of renovation*’, ‘*this type of renovation reduces my carbon footprint*’, ‘*my current insulation is not energy efficient*’ and ‘*the investment in this type of renovation pays for itself within a reasonable time*’. The barrier with the highest score in the insulation category is ‘*the right time for this type of renovation is yet to come*’, with a significantly higher score compared to the energy-efficiency category.

When looking at the extension category, we see that two of the statistically significant different facilitators score the highest in the extension category. They score significantly higher than the energy-efficiency category, and are related to improving the quality of life (‘*this type of renovation makes my house more pleasant to live in*’ and ‘*this type of renovation offers more comfort*’). In terms of barriers, three of the significantly different barriers score the highest in the extension category and also score significantly higher than the energy-efficiency category, i.e., ‘*starting to use energy efficient technologies is not that important to me*’, ‘*this type of renovation causes a lot of distractions in my life*’ and ‘*I depend on approval from my neighbours to do this type of renovation*’.

Lastly, for the energy-efficiency category, we note that four of the statistically significant different facilitators scores significantly higher in this category compared to the extension category, and are mostly linked to financial or environmental concerns (‘*this type of renovation reduces my energy costs*’, ‘*this type of renovation reduces my carbon footprint*’, ‘*subsidies are available for this type of renovation*’ and ‘*the investment in this type of renovation pays for itself within a reasonable time*’). For three of the statistically significant different facilitators, the energy-efficiency category scores significantly lower than insulation, i.e., ‘*My current insulation is not energy efficient*’, ‘*this type of renovation makes my house more pleasant to live in*’ and ‘*this type of renovation offers more comfort*’, which are all related to improving the quality of life. In terms of barriers, ‘*this type of renovation causes a lot of distractions in my life*’ scores significantly lower here compared to the other two renovation categories.

5 DISCUSSION AND CONCLUSION

The goal of this study was to identify and understand the differences in barriers and facilitators in three renovation categories. Before elaborating on the results, there are some limitations to address. First, due to space limitations, we solely focused on people categorized as renovators in this study. However, our complete sample also included non-renovators. Including these in our analyses might provide a more nuanced and comprehensive understanding. Moreover, in this study renovating was treated as a one-time decision, while the decision process often comprises different stages and is not necessarily linear (Klöckner & Nayum, 2016). Therefore, iterating this study with a stage model might give us more insights in which barriers and facilitators apply to different stages in the decision-making process. Additionally, our model considered an individual’s decision, disregarding the shared practices of life at home, which might influence decision-making (Wilson et al., 2015). Lastly, because of limitations in the initial setup of this study, we are unable to regress facilitators and barriers on an outcome variable measuring intent, and thus cannot provide any conclusions on how predictive barriers and facilitators are for the intention to renovate.

Of the newly added barriers and facilitators, we see that only '*this type of renovation reduces my carbon footprint*' significantly differs between categories. Surprisingly, the social influence facilitator was the lowest scoring facilitator. Earlier research in the context of Flanders showed that social relationships were significant barriers to perform an energy-efficient renovation or build a zero-energy dwelling (Camarasa et al., 2021; Souaid et al., 2020). However, social influence seems to not be present as a driver of energy-efficient renovations.

When looking at which themes are most prevalent in the highest-rated facilitators and barriers, it is clear that renovators are mainly motivated by financial facilitators and by facilitators related to improving their quality of life, which is in line with earlier research (Broers et al., 2019; Du et al., 2022; Ebrahimigharehbaghi et al., 2019). In terms of high-rated barriers, renovators are discouraged by uncertainty on the financial, time-related and informational level, as well as by practical impediments (e.g., the impact of hassle on daily life and technical limitations).

When looking at the differences between the three categories, we see that generally, for the barriers, there are only four barriers with differences between the renovation categories, of which 3 have a relatively low F-score, indicating that the reasons to not renovate transcend the specific renovation categories. Thus, when addressing potential renovators, for most barriers it seems superfluous to develop different communication strategies depending on the renovation category.

Most facilitators linked to financial concerns score significantly higher in the insulation and the energy-efficiency category. The higher scores of availability of subsidies for insulation and energy-efficiency renovations might be explained by the fact that there are primarily subsidies and support measures available for renovations such as the installation of renewable energy systems or insulation improvements (Vlaanderen, 2023). Similarly, the higher scores of returns of investment for the insulation and energy-efficiency category could be attributed to the tangibility of reducing your energy costs and a return of investment through improving your insulation or becoming more energy-independent by installing e.g., PV panels.

Additionally, the energy-efficiency and insulation category score significantly higher on environmental concerns compared to the extension category, suggesting that energy efficiency and insulation renovations are performed with a certain environmental awareness that is not as present for extension renovations. Thus, policy makers could use both the impact on the financial situation as well as the environment as leverage to convince potential renovators.

Lastly, insulation and extension score significantly higher than the extension category for the facilitators related to improving the quality of life. This might be explained by the fact that the goal of insulation is to better regulate the flow of heat and coolness in one's home, which can be associated with an improvement in comfort and a more pleasant living experience. Moreover, extension renovations often result in a bigger living space, which is correlated with a higher level of perceived comfort during relaxation at home (Torresin et al., 2022). Hence, when targeting potential insulation or extension renovators, it might be productive to focus on the increase in the quality of life in the home.

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BIBLIOGRAPHY

Artola, I., Rademaekers, K., Williams, R., & Yearwood, J. (2016). *Boosting Building Renovation: What potential and value for Europe?* https://www.europarl.europa.eu/RegData/etudes/STUD/2016/587326/IPOL_STU%28 2016%29587326_EN.pdf

Azizi, S., Nair, G., & Olofsson, T. (2019). Analysing the house-owners' perceptions on benefits and barriers of energy renovation in Swedish single-family houses. *Energy and Buildings*, *198*, 187-196. https://doi.org/10.1016/j.enbuild.2019.05.034

Azizi, S., Nair, G., & Olofsson, T. (2020). Adoption of Energy Efficiency Measures in Renovation of Single-Family Houses: A Comparative Approach. *Energies*, *13*(22), 6042. https://doi.org/10.3390/en13226042

Broers, W. M. H., Vasseur, V., Kemp, R., Abujidi, N., & Vroon, Z. A. E. P. (2019). Decided or divided? An empirical analysis of the decision-making process of Dutch homeowners for energy renovation measures. *Energy Research & Social Science*, *58*, 101284. https://doi.org/10.1016/j.erss.2019.101284

Camarasa, C., Kalahasthi, L. K., & Rosado, L. (2021). Drivers and barriers to energy-efficient technologies (EETs) in EU residential buildings. *Energy and Built Environment*, *2*(3), 290-301. https://doi.org/10.1016/j.enbenv.2020.08.002

Du, H., Han, Q., & De Vries, B. (2022). Modelling energy-efficient renovation adoption and diffusion process for households: A review and a way forward. *Sustainable Cities and Society*, *77*, 103560. https://doi.org/10.1016/j.scs.2021.103560

Ebrahimigharehbaghi, S., Qian, Q. K., Meijer, F. M., & Visscher, H. J. (2019). Unravelling Dutch homeowners' behaviour towards energy efficiency renovations: What drives and hinders their decision-making? *Energy Policy*, *129*, 546-561. https://doi.org/10.1016/j.enpol.2019.02.046

Hesselink, L. X. W., & Chappin, E. J. L. (2019). Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies. *Renewable and Sustainable Energy Reviews*, *99*, 29-41. https://doi.org/10.1016/j.rser.2018.09.031

International Energy Agency. (2019). *Global Status Report for Buildings and Construction*.

Klöckner, C. A., & Nayum, A. (2016). Specific Barriers and Drivers in Different Stages of Decision-Making about Energy Efficiency Upgrades in Private Homes. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01362

Klöckner, C. A., & Nayum, A. (2017). Psychological and structural facilitators and barriers to energy upgrades of the privately owned building stock. *Energy*, *140*, 1005-1017. https://doi.org/10.1016/j.energy.2017.09.016

Nielsen, K. S. (2017). From prediction to process: A self-regulation account of environmental behavior change. *Journal of Environmental Psychology*, *51*, 189-198. https://doi.org/10.1016/j.jenvp.2017.04.002

Pelenur, M. (2018). Household energy use: A study investigating viewpoints towards energy efficiency technologies and behaviour. *Energy Efficiency*, *11*(7), 1825-1846. https://doi.org/10.1007/s12053-018-9624-x

Pérez-Navarro, J., Bueso, M. C., & Vázquez, G. (2023). Drivers of and Barriers to Energy Renovation in Residential Buildings in Spain—The Challenge of Next Generation EU Funds for Existing Buildings. *Buildings*, *13*(7), 1817. https://doi.org/10.3390/buildings13071817

Pörtner, H.-O., Roberts, D. C., Poloczanska, E. S., Mintenbeck, KK., Tignor, M., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., & Okem, A. (2023). Summary for Policymakers. In *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1ste dr.). Cambridge University Press. https://doi.org/10.1017/9781009325844

Schleich, J., Gassmann, X., Meissner, T., & Faure, C. (2019). A large-scale test of the effects of time discounting, risk aversion, loss aversion, and present bias on household adoption of energy-efficient technologies. *Energy Economics*, *80*, 377-393. https://doi.org/10.1016/j.eneco.2018.12.018

Souaid, C., Van Der Heijden, H. M. H., & Elsinga, M. G. (2020). Barriers and drivers to the uptake of innovative, affordable, and zero-energy dwellings in Belgium and Ireland. *IOP Conference Series: Earth and Environmental Science*, *588*(3), 032017. https://doi.org/10.1088/1755-1315/588/3/032017

Statistiek Vlaanderen. (2019). Eigendomsstatuut. *Statistiek Vlaanderen*. https://www.vlaanderen.be/statistiek-vlaanderen/bouwen-en-wonen/eigendomsstatuut#72percent-eigenaar-van-hun-woning

Statistiek Vlaanderen. (2023). Energiescore van bestaande woningen. *Statistiek Vlaanderen*. https://www.vlaanderen.be/statistiek-vlaanderen/energie/energiescore-van-bestaande-woningen

Torresin, S., Albatici, R., Aletta, F., Babich, F., Oberman, T., Stawinoga, A. E., & Kang, J. (2022). Indoor soundscapes at home during the COVID-19 lockdown in London – Part II: A structural equation model for comfort, content, and well-being. *Applied Acoustics*, *185*, 108379. https://doi.org/10.1016/j.apacoust.2021.108379

Vlaanderen. (2022). Renovatieverplichting voor residentiële gebouwen. *Vlaanderen*. https://www.vlaanderen.be/een-woning-kopen/renovatieverplichting-voor-residentiele-gebouwen

Vlaanderen. (2023). Premies voor Renovatie. *Vlaanderen.be*. https://www.vlaanderen.be/premies-voor-renovatie

Wilson, C., Crane, L., & Chryssochoidis, G. (2015). Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research & Social Science*, *7*, 12-22. https://doi.org/10.1016/j.erss.2015.03.002

Exploring Determinants of Reducing Heating-Related Energy Consumption: Evidence from Five European Countries

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Abstract

Efforts to reduce heating-related energy consumption have great potential for overall energy reduction, especially considering the significant contribution of heating to energy usage in Europe. This study examines the factors influencing people's intention to decrease energy usage and involved 363 participants, who were part of a larger European project focused on promoting energy reduction. This article presents a smaller-scale model tested among individuals from Belgium (n = 58), Croatia (n = 82), Germany (n = 105), Greece (n = 33), and Portugal (n = 85). We applied three robust theoretical frameworks: the Theory of Planned Behaviour, the Value Belief Norm theory, and the Prototype Willingness Model. To ensure construct validity, we conducted a confirmatory factor analysis, followed by a structural equation model. Our findings show that perceived behavioural control, subjective norms, and attitudes (part of Theory of Planned Behaviour) significantly predict the intent to reduce energy consumption. Additionally, personal moral norms (from the Value Belief Norm Theory) and willingness (from the Prototype Willingness Model) play important roles in explaining the intention to reduce consumption. Our results highlight the practical importance of individuals' perceived ability and their personal moral beliefs to reduce consumption, while positive role models can positively impact willingness to change one's consumption behaviour.

Keywords: energy efficiency, behaviour, behavioural modelling

1. INTRODUCTION AND THEORETHICAL BACKGROUND

Across Europe, heating forms the single highest share of energy consumption at an average of 63%, with Malta's share at 18% and Luxembourg at 82% (Eurostat, 2021). More generally, homes contribute significantly to greenhouse gas emissions, responsible for 20% in the US and 25% in the EU (Goldstein et al., 2020; Jakučionytė-Skodienė et al., 2022), with research by Costa et al. (2013) also estimating that residential and commercial buildings contribute over 30% of CO_2 emissions. While efforts such as home renovation have a significant role to play in reducing energy consumption (Felius et al., 2020), research has also illustrated that occupant behaviour can contribute to energy consumption reductions, for example by lowering temperature settings (Lopes et al., 2012; Steemers & Yun, 2009). As a result, there is an interest in fostering an i n-depth understanding of the behavioural factors that contribute to people's intent to reduce their energy consumption generally, and reduction of heating related consumption specifically.

A particularly robust framework to understand behavioural intent is Ajzen's Theory of Planned Pehaviour (Ajzen, 1991) (TPB). It has been applied in a broad range of behaviour (Hardeman et al., 2002), including energy saving (La Barbera & Ajzen, 2021). Nonetheless, the TPB has been criticised, notably because it emphasises rational decision making (Gao et al., 2017). To heed these criticisms, the TPB has frequently been extended with additional variables (Perugini & Bagozzi, 2001) or additional behavioural models (Rivis et al., 2006). Given this, we have developed a behavioural model that extends the TPB to also capture socially reactive behaviour through the Prototype Willingness Model (PWM) (Gerrard et al., 2008) and the moral path to behaviour through the Value-Belief-Norm (VBN) Theory (Steg et al., 2005; Stern et al., 1999). Below we expand further on the use of these theories.

1.1 Theory of Planned Behaviour (TPB)

Centrally, Ajzen proposes that three variables are predictive of someone's intent to engage in an activity: attitude, perceived behavioural control (PBC) and subjective norms (SNs). Attitude can be seen as someone's appraisal of a particular behaviour, with people viewing the behaviour positively being more likely to also engage in that behaviour. Perceived behavioural control can be seen as the self-perceived ability people feel they have to engage in that behaviour and is positively associated with intent. Finally, subjective norms can be defined as someone's beliefs about what others close to them think of the behaviour.

The TPB has seen wide application in a variety of domains (Hardeman et al., 2002) and is a very robust theory of human behaviour. Examples include purchasing of sustainable housing (Judge et al., 2019), recycling behaviour (Tonglet et al., 2004) and energy reduction (La Barbera & Ajzen, 2021). Given this, we formulate the following hypothesis:

Positive attitudes towards energy reduction (**H1**), PBC (**H2**) and SNs (**H3**) are positively related to the intent to reduce energy consumption by lowering the temperature in winter.

1.2. Prototype Willingness Model (PWM)

An additional model of interest is the PWM (Gerrard et al., 2008). The PWM was originally developed to explore socially reactive paths to decision making, most prominently within the domain of health care and risk behaviour. While the PWM had an initial focus on adolescents, Gerard et al. (2008) emphasised that the model could also be applicable for adults. Additionally, despite its focus to understand risk and health related behaviours, it has also been used within the domain of sustainability (Ratliff et al., 2017). Of extra interest is the PWM's application in tandem with the TPB (Rivis et al., 2006). In brief, the PWM proposes that the willingness to engage in an activity is predicted by favourability of prototypes and the similarity of prototypes. These variables refer to how positively individuals perceive someone participating in an activity (prototype favourability) and how closely they perceive themselves in resemblance (prototype similarity) to the person engaged in that activity. The combined impact of prototype favourability and prototype similarity shapes an individual's willingness to perform an activity. We formulate the following hypothesis:

H4: Prototype favourability is positively associated with the willingness to reduce energy consumption behaviour by lowering the temperature in winter.

H5: Prototype similarity is positively associated with the willingness to reduce energy consumption behaviour by lowering the temperature in winter.

H6: Willingness is positively associated with the intention to reduce energy consumption behaviour by lowering the temperature in winter.

1.3. Value-Belief-Norm Theory (VBN)

We also extend our behavioural model with VBN Theory, that focuses on moral and personal norms related to sustainable behaviour. Stern and colleagues (1999) found that people are more likely to engage in sustainable behaviour if they feel a moral obligation to do so. This means that personal moral norms, or beliefs about what is right and wrong, can predict sustainable behaviour.

Given its prominence within the domain of sustainability, there is robust evidence of the value and predictive power of VBN Theory to predict reduction in energy consumption (Wang et al., 2018), but also intention to use renewable energy (Fornara et al., 2016) or behaviours related to climate mitigation (Zhang et al., 2020). Research by Steg et al. (2005) also highlighted a causal chain, proposing that people first need to be aware of the consequences caused by their behaviour, before they feel (jointly) responsible for energy problems. In turn, ascription of responsibility is predictive of pro-environmental personal norms, which finally predicts intent. In sum, we thus propose:

H7: Awareness of consequences is positively associated with ascription of responsibility.

H8: Ascription of responsibility is positively associated with pro-environmental personal norms.

H9: Pro-environmental personal norms are positively associated with intent to reduce energy consumption by lowering the temperature setting.

2. METHOD

2.1. Research context, instrument development and data gathering.

This research is situated within a larger project, NUDGE (European Commission, 2020), where, as part of an effort to understand the intent to reduce energy consumption, we developed a behavioural model that considers the aforementioned pathways of decision-making (socially reactive, moral or rational) and how it can predict reduction of heating related energy consumption. This led to the development of a survey and gathering data from 3098 people in 29 countries within Europe. The results found support for our three theoretical models discussed earlier (Conradie et al., 2023), and were also used to develop specific energy consumption profiles based on differences with regards to energy saving behaviour (Karaliopoulos et al., 2022), as well as forming the base of behavioural interventions evaluated later during the project (Burkhardt et al., 2022).

The goal of this study is to assess whether the participants in our pilots differ with regards to their behavioural intent, keeping in mind the results from our first, general study. To do so, we developed a smaller pilot-specific survey that was distributed among each of the pilot locations in the projects. Each pilot had a slightly different focus, with each pilot-specific survey tailored to the goals within the pilot. In brief, our Belgium pilot focused on the impact of intergenerational learning on energy use, while in Portugal the focus was on improving air quality and reducing energy consumption. Germany and Croatia focused on increasing self-consumption of energy, and the Greek pilot focused on reducing gas consumption. However, across all pilots, we measured the specific intent of participants to lower the temperature setting in winter through a survey. Although the scope of the pilots differed from one another, the operationalization of the measurements for this study are identical across all pilots.

Scale development was discussed at-length in the original article (Conradie et al., 2023), but in brief, we developed the items applied for each of the models by re-appropriating the questions from the models in question and modifying them for the purpose of this study. For the TPB, this included items by Ajzen (1991), developed specifically to assess energy reduction (La Barbera & Ajzen, 2021). For the PWM, we relied on Gerrard et al. (2008), but also drew from work in different domains (Van Gool et al., 2015), while for VBN we re-appropriated items from Abrahamse & Steg (2009).

	Belgium	Croatia	Germany	Greece	Portugal
Number of participants	58	82	105	33	85
Percentage male	53%	93%	88%	80%	51%
Mean age (2023)	45	49	58	36	41
Mean intent to reduce consumption	3.81	3.59	3.40	3.62	3.80

Table 1: Age, gender and mean intent to reduce heating related consumption across pilots.

The survey was originally developed in English and subsequently translated into the native languages used in the pilots: German, Croatian, Dutch, Portuguese and Greek. Native speakers within the consortium assisted with the translation. We used a backtranslation approach (Brislin, 1970) where we first translated the items to the native language, after which they were translated back to English. If differences with the original English items were found, this process was repeated until a satisfactory translation was achieved. A complete list of items can be found in table 2. All statements are measured using a 5-point Likert scale, except for attitude, which was measured on a 7-points semantic scale. We retained 363 participants across our pilots who fully completed the questions in our behavioural model. Our sample contained more men than women (73.83%). The mean date of birth was 1975 (i.e., 48 years old), while mean intent was 3.62 (on a 5-point Likert scale).

Latent variable	Item id	α	Factor Loadings	Item text
Intent	INT_SPEC_1	0.86	0.95	I intend to save energy by lowering the temperature setting in winter.
	INT_SPEC_2		0.79	There is a chance that I save energy by lowering the temperature setting in winter.
Attitude	ATT_1	0.82	0.75	Disadvantageous - advantageous
	ATT_2		0.95	Foolish – wise
Perceived Behavioural Control	PBC_1	0.70	0.68	I have the capabilities to save energy by lowering the temperature setting in winter.
	PBC_2		0.79	If it were entirely up to me, I am confident that I could save energy by lowering the temperature setting in winter.
Subjective Norms	SN_1	0.79	0.80	Most people who are important in my life would approve that I save energy by lowering the temperature setting in winter.
	SN_2		0.82	Most people who are important in my life save energy by lowering the temperature setting in winter.
Personal Moral Norms	PERS_NORM_1	0.76	0.75	I feel morally obliged to reduce my energy use, regardless of what other people do.
	PERS_NORM_2		0.75	I feel guilty when I use a lot of energy.
	PERS_NORM_3		0.66	I feel good about myself when I do not use a lot of energy.
Ascription of Responsibility	ASCR_RESP_1	0.87	0.84	I take joint responsibility for the depletion of energy resources.
	ASCR_RESP_2		0.93	I feel jointly responsible for the greenhouse effect.
Awareness of Consequences	C_AWARE_1	0.69	0.84	Energy conservation contributes to a reduction of global warming.
	C_AWARE_2		0.63	The increasing energy demand is a serious problem for our society.
Prototype Favourability	PROT_FAV_1	0.83	0.76	Conscious
	PROT_FAV_2		0.90	Smart

	PROT_FAV_3		0.68	Green
Prototype Similarity	PROT_SIM_1	0.91	0.91	Do you resemble the typical person who saves energy by lowering the temperature setting in winter?
	PROT_SIM_2		0.92	I am comparable to the typical person who saves energy by lowering the temperature setting in winter.
Willingness	WILL_1	0.60	0.60	You lower the temperature setting in all unused rooms when you are at home all day.
	WILL_2		0.72	You lower the temperature setting when you leave home.

Table 2: Latent variable, item id, Chronbach's α, factor loadings and item text for all observed variables

2.2. Analytic approach

We followed a common analytical approach for structural equation modelling, which includes a brief preliminary analysis of key variables (one-way analysis of variance, t-tests and Pearson's correlation analysis), followed by establishing a measurement model and subsequently a structural equation model (Anderson & Gerbing, 1988). Our measurement model serves to determine whether the observed variables (i.e., the questions or items that we will ask participants) reliably reflect the proposed latent variables (i.e., the constructs that we are trying to measure). To determine fit, we used a variety of indices, as suggested by Schreiber et al. (2006). First, Tucker Lewis index (TLI), ranging from 0 to 1.00, with values above 0.9 indicating good fit. Comparative fit index (CFI) similarly has a range from 0 to 1.00, with values above 0.9 indicating good fit. We combine this with the root mean square error of approximation (RMSEA), which also ranges from 0 to 1.00, with values below 0.05 indicating good fit and values from 0.06 to 0.08 indicating adequate fit. Threshold for statistical significance was set at $p = 0.05$.

3. RESULTS

3.1. Preliminary analysis

Average intent to reduce heating related energy consumption was 3.62 ($SD = 1.00$). We found a difference in intent across the pilots ($F(4, 358) = 2.601$, $p = 0.036$). A post-hoc Tukey test shows that the only statistically significant difference was between Portugal and Germany, with German intent the lowest. In terms of differences between gender, a Welch two-sample T-test suggests that no differences could be found between gender and intent ($t = 1.946$, $p = 0.053$).
Our Pearson correlation analysis finds statistically significant correlations for all the hypothesised relationships between intent on the one hand and attitude, PBC, SNs, personal moral norms and willingness on the other, indicating preliminary support for the predictive power of our three behavioural models on intent (see table 3).

3.2. Confirmatory Factor Analysis and Structural Equation Modelling

In line with our original study, we removed items with factor loadings below 0.4 and allowed error co-variance between similarly phrased items. This resulted in a satisfactory model fit: TLI

= 0.922, CFI = 0.945, RMSEA = 0.061, with error co-variance allowed between ASCR_RESP_1~~ASCR_RESP_2. All indices meet minimum fit requirements, and as a result, we proceed with our SEM.
As mentioned earlier, we found statistically significant differences in intent across the pilots between Portugal and Germany (in our Tukey post-hoc test). To assess whether this has an impact on our results, we performed an analysis using pilot locations as categorical predictors, regressed on intent. Germany was used as reference category. Fit was poor (TLI = 0.821, CFI = 0.850 and RMSEA 0.081) and our results show that pilot location has no statistically significant impact on intent when included in our overall model. Given this, we proceed with removal of our pilots as predictors. Consequently, our model fit improves with TLI = 0.904, CFI = 0.924 and RMSEA = 0.067**.** We proceed with this model.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Intent (1)									
Attitude (2)	0.49**								
Perceived Behavioural Control (3)	0.51**	0.30**							
Subjective Norms (4)	0.50**	0.30**	0.36**						
Personal Moral Norms (5)	0.46**	0.29**	0.30**	0.39**					
Ascription of Responsibility (6)	0.32**	0.24**	0.24**	0.28**	0.51**				
Awareness of Consequences (7)	0.30**	0.27**	0.22**	0.12	0.38**	0.37**			
Prototype Favorability (7)	0.46**	0.40**	0.40**	0.28**	0.45**	0.37**	0.34**		
Prototype Similarity (8)	0.58**	0.42**	0.42**	0.43**	0.45**	0.30**	0.22**	0.44**	
Willingness (9)	0.52**	0.38**	0.33**	0.31**	0.36**	0.22**	0.20**	0.35**	0.45**

Table 3: Pearson correlation table of all our latent constructs ($p < 0.05$ = *; $p < 0.01$ = **)

Examining our results more closely, we see support for all hypotheses. Firstly, within the TPB, attitude ($\beta = 0.159$, $p = 0.001$), PBC ($\beta = 0.214$, $p < 0.001$) and SN ($\beta = 0.257$, $p < 0.001$) are all predictive of intent. Second, willingness, as part of the PWM, is similarly associated with intent ($\beta = 0.433$, $p < 0.001$), with both prototype similarity ($\beta = 0.499$, $p < 0.001$) and prototype favourability ($\beta = 0.255$, $p < 0.001$) being associated with willingness. Lastly, within VBN-theory, we find awareness of consequences to be associated with ascription of responsibility ($\beta = 0.888$, $p < 0.001$), ascription of responsibility to be predictive of personal norms ($\beta = 0.878$, $p < 0.001$), and personal norms to be significantly associated with intent ($\beta = 0.099$, $p = 0.040$). Overall, our model was able to predict 72% of variance for intent, 77% for personal norms, 78% for ascription of responsibility and 45% for willingness.

4. LIMITATIONS AND DISCUSSION

Before reflecting more on our results, we note some limitations. First, while the overall model fit was satisfactory, we used two-item measures for many constructs. This was a deliberate choice in order to reduce participant fatigue, given that our study took place within the context of a much larger survey that also looked at specific behaviours including air quality (Gabriel et al., 2023) and self-consumption of electricity (Pelka et al., 2023). As a result, our overall model could be viewed as less robust. We also note that reliability for Willingness (as part of the PWM) was below the customary threshold of Cronbach α of 0.70 at 0.60.

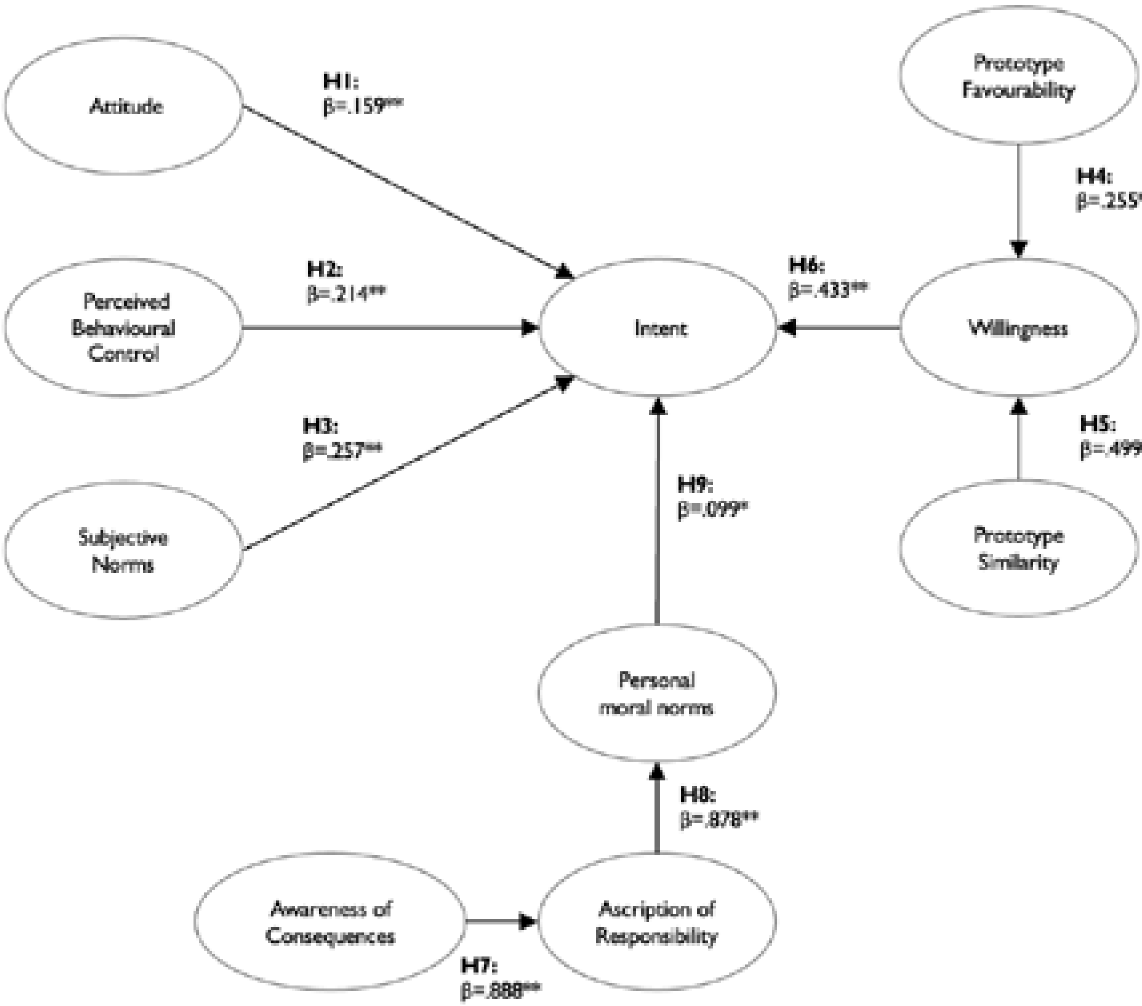

Figure 1: Results from our SEM analysis ($p < 0.05$ = *; $p < 0.01$ = **); TLI = 0.904, CFI = 0.924 and RMSEA = 0.067

Nonetheless, we find support for all hypotheses, with explained variance for intent at 72%. For the TPB, we see support for H1, H2 and H3. However, both PBC and SNs appear to have stronger relationships with intent than attitude.

H4, H5 and H6 were part of the PWM and are also supported, with both prototype favourability and prototype similarity being associated with willingness, and willingness being associated with intent. Moreover, willingness appears especially strongly associated with intent, which suggests that, at least within our sample, socially reactive decision making is a strong predictor of intent to reduce heating related consumption.

However, our VBN-theory implementation shows less promise. While reaching a level of statistical significance at $p = 0.04$, the association between personal moral norms and intent (H9) is comparatively weak. One reason for this may be that VBN-theory might be less suited to explain behaviour with a high personal cost, as also noted by Abrahamse & Steg (2009). Indeed, lowering the temperature in the home directly influences one's personal comfort. Nonetheless, support for the association between awareness of consequences and ascription of responsibility (H7) and the association between ascription of responsibility and personal moral norms (H8) is strong.

Compared with our original study, we find broadly similar results, suggesting our pilot participants do not diverge radically from the participants in our more general survey. Notable differences include a much stronger relationship between willingness and intent ($\beta = 0.433$, $p < 0.001$) (as part of PWM). VBN-Theory's support was slightly stronger compared to the original study, but the statistical significance remains weak compared to the other applied theories.

From a policy standpoint, our findings highlight the significance of decision-making influenced by social reactions, particularly in our support of the PWM. Prioritizing the favourability of prototypes proves to be a valuable method for increasing willingness. Additionally, the relevance of SNs underscores the idea that others' opinions matter. This emphasizes the importance of incorporating SNs into policies, such as highlighting energy conservation behaviours observed in others.

Furthermore, PBC's impact on intent also points towards better understanding of the perceived ability to reduce heating, which may include providing better tools which should allow better insight into consumption, but also helping people visualise and contextualise energy saving (i.e.: in money saved or reduced emissions). Other efforts here may include providing practical tips to households in order to strengthen their PBC over energy reduction.

Overall, our results contribute to existing work exploring the determinants of intention to reduce energy consumption. We emphasise the importance of both SNs and PBC on intent, while willingness also appears to have a strong association. Our evidence for the use of VBN-theory is, however, weak, arguing against its use to predict personal energy curtailment.

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REFERENCES

Abrahamse, W., & Steg, L. (2009). How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? *Journal of Economic Psychology*, *30*(5), 711–720. https://doi.org/10.1016/j.joep.2009.05.006

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin*, *103*(3), 411–423. https://doi.org/10.1037/0033-2909.103.3.411

Brislin, R. W. (1970). Back-Translation for Cross-Cultural Research. *Journal of Cross-Cultural Psychology*, *1*(3), 185–216. https://doi.org/10.1177/135910457000100301

Burkhardt, J., Kühnbach, M., & Pelka, S. (2022). Intervening me softly - Modeling nudging interventions to change EV user preferences. *Eceee Summer Study Proceedings*.

Conradie, P., Van Hove, S., Pelka, S., Karaliopoulos, M., Anagnostopoulos, F., Brugger, H., & Ponnet, K. (2023). Why do people turn down the heat? Applying behavioural theories to assess reductions in space heating and energy consumption in Europe. *Energy Research & Social Science*, *100*, 103059. https://doi.org/10.1016/j.erss.2023.103059

Costa, A., Keane, M. M., Torrens, J. I., & Corry, E. (2013). Building operation and energy performance: Monitoring, analysis and optimisation toolkit. *Applied Energy*, *101*, 310–316. https://doi.org/10.1016/j.apenergy.2011.10.037

European Commission. (2020). *NUDging consumers towards enerGy Efficiency through behavioral science*. https://cordis.europa.eu/project/id/957012

Eurostat. (2021). *Disaggregated final energy consumption in households - quantities*. https://ec.europa.eu/eurostat/databrowser/view/NRG_D_HHQ__custom_1731595/default/table?lang=en

Felius, L. C., Dessen, F., & Hrynyszyn, B. D. (2020). Retrofitting towards energy-efficient homes in European cold climates: a review. *Energy Efficiency*, *13*(1), 101–125. https://doi.org/10.1007/s12053-019-09834-7

Fornara, F., Pattitoni, P., Mura, M., & Strazzera, E. (2016). Predicting intention to improve household energy efficiency: The role of value-belief-norm theory, normative and informational influence, and specific attitude. *Journal of Environmental Psychology*, *45*, 1–10. https://doi.org/10.1016/j.jenvp.2015.11.001

Gabriel, M. F., Cardoso, J. P., Felgueiras, F., Azeredo, J., Filipe, D., Conradie, P., Van Hove, S., Mourão, Z., Anagnostopoulos, F., & Azevedo, I. (2023). Opportunities for Promoting Healthy Homes and Long-Lasting Energy-Efficient Behaviour among Families with Children in Portugal. *Energies*, *16*(4), 1872. https://doi.org/10.3390/en16041872

Gao, L., Wang, S., Li, J., & Li, H. (2017). Application of the extended theory of planned behavior to understand individual's energy saving behavior in workplaces. *Resources, Conservation and Recycling*, *127*, 107–113. https://doi.org/10.1016/j.resconrec.2017.08.030

Gerrard, M., Gibbons, F. X., Houlihan, A. E., Stock, M. L., & Pomery, E. A. (2008). A dual-process approach to health risk decision making: The prototype willingness model. *Developmental Review*, *28*(1), 29–61. https://doi.org/10.1016/j.dr.2007.10.001

Goldstein, B., Gounaridis, D., & Newell, J. P. (2020). The carbon footprint of household energy use in the United States. *Proceedings of the National Academy of Sciences*, *117*(32), 19122–19130. https://doi.org/10.1073/pnas.1922205117

Hardeman, W., Johnston, M., Johnston, D., Bonetti, D., Wareham, N., & Kinmonth, A. L. (2002). Application of the Theory of Planned Behaviour in Behaviour Change Interventions: A Systematic Review. *Psychology & Health*, *17*(2), 123–158. https://doi.org/10.1080/08870440290013644a

Jakučionytė-Skodienė, M., Krikštolaitis, R., & Liobikienė, G. (2022). The contribution of changes in climate-friendly behaviour, climate change concern and personal responsibility to household greenhouse gas emissions: Heating/cooling and transport activities in the European Union. *Energy*, *246*, 123387. https://doi.org/10.1016/j.energy.2022.123387

Judge, M., Warren-Myers, G., & Paladino, A. (2019). Using the theory of planned behaviour to predict intentions to purchase sustainable housing. *Journal of Cleaner Production*, *215*, 259–267. https://doi.org/10.1016/j.jclepro.2019.01.029

Karaliopoulos, M., Tsolas, L., Koutsopoulos, I., Haldiki, M., Van Hove, S., & Conradie, P. (2022). Beyond clustering: rethinking the segmentation of energy consumers when nudging them towards energy-saving behavior. *Energy Informatics Review*, *2*(4).

La Barbera, F., & Ajzen, I. (2021). Moderating role of perceived behavioral control in the theory of planned behavior: A preregistered study. *Journal of Theoretical Social Psychology*, *5*(1), 35–45. https://doi.org/10.1002/jts5.83

Lopes, M. A. R., Antunes, C. H., & Martins, N. (2012). Energy behaviours as promoters of energy efficiency: A 21st century review. *Renewable and Sustainable Energy Reviews*, *16*(6), 4095–4104. https://doi.org/10.1016/j.rser.2012.03.034

Pelka, S., Anatolitis, V., Karaliopoulos, M., Conradie, P., Martens, E., Anagnostopoulos, F., Vries, L. de, Chappin, E., & Preuß, S. (2023). Self-consumption rises due to energy crises? An evaluation of prosumers' consumption behavior in 2022. *International Conference on European Energy Markets (EEM)*.

Perugini, M., & Bagozzi, R. P. (2001). The role of desires and anticipated emotions in goal-directed behaviours: Broadening and deepening the theory of planned behaviour. *British Journal of Social Psychology*, *40*(1), 79–98. https://doi.org/10.1348/014466601164704

Ratliff, K. A., Howell, J. L., & Redford, L. (2017). Attitudes toward the prototypical environmentalist predict environmentally friendly behavior. *Journal of Environmental Psychology*, *51*, 132–140. https://doi.org/10.1016/j.jenvp.2017.03.009

Rivis, A., Sheeran, P., & Armitage, C. J. (2006). Augmenting the theory of planned behaviour with the prototype/willingness model: Predictive validity of actor versus abstainer prototypes for adolescents' health-protective and health-risk intentions. *British Journal of Health Psychology*, *11*(3), 483–500. https://doi.org/10.1348/135910705X70327

Schreiber, J. B., Nora, A., Stage, F. K., Barlow, E. A., & King, J. (2006). Reporting Structural Equation Modeling and Confirmatory Factor Analysis Results: A Review. *The Journal of Educational Research*, *99*(6), 323–338. https://doi.org/10.3200/JOER.99.6.323-338

Steemers, K., & Yun, G. Y. (2009). Household energy consumption: a study of the role of occupants. *Building Research & Information*, *37*(5–6), 625–637. https://doi.org/10.1080/09613210903186661

Steg, L., Dreijerink, L., & Abrahamse, W. (2005). Factors influencing the acceptability of energy policies: A test of VBN theory. *Journal of Environmental Psychology*, *25*(4), 415–

425. https://doi.org/10.1016/j.jenvp.2005.08.003

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Human Ecology Review*, *6*(2), 81–97.

Tonglet, M., Phillips, P. S., & Read, A. D. (2004). Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: a case study from Brixworth, UK. *Resources, Conservation and Recycling*, *41*(3), 191–214. https://doi.org/10.1016/j.resconrec.2003.11.001

Van Gool, E., Van Ouytsel, J., Ponnet, K., & Walrave, M. (2015). To share or not to share? Adolescents' self-disclosure about peer relationships on Facebook: An application of the Prototype Willingness Model. *Computers in Human Behavior*, *44*, 230–239. https://doi.org/10.1016/j.chb.2014.11.036

Wang, B., Wang, X., Guo, D., Zhang, B., & Wang, Z. (2018). Analysis of factors influencing residents' habitual energy-saving behaviour based on NAM and TPB models: Egoism or altruism? *Energy Policy*, *116*, 68–77. https://doi.org/10.1016/j.enpol.2018.01.055

Zhang, L., Ruiz-Menjivar, J., Luo, B., Liang, Z., & Swisher, M. E. (2020). Predicting climate change mitigation and adaptation behaviors in agricultural production: A comparison of the theory of planned behavior and the Value-Belief-Norm Theory. *Journal of Environmental Psychology*, *68*, 101408. https://doi.org/10.1016/j.jenvp.2020.101408

Logics and stakes of the 'Just transition'

Principles and implications for public action

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Abstract

What is a "just transition" and what does it mean for a public agency like the French French Agency for Ecological Transition (ADEME)? Depending on times and actors, the definition, challenges, and rationales of "just transition" may vary. Still, Trade Unions, NGOs, governments, international organisations refer to "just transition" to say three different things. First, the transition must be done and, therefore, policies should focus on emitters. Though, environmental public regulation, enacted for the sake of everybody, mays cause job destructions for some workers. Therefore, society should take care of them, but also of firms, sector and regions economically affected by the transition. Second, focusing on emitters and emissions does not consider the inequal capacities of actors to adapt to environmental policies. Third, people and stake holders should have the capability to contribute to the elaboration and the implementation of environmental policies.

Each of these logics requires a great deal of knowledge to clarify the stakes of these current issues and the implications for public action. ADEME has already engaged various kind of actions from producing knowledge to elaboration of tools and recommendations for

INTRODUCTION

The expression "just transition" is one of those "portmanteau" words that everyone - scientists, experts, journalists, politicians, activists - uses without defining it or checking that the various people involved share its meaning. The vagueness of the concept is also accompanied by a "magical" character: the "just transition" would be one, if not the main vector towards a fairer, calmer, more cohesive, democratic society. Conversely, the injustice of the transition is now clearly identified as one of the current arguments justifying climate inaction3.

How can we clarify this notion to gain a better understanding of its potential for driving the transition and the future of our societies? What are the implications for public authorities of this demand for justice within the transition? How has a public environmental agency such as the French Agency for Ecological Transition (ADEME) grasped this issue at its level?

This paper will first seek to clarify the notion of 'just transition', as it appears in the literature, which turned out to be more gray than academic on this subject. This qualitative analysis shows that the notion of "just transition" covers three interwoven and sequenced normative logics that should guide public action. Although the "just transition" is about the whole ecological transition, this paper will focus on the climate transition and its mitigation policies. However, the logics presented here should easily be applied to climate adaptation policies as well as to environmental policies. Second, the paper will study the actuality of the stakes related to each three logic and the implications for public action, particularly for ADEME. To this end, this paper will mainly focus on France and Europe.

1 A NORMATIVE FRAMEWORK TAILORED TO TRANSITION MANAGEMENT

1.1 Emergence around "brown" jobs and activities and extension to political and social issues

The term "just transition" appeared in North American trade unions in the early 1990s. At that time, the president of the Energy and Chemical Workers Union, Tony Mazzocchi, proposed the creation of a "super compensation fund for workers" that would provide income (and pensions) as well as sufficient training to reintegrate workers who lose their jobs because of environmental policies4. Tony Mazzocchi pointed out that of the one million employees a year made unemployed during the 1980s in the United States, only 2,000 were in this situation. However, few they are, the trade unionist insisted that it must be guaranteed that "they will not have to pay for clean air and water with their jobs, their living standard or their future."

Folowing Tony Mazzocch’s footsteps, several trade union organisations in the United States and Canada officially endorsed the "just transition" principle, followed by the European Trade Union Confederation (ETUC)5 and the forerunner of the International Trade Union Confederation (ITUC)6. Later, the "just transition" was officially included in the final agreement of COP16 in 2010 and appeared in the preamble to the 2015 Paris Agreement7. The "just transition" has also been the subject of a specific declaration at COP 24 in 2018: the

"Silesian Declaration on Solidarity and Just Transition", which extends the concern for brown jobs to sectors, cities and regions that need to move away from fossil fuels8.
Let's spend some time on this first rationale of the "just transition". The original idea does not call into question the need for ecological transition itself. It advocates reconciling ecology and employment by saying that it is the responsibility of everyone, not just a few, to "pay" for common objectives9. It is because the ecological transition serves the general interest that specific protection must be put in place to offset its negative impact on workers *i.e.* on individual interests. The "just transition" it's not a question of giving up on regulating current and future production and consumption, but rather of accompanying the socio-economic losses of inherited activities and implementing the human and financial resources needed to reap the maximum socio-economic benefits from the ecological transition. Therefore, some public action on energy and environment may still be based on the polluter pays principle. The "just transition" imperative comes, in a second phase, and only in a second phase, to correct the most deleterious effects for certain populations, businesses and territories and to reach all the possible benefits of the transition for society as a whole[10].
Meanwhile the international institutionalisation of its first meaning, the "just transition" concept has been broadened to include wider social and political issues. This evolution is particularly visible in the "Guiding principles for a just transition to ecologically sustainable economies and societies for all" established by the ILO in 201511. From now on, the "just transition" should also contribute to "decent work for all in an inclusive society, with poverty eradication" and the "process" must be based on "a well-managed transition, with constructive social dialogue at all levels to ensure a fair distribution of burdens and that no one is left behind". The "just transition" in France's climate policy[12] is part of this approach, which focuses on particularly vulnerable citizens and businesses instead of brown activities. Recently, the scope - what "just transition" is likely to apply to – has been broaden by the European Commission, as well as the French High Council on Climate[13] to adaptation policies[14] in addition to mitigation ones.

1.2 Three sequenced and interlocking courses of action

What is regarded to be "just" within the transition in all these official materials corresponds to three ethical objectives and logics:

1. **Compensation for the economic damage caused by the transition to employees, towns and regions, sectors dependent on fossil fuels, along with the creation of quality jobs and green activities.** This requirement supports the cessation or the transition of old and current brown activities and jobs and enhances the development of current and future green activities and jobs. The logic for action is to focus on emissions/pollution.
2. **Reducing poverty and overall inequality and exclusion.** The logic for action is no longer to operate on the basis not of emissions but focusing on the vulnerabilities of the individuals, groups, organisations or territories. This means helping the poorest and most disadvantaged categories of the population, not because they are particularly

high emitters, but because they will be proportionally more affected by the effects of climate policies such as environmental taxation for example. This second logic corrects the effects of the first one.

3. **The participation of all stakeholders in ecological decision-making.** The logic for action is to work with the free and equal citizens and stakeholders of a democracy. This third logic concerns the implementation of the first two.

In the end, this conceptual and normative framework of "just transition" might seem more suitable than that of sustainable development and the 17 SDGs for structuring the action of the public authorities responsible for drawing up and implementing public transition policies. Indeed, the SDGs propose a "flat" vision of various objectives of general interest. All are considered at the same level and rather independently of each other. However, an environmental agency such as ADEME may feel illegitimate when it comes to ethical objectives that are not directly within its legal scope of action. The concept of «just transition» has the advantage of proposing a broad vision, starting with transition as the point of entry and therefore as the primary objective. Starting from there, the "just transition» makes it possible to prioritise, articulate and sequence the other different normative principles and logics of action.

2 A «JUST TRANSITION» TO BROWN AND GREEN ACTIVITIES

The "just transition" enshrined in treaties and speeches, shouldn't be confined to a programmatic or even incantatory use. It is well established in the literature, as reviewed by the IPPCC, that "just transition" is one of the core aspects of climate-resilient development pathways for transformational social change[15]. Here, it should be noted that this statement goes well beyond linking "just transition" with "achieving energy efficiency through behaviour change". "Justice" within the transition facilitate or condition the transition implementation by whatever means: behaviour change, green technologies, new organisations, amendments in legal frameworks, and so on. Thus, the continuation of this paper will take the crucial role of the "just transition" for granted and focus on the stakes to be addressed by public authorities, before drawning in conclusion on the type of policy and action likely to respond to them. The focus will be on ADEME's action French policies and European examples.

2.1 Stakes for brown jobs and green ones

Studies carried out by ADEME, coherent with other works on the topic[16], on 4 carbon neutrality scenarios for France in 2050 show that the transition has little effect on the unemployment rate, GDP or standard of living of the French population[17]. In 3 out of 4 scenarios, however, there is a job net creation of 3 to 5% compared with the trend. Only the rapid and massive activation of the sufficiency lever leads to a reduction of 4%. Studies at regional level show that several business sectors are benefiting from the energy transition, with significant potential for the creation of jobs that cannot be relocated[18]. In contrast, certain sectors, some of which are concentrated in certain regions, are going to have to change, lose business or even disappear.

On the other side, transition can also be slowed by underdeveloped markets and skills. In this reverse perspective, the challenge is to identify and prevent shortages, i.e. to match the skills available in a given area with the public policy objectives. In France, ADEME has observed a shortfall of around 17,000 FTE jobs in 2021 in the 3 key sectors of the energy transition (energy efficiency, production of energy & renewable heat and land transport). The French national task force on green jobs estimates that more than a half of jobs in the green economy are facing recruitment difficulties in 2020[19]. In the short term, the building energy efficiency sector is the one that faces the most problems in terms of human resources. It is estimated that between 170,000 and 250,000 the jobs to be created in France by renovation in 2030[20].
Yet, the volume of jobs identified as being related to the ecological transition seems relatively low in France[21] and elsewhere. Out of 10 countries studied, the World Economic Forum estimates the current volume of green jobs at just under 1% of the total workforce. They are expected to increase by 12 million (including 11 million in the agriculture and forestry sectors) by 2030, i.e. an increase of 66%. However, the new green jobs to be created in Germany between now and 2030, for example, correspond to 3% of the number of unemployed Germans at the end of 2022. Tomorrow's new jobs will, in volume terms, be less "green" than "social".
The fact remains that the effects of transition on current and future employment systems are still complex to grasp, if only for reasons of definition and identification[22]. A mapping of the professions and skills due to or impacted by the transition is still in the process of being stabilised in France A first lesson might then be that targeting policies on job creation and destruction strictly attributable to transition remains limited by the difficulty of isolating these jobs. Therefore, institutional work on employment, skills, and training in relation to transition in France is now considering a transformation of all occupations, over and above green and greening occupations[23].

2.2 Stakes for material and financial assets destroyed, impaired or recreated

The same rationale, previously established about brown and green jobs, can be applied to material and financial assets destroyed or depreciated by environmental policies enacted in the name of society as a whole. At international level, trade unions have taken up the issue of financial assets because of profit-sharing and retirement managed by some sectors of brown activities themselves[24]. However, attention to financial assets has mainly come from the financial sector[25]. Back in 2011, a concern arose about the depreciation in the financial value of fossil fuels stocks. In fact, the fossil fuel stocks valued on the financial markets, but which must not be exploited to limit global warming to 2°C, reached already over 20,000 billion dollars at that time. This staggering sum could justify broader public intervention aimed at putting a stop to extractive activities while avoiding a major financial crisis. Today, investment in fossil fuels may be declining, it is continuing, as it remains more profitable than the one in renewable energies, prompting the oil majors to change their model a little bit and their communication a lot[26].
However, the question of assets goes far beyond high emitters industries. From farm equipment for spreading fertiliser to internal combustion-powered household vehicles, there

are many material assets belonging to firms and households that could be destroyed or depreciated by the transition. Here, the aim of a would be to help the constitution of green assets, from financing the decarbonisation of the energy and industry sectors to subsidy for the purchase of electric vehicles. A lot of work still must be done to identify these brown assets that could lead to an important underestimation of the need for public finance[27].
In France, the most recent and complete evaluation culminates to a major financing effort on the part of the public authorities up to an additional 34 billion euros each year between now and 2030[28]. The investment capacity of public authorities at all levels, which are often already highly indebted, depend on political choices and fiscal and budgetary policies that are also decided at Community level. Sharing the burden of financing the transition, through reallocation of budget, debts, taxation, is directly linked to political and social justice. The question of how to help public authorities financing the transition more, better and fairly in today’s open economies could be the most important regarding the "just transition".

3 A SOCIALLY «JUST TRANSITION» IN TERMS OF VULNERABILITY

Until now, we have only been interested in the impact of the transition from “brown” to “green” in terms of justice, as if it were possible to isolate this transition from the rest of society. However, the transition affects economies and societies, at least in terms of jobs, assets or public finances. Moreover, operating based on emissions leaves aside the question of the unequal capacities of the various categories of population, businesses and territories to adapt to climate policies. Consequently, this initial approach needs to be supplemented by an approach based on vulnerabilities and differences in vulnerability. In fact, at European level, two instruments have been implemented that correspond to these two main logics of action of the "just transition" (see Box 1). In the remainder of this document, particular attention will be paid to the contrasting effects of increasing the price of carbon. The specific case of carbon taxation in France will be addressed, given the importance of this measure and the difficulties of implementing it in France.

3.1 Considering vulnerabilities arising from pre-existing inequalities

Issues of inequality, precariousness, exclusion, discrimination and social downgrading are likely to arise for a number of climate measures, especially when they lead to a reduction in the population's purchasing power or the viability of low-profit activities. For example, ecological bonuses for the purchase of electric vehicles favour the most affluent and therefore also the oldest people, given the price differential, even after subsidies, between electric and internal combustion and between new and second-hand vehicles. A tax on emissions will make the richest people investing in better devices or insulations whereas the poorest ones will strongly reduce consumption and then, will suffer from cold. The "zero waste" practices are contributing to an increase in domestic tasks and therefore their burden on women, given the current distribution between men and women. Cutting back on pavements to create cycle lanes makes it harder for women to get around, as they are more likely to be on foot or with pushchairs, etc.
In the same way as for employment issues, the effects of the transition on the average

income of the French are relatively small. However, this average invibilize significant disparities. "Justice" here means focusing not on emissions but on the differences in vulnerability resulting from inequalities that, while pre-existing, could be exacerbated by the transition. In France by 2022, 3.4 million households, or 11.9% of households living in mainland France, face a situation of fuel poverty[29].The first imperative in achieving a socially «just transition» is to take stock of these contrasting effects and propose solutions to overcome them and avoid increasing inequalities.

Furthermore, in a French context marked by rising inequality, it would seem necessary to monitor the distributive effects of climate policies on the most vulnerable as well as on society as a whole, to avoid increasing the sense of social injustice. There is a major risk here, which is that the transition could pay the price for global evolutions whereas its impacts on revenues (and discrimination) may remain marginal compared with other determinants such as inflation, unemployment rate, evolution of wages, redistribution mechanisms, international trade, geostrategic crisis social norms, regional development, etc.

Box 1 : Two european instruments for two approaches of the "just transition"

The "just transition" is implemented as part of the Green Pact for Europe, via the "**Just Transition Mechanism**" and its Fund endowed in 2020 with €17.5 billion for the period 2021-2027.[30] It aims at compensating for the cessation of particularly polluting activities (and therefore for jobs and material and financial assets), while facilitating change and the creation of green activities. The Member States must identify the beneficiary territories and sectors in dialogue with the Commission. Next, they draw up their territorial plans for a just transition, which may include productive investments in small and medium-sized enterprises, the creation of new businesses, research and innovation, environmental restoration, clean energy, professional development and retraining programmes, job search assistance and active inclusion of jobseekers, as well as the transformation of existing carbon-intensive installations if these investments lead to significant reductions in emissions and job protection.

Following on in 2023, as part of the Fit for 55 package, the Council formally adopted the "**Social Climate Fund**"[31]. One year before the extension of the EU ETS to the building and transport sectors planned in 2027, this fund aims to provide financial support to Member States for the measures and investments set out in their social climate plans for households, micro-businesses, and transport users, in particular households in fuel poverty or those in precarious transport situations. The total budget reaches €86.7 billion (65 billion from Europe + 25% from Member States) for the period from 2026 to 2032. It will finance long-term investments, such as the renovation of buildings, the integration of renewable energies, infrastructure for zero-emission vehicles and public transport. Direct support for consumers and businesses can represent up to 37.5% of the total cost of each national plan.

3.2 Justice and perception of justice: the example of the carbon tax in France

The economic effects on household income in general and on the income category to which one belongs are two of the three most important criteria for explaining the acceptance of pro-climate public policy measures (the third being the environmental effectiveness of these measures)[32]. Public support for climate policies also depends on the type of public policy tool implemented and the specific context. A recent study by the

OECD[33] on a panel of 30 OECD countries between 2001 and 2015 showed that only market instruments are proven to be politically costly for the governments in place, and then only in specific cases: when fossil fuel prices are high, in countries that are highly dependent on fossil fuels, before elections, when inequalities are high and/or social protection systems are insufficient to correct the regressive effects of these policies.
First important lesson: the public consider market instruments as the most unfair ones.
By comparison, standards and norms are more costly than fiscal measures, because the additional costs are *ultimately* passed on to consumers and/or taxpayers, in "a ratio of 1 to 2, or even much more"[34]. Similarly, among market instruments, taxes are also considered to be more direct and less regressive than subsidies. Subsidies entail costs not only for public finances but also in terms of welfare[35]. Still social acceptability of explicit carbon pricing remains low and is even currently declining[36]. Paradoxically, the least regressive policies may remain the least popular.
The "yellow jacket" crisis in France is a case in point, but other countries such as Australia[37] and the United States[38] have also encountered public opposition to carbon taxation. This is a major problem because explicit carbon pricing via market instruments - a tax or an allowance market - is considered by economists to be the most efficient mechanism and an essential, albeit insufficient, tool for achieving the objectives of the Paris Agreement[39]. In France, the freeze on carbon taxation from 2019 onwards, leaving on third of emission reduction targets backed by no public policies[40].

3.3 Fair governance of the transition

To overcome the paradox and contradiction between justice and perception of justice, it is necessary to inform and clarify public debates. Here we need to be attentive to another source of inequality: the unevenly distributed ability to make one's point of view (preferences, values, beliefs and convictions) heard, to assert one's interests and, ultimately, to influence decisions. This is, moreover, the second most important condition for acceptance of major changes in the lifestyle of the French people (46%), behind the equitable distribution of efforts among all members of society (67%)[41] .
The Commission is currently seeking to strengthen social dialogue to ensure equitable transitions[42]. The European Trade Union Confederation (ETUC)[43], for its part, is calling for a social and political transition on a European scale, to prevent excessive tensions within societies. Still, a context of mistrust towards institutions and the development of fake news can only be detrimental to a climate transition - adaptation and mitigation - which implies relying on scientific facts with different levels of uncertainty. The issues of social cohesion and the political legitimacy of institutions appear to be crucial for the public authorities' management of the transition.

CONCLUSIONS

The first practical implication for public authorities regarding the "just transition" is producing knowledge of the effects of the transition as a whole and of each climate policies on employment, distribution of revenues, indirect discriminations etc. at all territorial levels.

This is the *sine qua non* condition for developing relevant tools, methods and public policies tasks on which ADEME is already heavily involved.

Regarding transition of brown and development of green activities in France: in addition to macro national foresight, ADEME and the "Climate Action Network" (RAC), the French umbrella organisation for Climate NGOs, have developed a tool to help local authorities understand and support these changes at local level[44]. The "TETE tool" can be used to calculate the direct and indirect jobs created and destroyed by an ecological transition action plan, excluding industry and agriculture, at all levels, from the commune to the whole of France. This could help to settle up specific compensation and training schemes for brown jobs directly destroyed by transition policies as required by the "just transition". Yet, because the impacts of the transition are not easily identifiable, it remains necessary to maintain strong social protection to support all the jobs threatened by, among other things, ecological transition.

If labour is at a subject of the "just transition", so are assets, whether physical or financial. Making a "just transition" from "brown" assets involves identifying them, discouraging new investment and supporting their "green" transition/reconstitution. Through its coordination of the European Finance Clim Act project[45], ADEME is developing new tools, methods and knowledge to enable savers and financial institutions to integrate environmental objectives into their investment choices. Still, this won't be enough to regulate global financial markets and solve the "brown asset" problem. If a just transition is not only a moral imperative but also a pragmatic one, aimed at avoiding opposition and allowing the transition to proceed smoothly, the issue of brown assets should, given the sums involved, be a subject of major interest for public authorities and the research community.

Regarding the unequal vulnerabilities to climate policies: ADEME is piloting the National Observatory on Fuel Poverty (ONPE). The ONPE highlights notably the difficulties for low-income households in accessing energy renovation grants, either because they are tenants or because they are unable to afford the "remaining costs" of refurbishment. In 2023, France has ban on renting very not efficient flats (DPE "F" and "G"). This measure aims to improve this situation in the long term. ADEME has also worked to study the conditions for support for the carbon tax thanks to a serie of specific workshops and a review of the wordwile substantial literature on this subject. In this respect, ADEME has concluded that the use of the tax profits and of the quality of the public debate are crucial on these issues[46].

Still, the current dynamics of employment, inequality and exclusion are not primarily determined by the ecological transition. As a matter of fact, it should also be remembered that digital technology, AI, demographics, and de-industrialisation have had, and continue to have, far greater consequences than the ecological transition on unemployment. Therefore, ADEME recommends, in the debates on "just transition", avoiding demonising the transition in terms of its impact on employment or turning it into a panacea capable of solving all unemployment problems[47].

Moreover - climatic, energy, health, geostrategic, economic and social, as well as the digital transition - are cumulative in Europe. These crises and changes amplify each other's economic and social effects, and sometimes even contradict each other. For example, the energy price shields put in place by European governments in the wake of the war in Ukraine have proved to be reactive measures for managing the energy crisis and inflation, but helping to maintain dependence on fossil fuels, and increasing budgetary and climate problems. Solving each of these crises in isolation seems increasingly complicated. The transition risks paying the price for all these current difficulties. Climate, social, political, economic and geostrategic problems will then be exacerbated but postponed...

REFERENCES

3 Lamb, W., Mattioli, G., Levi, S., Roberts, J., Capstick, S., Creutzig, F., . . . Steinberger, J. (2020). Discourses of climate delay. *Global Sustainability*, 3, E17. doi:10.1017/sus.2020.13
4 Mazzocchi, T. (1993). A Superfund for Workers. *Earth Island Journal*, 9(1), pp. 40-41. https://www.jstor.org/stable/43883536?read-now=1&seq=1#page_scan_tab_contents
5 World, Worldwatch Institute & Cornell University Global Labor Institute. (2008). *Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon world*. UNEP/ILO/IOE/ITUC. https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_158727.pdf
6 International Trade Union Confederation. (2010, June 21 – 25). *Resolution on combating climate change through sustainable development and just transition*, 2CO/E/6.10 (final). 2nd World Congress,Vancouver, Canada. https://www.ituc-csi.org/IMG/pdf/2CO_10_Sustainable_development_and_Climate_Change_03-10-2.pdf
7 UNFCCC. (2015). The Paris Agreement. (2015). COP 21, UNFCCC. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
8 Council of the European Union. (208). *Silesia Declaration on Solidarity and Just Transition.* COP 24, UNFCC, Katowice, Poland. https://data.consilium.europa.eu/doc/document/ST-14545-2018-REV-1/en/pdf
9 Young, J. (1998). Just Transition. A new approach to jobs v. Environment, *Working*, 2(2), pp. 42-48. https://doi.org/10.1111/j.1743-4580.1998.tb00090.x
10 European Trade Union Confederation. (2018). *Involving trade unions in the fight against climate change to build a just transition*, https://www.etuc.org/sites/default/files/publication/file/2018-09/Final%20FUPA%20Guide_FR.pdf
11 International Labour Organization. (2015). *Guiding principles for a just transition to environmentally sustainable economies and societies for all*. https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_432864.pdf
12 National Low Carbon Strategy (SNBC), 2020 "Orientation ECO 2: ensure a just transition for all", https://www.ecologie.gouv.fr/sites/default/files/2020-03-25_MTES_SNBC2.pdf
13 High Council for the Climate. (2020). *Annual carbon neutrality report*. https://www.hautconseilclimat.fr/publications/rapport-annuel-2020/
14 European Commission. (2021). *EU Strategy on Adaptation to Climate Change*. https://ec.europa.eu/clima/sites/clima/files/adaptation/what/docs/eu_strategy_2021.pdf
15 IPCC. (2022). Sustainable Development, Poverty Eradication and Reducing Inequalities. In *Global Warming of 1.5°C: IPCC Special Report*. (pp. 445-538). Cambridge: Cambridge University Press. doi:10.1017/9781009157940.007 & IPCC. (2022). Accelerating the transition in the context of sustainable development. In *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA. (pp. 1727-1792). doi: 10.1017/9781009157926.019
16 Pisani-Ferry, J. & Mahfouz, S. (2022). L’action climatique : un enjeu macroéconomique. La note d'analyse de

France Stratégie, 114, 1-19. https://www.cairn.info/revue--2022-9-page-1.htm.
17 Callonnec, G., Gouëdard, H., Jolivet, P. (2022). *Les effets macroéconomiques. Transition 2050*. ADEME. https://librairie.ademe.fr/cadic/6940/feuilleton_macroeconomie_transitions2050_ademe.pdf
18 ADEME. (2021). *Impact sur l'emploi et l'économie de la transition énergétique en Grand Est.* & ADEME (2020). *Enjeux énergétiques et emplois dans les Hauts de France - Scénarios pour la Troisième Révolution industrielle* & ADEME. (2018). *Etude de quantification des conséquences sur l'emploi de la transition énergétique dans le cadre du pacte de Cordemais*.
19 Margontier, S. (2022). *Les métiers de l'économie verte rencontrent des difficultés de recrutement en 2020 et 2021. Données et études statistiques.* MTECT. https://www.statistiques.developpement-durable.gouv.fr/les-metiers-de-leconomie-verte-rencontrent-des-difficultes-de-recrutement-en-2020-et-2021
20 France Stratégie. (2023). Synthèse des principaux messages sur les enjeux emplois de la rénovation énergétique des bâtiments en vue de la Conférence des métiers du 04/07/2023. https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/synthese_des_principaux_messages_sur_les_enjeux_emplois_de_la_renovation_energetique_des_batiments.pdf
21 Nauroy, F. (2020). *Eco-activities and environmental employment in 2018*, Datalab. Essentiel, n°224, Ministère de la Transition écologique et solidaire, CGDD/SDES. https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2020-09/datalab_essentiel_224_eco_activites_2018_septembre2020.pdf
22 Baghioni, L., Moncel, N. (2022). *La transition écologique au travail : emploi et formation face au défi environnemental*. Céreq Bref, n° 423. https://www.cereq.fr/sites/default/files/2022-06/Bref%20423_web_0.pdf
23 Parisot, L., (2019). Plan de programmation des emplois et des compétences. Ministère de la Transition écologique et solidaire, Ministère du Travail, Ministère de l'Education nationale, Ministère de l'Enseignement supérieur, de la Rechercher et de l'Innovation. https://travail-emploi.gouv.fr/IMG/pdf/rapport_parisot_ppec_200219.pdf
24 European Trade Union Confederation. (2018). *Involving trade unions in the fight against climate change to build a just transition*. hps-://www.etuc.org/sites/default/les/publication/le/2018-09/Final%20FUPA%20Guide_FR.pdf
25 Carbon tracker. (2011). *Unburnable Carbon: Are the World's Financial Markets Carrying a Carbon Bubble?* https://carbontracker.org/reports/carbon-bubble/
26 Augé, B. (2023). Les majors pétrolières, du tout pétrole aux énergies renouvelables, décryptage d'un changement de modèle ou de communication. Hérodote, 188, 11-26. https://doi.org/10.3917/her.188.0011
27 Couppey-Soubeyran, J. & Kalinowski, W. (2023). VII/ Financement de la transition écologique : où est le problème ?. Dans : CEPII éd., L'économie mondiale 2024 (pp. 101-117). Paris: La Découverte.
28 Mahfouz, S., Pisani-Ferry, J., *Les incidences économiques de l'action pour le climat*. France Stratégie & IGF https://www.strategie.gouv.fr/publications/incidences-economiques-de-laction-climat
29 Les chiffres clés de la précarité énergétique (édition mars 2023)
30 European Commision. (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on the Green Pact for Europe [COM(2019)0640]. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN
31 European Union, The European Parliament, The Council (2023) Regulation of The European Parliament and of The Council establishing a Social Climate Fund and amending Regulation. (EU) 2021/1060. https://data.consilium.europa.eu/doc/document/PE-11-2023-INIT/en/pdf
32 Dechezleprêtre, A., Fabre, A., Stantcheva, S. (2022). *Les Français et les politiques climatiques*. Les notes du conseil d'analyse économique, n° 73, Juillet. https://www.cae-eco.fr/staticfiles/pdf/CAE073_Pol.clim.pdf
33 Furceri, D., Ganslmeier, M., Ostry, J. (2023). Are climate change policies politically costly? *Energy Policy*,178. https://doi.org/10.1016/j.enpol.2023.113575
34 Bureau, D., Henriet, F., Schubert, K. (2019). *Pour le climat : une taxe juste, pas juste une taxe.* Les notes du conseil d'analyse économique, n° 50, mars. https://www.cae-eco.fr/Pour-le-climat-une-taxe-juste-pas-juste-une-

taxe
35 Pommeret, A., Ricci, F., Schubert, K. (2023). *Energy transition: the cost of acceptability*. Paris School of Economics, Chair for a successful energy transition, Policy Brief, July. https://www.parisschoolofeconomics.eu/IMG/pdf/note1-chaire-reussir-la-transition-energetique-schubert.pdf
36 Credoc (2023). *Sensibilité à l'environnement, action publique et fiscalité environnementale : l'opinion des Français en 2023*. ADEME, https://librairie.ademe.fr/changement-climatique-et-energie/6365-sensibilite-a-l-environnement-action-publique-et-fiscalite-environnementale-l-opinion-des-francais-en-2023.html
37 Crowley, K. (2017). Up and down with climate politics 2013–2016: the repeal of carbon pricing in Australia. *WIRES Clim. Change* 8, e458. https://doi.org/10.1002/wcc.458
38 Anderson, S. T., Marinescu, I. & Shor, B. (2019). Can Pigou at the polls stop us melting the poles? *NBER Working Paper Series*, 26146. National Bureau of Economic Research, Inc. https://ideas.repec.org/p/nbr/nberwo/26146.html
39 Carbon Pricing Leadership Coalition. (2017). Report of the High Level Commission on Carbon Prices. https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices
40 Callonnec, G., Gouëdard, H., Jolivet, P. (2020). Evaluation d'un scenario snbc 2 sans hausse de taxe carbone et sans prix-fictifs ad hoc. ADEME & HCC. https://www.hautconseilclimat.fr/wp-content/uploads/2020/07/valuation-dun-scnario-snbc2-sans-hausse-de-taxe-carbone-et-sans-prix-fictifs-ad-hoc-ademe.pdf
41 ADEME. (2022). *Représentations sociales du changement climatique*. https://librairie.ademe.fr/changement-climatique-et-energie/5917-representations-sociales-du-changement-climatique-23-eme-vague-du-barometre.html
42 European Commision. (2023). Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. *Strengthening social dialogue in the European Union: harnessing its full potential for managing fair transitions*. COM/2023/40 final (2023). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A40%3AFIN.
43 Countouris N., Piasna A. and Theodoropoulou S. (eds.) (2023) *Benchmarking Working Europe 2023*, European Trade Union Institute (ETUI) and European Trade Union Confederation (ETUC). https://www.etui.org/sites/default/files/2023-03/Benchmarking%20Working%20Europe%202023_Towards%20sustainable%20resilience_2023.pdf
44 https://territoires-emplois.org/
45https://finance-climact.fr/
46 Combet, E. ; Jolivet, P. ; Pour un contrat social de transition - Propositions pour une réforme équitable de la valeur du carbone, ADEME, 2022. https://librairie.ademe.fr/cadic/7230/contrat-social-de-transition-2022-011883.pdf & Analyse des conditions de reprise d'une valeur équitable du carbone -État des lieux des arguments et examen comparé des options de politique publique, ADEME, 2021. https://librairie.ademe.fr/cadic/7230/valeur-carbone-equitable_202207.pdf
47 Gaudin, T. (2021). *Coconstruire les conditions favorables d'une transition écologique créatrice d'emplois. Feuille de route pour l'emploi pour la période 2021/2023*. ADEME. https://librairie.ademe.fr/urbanisme-et-batiment/5212-coconstruire-les-conditions-d-une-transition-ecologique-creatrice-d-emplois.html

WHAT CAN WE SAY ABOUT THE LONGER-TERM IMPACTS OF A LIVING LAB EXPERIMENT TO SAVE ENERGY AT HOME?

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Abstract

There is a wide evidence base on various interventions to change energy behaviours in households, but limited evidence on their long-term effects. It is argued that interventions in individual behaviours are subject to attrition over time following the withdrawal of the intervention. Evaluation of these arguments is difficult since the conditions and composition of households changes over time, making it hard to isolate the effects of a behavioural intervention several years later. Social practice theory argues for interventions that do not target individual attitudes or behaviours but focus instead on household practices (such as laundering and heating homes), and the underlying notions of cleanliness and comfort that are the causes of energy consumption in households. In contrast to behaviours, practices are also seen as socially-shared, bundled with other practices, and embedded in social structures and processes. Practices are durable entities that persist over time; true practice change would hence entail durability of intervention impacts. Our paper investigates the long-term effects (2018-2023) of a practice-based living lab intervention that aimed to influence laundry and heating practices. In particular, we focus on how the new or changed practices households learned during the intervention have persisted through societal changes (i.e., the Covid pandemic, the energy crisis), and on whether the new practices helped households to deal better with these crises. In this way, we contribute to, and reframe, the problem of evaluating long-term effects, and critically consider the persistence of small-scale interventions in practices.

Keywords: Energy efficiency, Everyday behaviour, Household, Living lab intervention, Long-term change, Social practices

1. Introduction

The need for sustainability transitions in the energy sector has long been recognised and became even more prevalent during the energy crisis in Europe starting in 2021, during which, for example, the IEA and EU outlined key energy saving actions for Europeans to reduce dependence on Russian fuels (EC, 2022). Action to reduce energy consumption has been expected from households also. The problem is that households' energy consumption is related to fulfilling various kinds of needs such as the need to stay warm or the need to take care of one's family (e.g. Shove and Walker, 2014), and conservation actions require changes in routinised everyday behaviours and practices that are steered by shared notions of e.g. thermal comfort, representability, and hospitality (e.g. Laakso et al., 2021b; 2022).

There is a growing field of research that focuses on intervening in these escalating expectations that have led to ever-increasing use of energy and other resources despite technological innovations and efficiency measures. Known either as practice-based interventions (Laakso et al., 2021a), or practice-based design (Kuijer and de Jong, 2012), the idea of these approaches is to understand the current situation, co-create knowledge with experts and households on the ways to change practices to be more sustainable, and then test these solutions in real life. In the meanwhile, there is a wide evidence base on interventions designed to change energy behaviours in households and on their immediate impacts, yet the evidence-base of their long-term effects is weak, since most interventions are organised within the time limits of a single project. It is argued that such temporally-bounded interventions in individual behaviours are subject to attrition over time following the withdrawal of the intervention.

To fill this knowledge gap, we investigate the longer-term effects of a practice-based intervention, ENERGISE Living Labs (LLs). In these LLs, conducted as part of the European ENERGISE project in 2018, the participating households developed new ways of keeping warm and doing laundry, with the goal of reducing indoor temperatures and laundry wash cycles to save energy. In 2023, we organised a follow-up survey in Finland, and in this paper we qualitatively analyse the survey responses to examine whether the LLs have longer term impacts. We focus on how the new or changed practices that households learned during the intervention have persisted through societal changes (i.e., the Covid pandemic, the energy crisis), and on whether the new practices helped households to better deal with these crises. The impacts of the pandemic on energy and sustainability have been previously discussed e.g., by Greene et al. (2022) and Kanda and Kivimaa (2022). Here, we contribute to, and reframe, the problem of evaluating long-term effects, and critically consider the persistence of small-scale interventions in practices.

2. Persistence of Effects of Practice-Based Household Interventions

2.1. Living Labs as an Intervention Approach

In the 2000s, the notion of 'experimentation' has occupied a central position within the academic field that investigates transformations towards sustainable socio-technical systems. Experimentation in this sense can be defined as conducting inclusive, real-life and challenge-led initiatives, which are designed to promote system innovation through social learning under conditions of uncertainty and ambiguity (see Sengers et al., 2016). Living laboratories, or living labs, (LL) have proliferated as a particular form of experimentation and as a transition governance tool to drive sustainable development (Bulkeley et al., 2016).

The concept of living labs can be seen as an approach/methodology, an organisation, a system, an arena or an environment involving systemic innovation (e.g. Voytenko et al., 2016). While the range of initiatives that call themselves living labs is diverse, some core characteristics can be identified. Almirall et al. (2012) note that living labs are driven by two main ideas: (1) involving *users as co-creators* on equal grounds with the rest of the participants, in order to work together to frame research that delivers more effective solutions, and (2) intentional *experimentation in real-world settings* that make social and/or material alterations. LLs are not just focused on services or technologies but also on how various technologies and practices interact in the context of consumption and lifestyles, and as other forms of social experimentation. They are initiated by research organisations and universities, as well as by communities, firms and grassroots organisations (e.g. Voytenko et al., 2016).

Social practice theories (SPT) have also gained prominence in studies of (especially mundane) consumption and sustainable consumption (see, e.g., Keller et al., 2016; Welch and Warde, 2015). SPT argue for interventions that do not target individual attitudes or behaviours but focus instead on practices, such as laundering and heating homes, as well as the underlying notions of cleanliness and comfort that are the causes of energy consumption in households. In contrast to behaviours, practices are also seen as socially-shared, bundled with other practices, and embedded in social structures and processes. Recent years have seen some practice-based suggestions for how to reduce household energy use. With regards to space heating and cooling, these are often linked to the notion of heating or cooling the people rather than the space (e.g. Strengers, 2014). Some studies have investigated practice-based approaches to reduce hot water use by new, energy-conserving bathing practices and adaptive washing skills, supported by the use of social benchmarking information, suggestions for culturally accepted forms of washing, and automatic adjustments to flows of water-using devices (Kuijer et al., 2013). Interventions around laundry practices have challenged the conventions of cleanliness by engaging people to wear the same pair of jeans for months without washing them (Jack 2013). A practice-based intervention thus aims "to disrupt, relocate, innovate, redirect or otherwise reorient" the practices in question (Strengers et al., 2014: 74).

2.2. Persistence of Intervention Effects

Interventions focusing on energy behaviours (e.g., by providing tips and feedback) commonly struggle with attrition of effects over time (e.g. Composto and Weber, 2022; Khanna et al., 2021). They may have significant effects in the short term, but these effects fail to persist once the intervention is withdrawn. Interventions that involve changes in physical infrastructures might have better persistence over the duration of the equipment or investment (e.g. Allcot and Rogers, 2014; Bergquist et al., 2023), but these effects are often lower than predicted, and may degrade as the equipment ages (Vine et al., 2014). Commitments and other team-based methods have been found to render relatively persistent results (Burns and Savan, 2018), but overall, the evidence on persistence of energy interventions is quite patchy (Vine et al., 2013).

Practice-based interventions are expected to render more persistent effects, since they do not target simple energy behaviours, but underlying patterns of consumption that result in energy use, influencing material, meaning and competence elements in the performance of practice. Using behavioural terms, this could include habit-formation, changes in physical infrastructures, changes in self-perception and identities, and changes in social reinforcement – which are all more persistent than behavioural responses (Frey and Rogers, 2014). Moreover, these interventions aim to target "practices as entities", i.e., socially-shared understandings of the practices, rather than merely individual performances of practices (e.g. perceptions concerning appropriate levels of cleanliness).

3. The Context of Research: the ENERGISE Living Labs

The ENERGISE project implemented LLs in an experimental setting in various contexts in eight European countries, and with a particular focus on the longer-term effects of the experiment. Furthermore, the collective elements employed in the LLs aimed at supporting the scalability and stability of the novel ways of heating and washing laundry (Sahakian et al., 2021). The design and process of executing the LLs are described in detail in the project's webpage (www.energise-project.eu; see also Laakso et al. 2021b).

The LLs were designed so that participants faced a heating and a laundry-related challenge and had to adjust their everyday lives accordingly for 7 weeks. Most of the LL participants in Finland voluntarily took on a challenge to halve the number of wash cycles in laundry and reduce indoor temperatures to 18°C. The households reduced the number of wash cycles on average by one-third, and the room temperatures by 1°C (Sahakian et al. 2019). Heiskanen and colleagues (2019) report that households used more alternative ways of keeping the clothes clean, such as washing and brushing stains from clothes instead of washing the whole piece, and simply wore clothes for longer without washing them. Many also separated their work and home clothes, with home clothes being washed less often warm clothes such as woollen socks were used quite commonly already before the heating intervention but were shown to increase during the LL intervention. The participants also got used to cooler indoor temperatures, and some found that they slept better in new, cooler temperatures (Heiskanen et al., 2019).

The societal context has changed significantly since 2018, thanks to the COVID-19 pandemic. In Finland, digital services were well developed already when the pandemics started and switching to home office or home-schooling did not cause much difficulty (Andere, 2021; OECD, 2020). Some experts believe that the pandemic has changed working practices permanently as remote work has now become more of a rule than an exception in many professions (Erdsiek and Rost, 2022). Finland has been considered a country that survived the pandemics in a good manner (EURACTIV, 2020; Kinnunen, 2021).

The second shock was caused by the impacts of the Russian invasion of Ukraine and its energy war against Europe (European Council, 2023). Russia cut its electricity and wood imports to Finland altogether during 2022, which led to fears of energy shortages during the winter season of 2022-2023 (Statistics Finland, 2023). Energy prices rose in an unprecedented manner and many struggled to pay their electricity bills. Energy consumption was reduced by eight percent in October 2022 compared to the year before (Fingrid, 2022), much thanks to the actions of normal people in their everyday lives, and Finland did not suffer any blackouts.

4. Research Data and Methods

Data was collected in several stages prior, during and after the intervention. The baseline survey was executed four weeks before the start of the intervention, and a closing survey was sent seven weeks after it started. The first follow-up survey was executed three months after finishing with the LLs, in March 2019. To capture the longer-term effects of the Finnish LLs, we conducted another follow-up survey four years after the end of the intervention. The most recent follow-up survey was sent to 25 out of 37 households, those who had participated in the LLs and who could still be reached by email in April 2023. We received 21 responses. The survey questions followed the structure of the previous follow-up survey conducted in 2019, with additional questions regarding the impacts of the Covid-19 pandemic and the energy price crisis for heating and washing laundry. We also asked whether the respondents considered their participation in the project was useful in terms of the lessons learned for less energy-using practices regarding cleanliness and thermal comfort. This research compares the average results of the two follow-up surveys to see if practice changes have persisted from 2019. We also examine the responses related to the questions on Covid-19 and energy crises to understand whether having taken part in the challenges to reduce the indoor temperature or halving the number of laundry cycles has given participants competences that they could use during exceptional times.

There are some important limitations to consider. There may be some bias in those who answered towards being more interested in these topics and thus perhaps more active in their everyday lives towards energy saving (yet, only four did not response, so the impact may not be very severe). In addition, we cannot combine the datasets from 2018/19 with 2023 to match respondents as responding was anonymous. We also wish to point out that the numbers of temperature or of laundry cycles from prior, at the end and three months after the LL cannot be directly compared with the numbers from the survey in 2023. This is due to differences in measurement and reporting. The average numbers for temperatures and numbers of laundry cycles in 2023 are based on the self-evaluation of the respondents, whereas the numbers from 2018-2019 are based on temperature measurement with temperature saving loggers and the laundry cycles on diary data that the respondents kept each time they washed laundry. Therefore, the numbers from 2023 should be treated as more indicative and not as exact as from 2018-2019. Due to the qualitative difference of the data between datasets and small number of responses, we cannot calculate any statistical significance. We thus focus on the qualitative content analysis and present quotes from the responses as an illustration of typical responses and complement it with the quantitative, comparative examination of the survey data.

5. Findings

5.1. Changes in indoor temperatures and heating-related practices

71% of 21 respondents stated that the temperature in their homes has remained at the reduced level that they had set as a target during the project. The respondents assessed their 2023 living room temperature as 19.7°C, on average (Table 1). Prior to the LL in 2018, the average living room temperature was 21.1°C and during the intervention, the temperatures reduced on average by 0.9°C to 20.1°C (Heiskanen et al. 2019). Many respondents explain the reason for keeping the lower temperature with experiences gained during the project: that 18 degrees at home is doable, that they can manage the lower temperatures quite well, and that the project provided novel understanding of reasons for heating, which is why the change is permanent: "*The goal of the project was to understand why, and that is why the change is permanent*" (R12). Further explanations for keeping temperatures low were the price of energy, the overall temperature reduction of the central heating in the housing company, and a new home in which it is possible to control the temperature better.

Table 1. Living area temperatures and numbers of laundry cycles from prior to LL to four years after

	Average before, August 2018 (n=40)	Average directly after, December 2018 (n=36)	Average 3 months after, March 2019 (n=33)	Average, April 2023 (n=21)*
Living area, °C	21.2	20.2	20.3	19.7
Numbers of laundry cycles per week	3.7	2.6	2.4	2.4

Source: Heiskanen et al. (2019) and novel calculations for 2023.

The respondents were asked questions with regard to their heating practices. The questions included a list of practices which they were asked whether they now engaged more or less in. Figure 1 presents the change in practices as reported by the respondents right at the end of the LL, 3 months after closing, and in 2023. The findings show that the share of respondents engaging more in a practice 4 years later is higher in all practices than right after the LL.

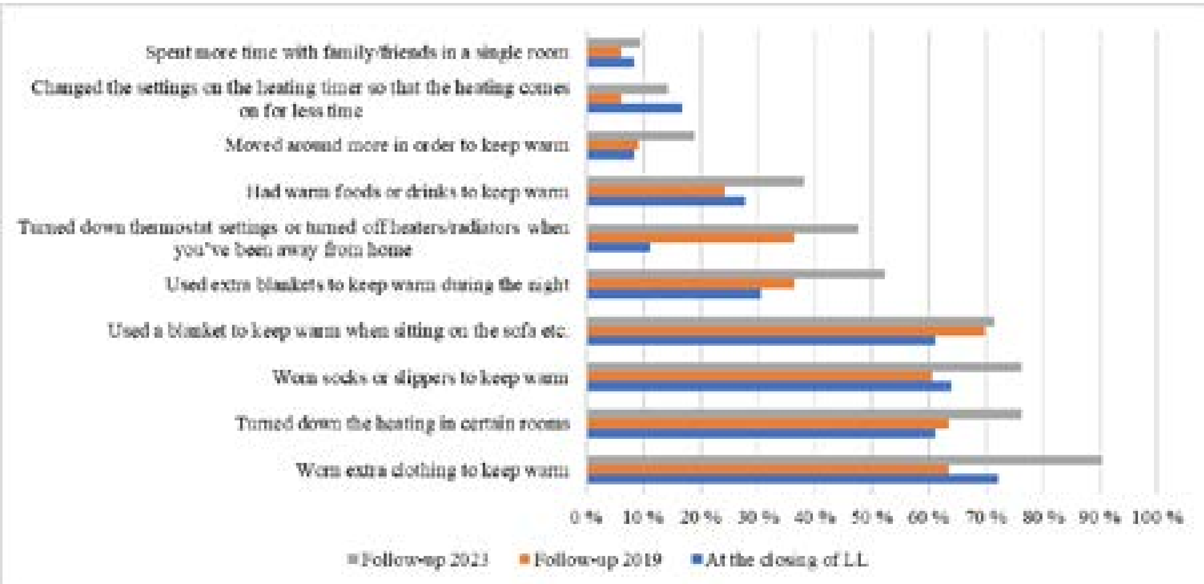

Figure 1. Change in heating related practices compared to time before the LL experimentation

The observations in Figure 1 suggest that the participants have adopted and retained a repertoire of ways to stay warm without turning up the heat. These include extra blankets, extra clothing and adjusting the temperature in different rooms, which is not usually a standard practice in Finland (Karjalainen 2009).

5.2. Changes in washing laundry

Related to the laundry intervention, respondents reduced the number of their daily laundry cycles from 0.52 to 0.38 (a reduction of 0.15) per day during the intervention (Heiskanen et al. 2019). In the follow-up survey in 2023, the respondents evaluated the number of their laundry cycles as 0.34 per day (Table 1). 71% of respondents stated that the number of their laundry cycles is the same as during the intervention, and 19% of respondents reported having reduced the number of cycles even further. One respondent explained several ways, in which they had attempted to reduce the amount of laundry purposefully further: "*Awareness. Taking care of clothes, adding smart materials such as wool. Cleaning the closet for clothes, reducing clothes, and dressing smarter*" (R12). None of the respondents had increased the number of laundry cycles (even though one family had had another child).

Also related to laundry, survey questions listed a set of practices, and the respondents were asked whether they now engaged in the practice more or less frequently than before the LL intervention. Figure 2 presents the change in practices as reported by the respondents. As in the case of heating, many practices were performed more often than before the LLs: the respondents examined clothes carefully to see if they needed washing, aired clothes and removed stains to postpone washing the whole piece, and washed fuller loads. These were also the main ways to reduce washing laundry listed by one of the respondents: "*The understanding that emerged during the project is that laundry does not need to be washed so often. Removing stains, airing clothes, using separate work clothes*" (R5). However, slightly used clothes were not stored to be reused before washing as often as during the LLs, and colder wash temperatures and eco programmes were used less often.

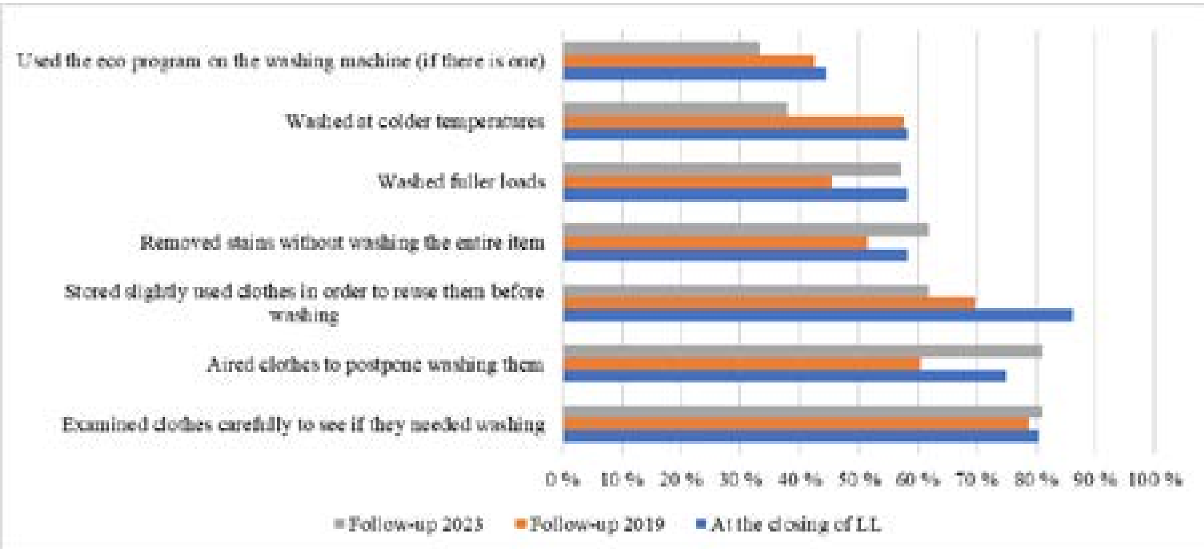

Figure 2. Change in laundry related practices compared to time before the LL experimentation

5.3 Impact of the energy crisis and Covid-19 on heating and washing laundry

Related to the energy price rises, we asked whether it motivated the households to reduce their room temperatures or the number of laundry cycles washed. 57% of respondents reported that they had reduced their room temperatures, 38% that they had reduced washing laundry, and 38% responded that they had done nothing as a reaction to the rising energy prices. Based on this survey, 40% had reduced indoor temperatures and 60% had washed full laundry loads.

The respondents explain the changes in their energy use for heating by saying that they lowered the temperatures in some spaces such as in the bedroom and in rooms less used, for example on the upper floor or in outside spaces. Many respondents had also tried to avoid using electricity for heating and instead used wood stoves and fireplaces.

The Covid pandemic seems to have impacted energy consumption for heating less than the energy crisis. There are, however, some changes to be seen caused by both crises. During the pandemic people had to stay at home more, which could be expected to increase the need for indoor heating. The respondents stated that because they were more at home, they could better control heating for example with the fireplace, and the increased home cooking provided indirect heat from the stove and oven.

The energy crisis changed the number of laundry cycles of one third of the respondents. It had more influence on the washing temperature: 19% stated changes towards colder wash temperatures. Other changes include washing laundry more seldomly or during the times when electricity is cheaper, such as during the night. The electricity price thus influenced practices despite only 14% of the respondents stating that the energy crisis had caused them financial difficulties during the previous nine months (as from July 2022).

When asked if the respondents had discussed energy saving with others, the results are strikingly similar compared with the follow up survey from 2019, where the respondents were asked if they had shared their experiences from LLs with others 71% of the respondents have discussed with their friends and more than half with their relatives, followed by colleagues and other household members (38%), while the shares were 73%, 48%, 39% and 33% in the previous survey, respectively.

6. Discussion and Conclusions

Our aim in this paper was to examine whether the living lab intervention, which took place in 2018, had longer-term impacts for the energy use of participating households. Based on our findings from the 2023 follow-up survey several participating households showed persistent practice changes. Respondents explained that participating in the LL had brought them a novel understanding of their energy use and taught them various ways to live in colder temperatures without having to compromise their comfort. Similarly, people had learned adaptive practices to avoid doing laundry as frequently, and change ways of thinking about cleanliness.

The respondents also indicated that their energy consumption for heating has changed somewhat due to the energy crisis, and therefore we cannot claim that the temperature reductions were solely due to the lessons learned in the LL intervention. Nevertheless, an increased understanding of their energy-consuming practices and positive experiences with the

LL were highlighted in the responses, while no one indicated the energy crisis as the main cause for reduced indoor temperatures.

Also the impacts of the Covid-19 pandemics for energy use cannot be ignored (cf. Greene et al., 2022; Kanda and Kivimaa, 2022). It has permanently changed the way of working and most of the respondents reported working both at home and at the workplace, which reduces the need to wash work clothes as frequently but has different kinds of implications for indoor heating, as described in the previous section. Nevertheless, we can assume that the changed practices of keeping warm and clean during the pandemic supported less energy-intensive living. However, the responses also show a decline in usage of colder wash temperatures and eco-programmes, of which former could be explained with the increased expectations of hygiene during the pandemic, while the latter is somewhat surprising as the respondents also reported how they could wash laundry during the daytime when working from home, so using longer eco-programmes should not have been a problem at least from the time-use perspective.

A limitation related to the persistence of practices indicated by this research relates to the small number of respondents. We could thus make no statistical analysis of significance because the sample was so much smaller than in 2019. In addition, there may be a bias towards interested respondents. We can however conclude that organising such experimental practice-based living labs is not a futile exercise as they can indeed teach normal people novel ways to organise their everyday life and adopt persistent practices contributing towards sustainability. Nevertheless, the problem with such interventions is that they often are small-scale and laborious due to the intense interaction with the participants - a problem that still remains unsolved. However, the findings show households exchange experiences with several others, so there is some upscaling potential and an indication that the lessons learned in an intervention may have broader influence.

As we experience the effects of global warming, unexpected situations are more and more likely to arise. The types of low-energy practices that households adopted in our LL are likely to help the participating households adapt to changing circumstances and live well, or at least better, through various kinds of energy crises. In this way, they can enhance households' flexibility and resilience, and perhaps, one day, also the resilience of the entire energy system.

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References

Allcott, H., & Rogers, T. (2014). The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. *American Economic Review, 104*(10), 3003-3037.

Almirall, E., Lee, M. & Wareham, J. (2012). Mapping living labs in the landscape of innovation methodologies. *Technology Innovation Management Review, 2*(9), 12-18.

Andere, E. (2021). Why were Finnish schools so successful with distance and in-person learning during the pandemic? A blog post Aug 4, 2021. Available at https://blog.oup.com/2021/08/why-were-finnish-schools-so-successful-with-distance-and-in-person-learning-during-the-pandemic/, last accessed Aug 16, 2023.

Bergquist, M., Thiel, M., Goldberg, M. H., & van der Linden, S. (2023). Field interventions for climate change mitigation behaviors: A second-order meta-analysis. *Proceedings of the National Academy of Sciences, 120*(13), e2214851120.

Bulkeley, H., Coenen, L., Frantzeskaki, N., Hartmann, C., Kronsell, A., Mai, L., ... & Palgan, Y. V. (2016). Urban living labs: governing urban sustainability transitions. *Current opinion in environmental sustainability, 22*, 13-17.

Burns, S. B., & Savan, B. (2018). The post-intervention persistence of energy conservation behaviors: An evaluation of the 'Start Green'Program. *Sustainability, 10*(3), 809.

Composto, J. W., & Weber, E. U. (2022). Effectiveness of behavioural interventions to reduce household energy demand: a scoping review. *Environmental Research Letters, 17*(6), 063005.

European Commission (2022). The European Commission and the IEA outline key energy saving actions. European Commission News article, Apr 21, 2022. Available at: https://commission.europa.eu/news/european-commission-and-iea-outline-key-energy-saving-actions-2022-04-21_en, last accessed Aug 16, 2023.

Erdsiek, D. & Rost, V. (2022). Working from home after COVID-19: Firms expect a persistent and intensive shift, ZEW Expert Brief, No. 22-06, ZEW - Leibniz Centre for European Economic Research, Mannheim. http://hdl.handle.net/10419/271652

EURACTIV (2020). Finland: Europe's quiet success in Covid-19 fight. Nov 4 2020. Available at: https://www.euractiv.com/section/languages-culture/news/finland-europes-quiet-success-in-covid-19-fight/, last accessed Aug 16, 2023.

European Council (2023). Infographic - Energy crisis: Three EU-coordinated measures to cut down bills. Available at: https://www.consilium.europa.eu/en/infographics/eu-measures-to-cut-down-energy-bills/, last reviewed March 23, 2023.

Fingrid (2022). Electricity consumption fell by seven per cent in October. Press release Nov 1, 2022. Available at https://www.fingrid.fi/en/news/news/2022/electricity-consumption-fell-by-eight-per-cent-in-october/, last accessed Aug 16, 2023.

Frey, E., & Rogers, T. (2014). Persistence: How treatment effects persist after interventions stop. *Policy Insights from the Behavioral and Brain Sciences, 1*(1), 172-179.

Greene, M. Hansen, A., Hoolohan, C., Süßbauer, E. & Domaneschi. L. (2022). Consumption and shifting temporalities of daily life in times of disruption: undoing and reassembling household practices during the COVID-19 pandemic. *Sustainability: Science, Practice* *and Policy, 18*(1), 215-230.

Heiskanen, E., Laakso, S., Apajalahti, E.L., & Matschoss, K. (2019). ENERGISE Living Lab country report - Finland [Data set]. Zenodo. https://doi.org/10.5281/zenodo.3354053

Jack, T. (2013). Nobody Was Dirty: Intervening in Inconspicuous Consumption of Laundry Routines. *Journal of Consumer Culture 13*(3), 406–421. doi:10. 1177/1469540513485272.

Kanda, W. & Kivimaa, P. (2022). What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? *Energy Research & Social Science, 68*, 101666.

Karjalainen, S. (2009). Thermal comfort and use of thermostats in Finnish homes and offices. *Building and Environment*, *44*(6), 1237-1245.

Keller, M., Halkier, B., & Wilska, T. A. (2016). Policy and governance for sustainable consumption at the crossroads of theories and concepts. *Environmental Policy and Governance*, *26*(2), 75-88.

Khanna, T. M., Baiocchi, G., Callaghan, M., Creutzig, F., Guias, H., Haddaway, N. R., ... & Minx, J. C. (2021). A multi-country meta-analysis on the role of behavioural change in reducing energy consumption and CO2 emissions in residential buildings. *Nature Energy, 6*(9), 925-932.

Kinnunen, A. (2021). Finland: Working life in the COVID-19 pandemic 2020. Industrial relations and social dialogue. European Foundation for the Improvement of Living and Working Conditions (Eurofound), 2021. Available at https://euagenda.eu/upload/publications/wpef21014.pdf, last accessed Aug 16, 2023.

Kuijer, L. & de Jong, A. (2012). Identifying Design Opportunities for Reduced Household Resource Consumption: Exploring Practices of Thermal Comfort. *Journal of Design Research, 10*(1–2), 67–85. doi:10.1504/JDR.2012.046140.

Kuijer, L., Jong, A. D. & Eijk, D. V. (2013). Practices as a unit of design: An exploration of theoretical guidelines in a study on bathing. *ACM Transactions on Computer-Human Interaction (TOCHI), 20*(4), 1-22.

Laakso, S., Heiskanen, E., Matschoss, K., Apajalahti, E. L. & Fahy, F. (2021a). The role of practice-based interventions in energy transitions: A framework for identifying types of work to scale up alternative practices. *Energy Research & Social Science*, 72, 101861.

Laakso, S., Jensen, C. L., Vadovics, E., Apajalahti, E. L., Friis, F. & Szőllőssy, A. (2021b). Towards sustainable energy consumption: Challenging heating-related practices in Denmark, Finland, and Hungary. *Journal of Cleaner Production*, 308, 127220.

Laakso, S., Matschoss, K. & Apajalahti, E. L. (2022). What is clean and comfortable? Challenging norms and conventions in everyday life toward sustainability. *European Journal of Cultural and Political Sociology*, 9(3), 273-298.

OECD (2020). School Education During Covid -19: Were Teachers and Students Ready? OECD Country note: Finland. Available at https://www.oecd.org/education/Finland-coronavirus-education-country-note.pdf, last accessed Aug 16, 2023.

Sahakian, M., Wallenborn, G. & Godin, L. (2019). Report on the analysis of ENERGISE Living Labs data across all eight participating countries. ENERGISE – European Network for Research, Good Practice and Innovation for Sustainable Energy, Grant Agreement No. 727642, Deliverable No. 5.2.

Sahakian, M., Rau, H., Grealis, E., Godin, L., Wallenborn, G., Backhaus, J., ... & Fahy, F. (2021). Challenging social norms to recraft practices: A Living Lab approach to reducing household energy use in eight European countries. *Energy Research & Social Science*, 72, 101881.

Shove, E. & Walker, G. (2014). What is energy for? Social practice and energy demand. *Theory, culture & society, 31*(5), 41-58.

Sengers, F., Berkhout, F., Wieczorek, A. J. & Raven, R. (2016). Experimenting in the city: Unpacking notions of experimentation for sustainability. In: Evans, J., Karvonen, A. & Raven, R. (Eds.) *The Experimental City* (pp. 15-31). Routledge, London.

Statistics Finland (2023). Venäjältä tuodun energian osuus 18 % energian kokonaiskulutuksesta vuonna 2022 (authors' translation: The share of imported energy from Russia 18 % of total consumption in 2022). Review May 17, 2023. Available at: https://www.stat.fi/julkaisu/clhomy00rtq7g0buvlkdxhfig, last accessed Aug 16, 2023.

Strengers, Y. (2014). Smart energy in everyday life: are you designing for resource man?. *Interactions, 21*(4), 24-31.

Strengers, Y., Moloney, S., Maller, C. & Horne, R. (2014). Beyond behaviour change: Practical applications of social practice theory in behaviour change programmes. In *Social Practices, Intervention and Sustainability. Beyond behaviour change,* (pp. 63-77). Routledge.

Vine, E., Hall, N., Keating, K., Kushler, M., & Prahl, R. (2013). Emerging evaluation issues: persistence, behavior, rebound and policy. *Energy Efficiency, 6*, 329–339

Vine, E., Sullivan, M., Lutzenhiser, L., Blumstein, C., & Miller, B. (2014). Experimentation and the evaluation of energy efficiency programs. *Energy Efficiency*, *7*, 627-640.

Voytenko, Y., McCormick, K., Evans, J. & Schliwa, G. (2016). Urban living labs for sustainability and low carbon cities in Europe: Towards a research agenda. *Journal of Cleaner Production, 123*, 45-54.

Welch, D., & Warde, A. (2015). Theories of practice and sustainable consumption. *Handbook of research on sustainable consumption*, 84-100.

Technical and social innovation actions in social housing: a pilot case in the South of Italy

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Abstract

Energy efficiency retrofitting of public social housing is a key challenge for a more sustainable and inclusive society, alleviating energy poverty, increasing living conditions and indoor comfort quality of vulnerable households, improving dwellings and neighbourhoods. However, every action should be inspired by a "people-centric" approach. Within REHOUSE, Renovation packagEs for HOlistic improvement of EU's bUildingS Efficiency, maximizing RES generation and cost-effectiveness", Horizon Europe, ENEA coordinates a pilot case in Italy, in Apulia Region. Interventions on social housing will address both the active and passive components of the building leading to the improvement of the envelope insulation level, while locally producing RES electricity from the Building integrated Photovoltaic Panels located in favourably-oriented façades. PV will be coupled to renovated active energy supply based on the central heat pump, Biobased PCM storage. It is crucial that innovative technological solutions installation is based on occupants' acceptance, including co-design elements, since end-users and even those stakeholders not used to participate in research/innovation projects become an integral part of the process. Households have been engaged since the beginning of the prototype specifications, through social requisites elicitation, and thanks to a social task force.

The methodology has started from a mutual understanding, with interviews and questionnaires, this operation was carried out by experiences and surveys in presence and proximity (ethnographic approach). A bottom-up approach aims at achieving new behaviours in the future renovated dwellings. Therefore, starting from an empirical analysis of users' needs we have acquired useful information to reach high level of acceptance of innovations.

1. INTRODUCTION

REHOUSE is a project co-funded by the European Commission's Research and Innovation Programme Horizon Europe, with the goal to rise, in the scope and productivity of the renovation process, the improvement of comfort and satisfaction of the building inhabitants and users, and the increased use of integrated solutions for the decentralized generation of renewable energy. The project started in October 2022 and in the next four years, eight innovative and holistic solutions for efficient, cost-effective, and sustainable renovation processes (RPs) will be developed in 4 demo sites: Greece, Italy, France, and Hungary respectively. ENEA, the Italian National Agency for new Technologies, Energy and Economic sustainable Development, is the Italian DEMO responsible and has decided to carry out the pilot experience in Apulia Region renovating a social housing building.
Rehouse project aims to pursue a "people-centric" approach in the phases of design, development and demonstration of the RPs, considering end-users and stakeholders involvement in order to acquire a high level of social acceptance of the innovations, securing the well-being of the users, and reaching a sustainable built environment. This is especially relevant in the Italian Demo, where the end users' target group includes vulnerable people.
Italy allocated relevant financial resources to renovate the social housing building stock as a measure to fight energy poverty, as mentioned in the Italian NECP [i]. Outcomes of REHOUSE actions can provide a methodology to be implemented in a large scale and adapted to different chosen technical solutions.
The methodology carried out in the Italian Demo, in Margherita di Savoia, is based, in part, on an "action research" approach as developed in the field of social sciences. Main aim of such method is to achieve a *behavioural change*.
An "action research", consists of a participatory research methodology conceived both as a form of knowledge and as a transformation of reality in which the object of study can be considered as a participating subject (Lewin, 1948 and 1951); all that in order to underlying causes of a behaviour and allowing future predictions on possibilities and/or ways to change it, both on a personal and a group level (Sunding & Ekholm, 2015; Stevenson, Baborska-Narozny & Chatterton, 2016; Petrescu, Petcou & Baibarac, 2016; Xiao, Luo & Li, 2023; Sagaris, Peñafiel, Orellana & Guajardo, 2023). From this perspective, an "Action research" approach aims to improve the quality of behaving within a social situation, through a *practical* evaluation. The validity of the "theories" or hypotheses that it generates strictly depends on their usefulness in helping people to act in a more intelligent and skilful way (for example, in the use of energy in Margherita di Savoia's homes).
In a nut shell, key words of an action research might be: *complexity* (attention to all aspects of a phenomenon and all dimensions of the human being), *sensitive listening* (based on empathy), *collective researcher* (the subject of research is made up of the researcher and all the actors involved) and *change* (the purpose of the research is not knowledge, but the

[i] *INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN* - Ministry of Economic Development, Ministry of the Environment and Protection of Natural Resources and the Sea, Ministry of Infrastructure and Transport – December 2019, Italy https://energy.ec.europa.eu/system/files/2020-02/it_final_necp_main_en_0.pdf

introduction of changes in a practice, in a behaviour) (Barbier, 2007).

3. REHOUSE METHODOLOGY FOR A PARTICIPATION APPROACH

3.1. Rehouse pilot case

The main objective of the REHOUSE project is to develop and demonstrate eight renovation packages of promising technology innovations until TRL7), in 4 DEMO sites in different countries (Greece, Italy, Hungary and France). Each Demo-site represents a type of building (social housing and student dormitory buildings) in a specific climate area, with different peculiarities and different type of inhabitants. For each demo-sites, the challenge is to drive tenants in innovation technology acceptance, and to pave the way to an energy behavioural change in managing day-to-day new technologies.

In the Italian Demo-Site, two renovation packages are foreseen: 1) centralized holistic H&C renovation kit and 2) multipurpose façade system with bio-based insulation and BIPV. These packages will lead to the improvement of the envelope insulation level while locally producing RES electricity from the BIPV (Building Integrated Photovoltaics) located in favourably oriented façades (295 m^2) plus 120 m^2 of fixed conventional PV on the rooftop. PV will be coupled to the renovated active energy supply based on the central heat pump, the PCM (Phase Change Material) storage, as well as the smart energy distribution (based on the installation of the smart rubber solution at 2 strategic points of each one of the 8 flats). The envelope will include prefabricated façade integrated system: it incorporates hemp-based insulating materials and easy-to-install aesthetic BIPV panels into a dedicated exoskeleton to be specifically designed to support these individual components. The innovative plant is designed around a commercial reversible air-to-water heat pump fed by onsite BIPV and connected to the innovative stratified bio-based PCM Thermal Energy Storage system.

Thanks to the "picture" of the real social and environmental situation in each DEMO site, an experimental methodology has been proposed by ENEA, which is characterized by a bottom-up approach, tested in the Italian Demo site during the first year of the project.

The two pillars of this process adopted are a participatory approach to collect useful information and sharing experiences with end-users, and the identification of solutions (action-research) to avoid problems in the design and operation phase of the building energy renovation process.

The starting point was a "participatory design approach" that put together the expertise of the system designers and researchers, and the perceptions and needs of people being affected by the change. As mentioned in "Co-creation and the new landscapes of design" by Elizabeth B. N. Sanders and Pieter J. Stappers (Sanders & Stappers, 2008) it means co-design in a "broader sense to refer to the creativity of designers and people not trained in design working together in the design development process".

In such a way, in REHOUSE the role of designers became now less about 'designing for' and more about 'designing with' users and other stakeholders. In the end users' engagement phase, face-to-face meetings were organized and structured and semi-structured interviews

conducted. The interviewer team was composed by a group of three or four people: stakeholders (owners and managers of the building), researchers, working with designers, and social task force representatives.
The set of questions of the interviews and the guide were prepared together with representatives of two key actors: ARCA Capitanata, the territorial housing agency, and Apulia Region, playing a doble role as facilitator (thanks to the experience and skills of the person in charge of the activities) and co-financing the energy renovation of the building.
The questionnaire, the structured part of the interview, has been the baseline shared among partners project to be adapted and tailored to the different case studies of the projects and the different end users, but allowing to collect comparable data.
In Italy, the pilot case is the demo site of a social housing in Margherita di Savoia in an Adriatic coastal municipality in the Apulia (South of Italy). It is a four stories building, where eight families have been living since the final construction (in 1986).
In the years, the typology of families has changed: at the beginning households with more than two or three persons, now most of them are elderly, living alone, and with health problems. Only in one apartment there are children.
The “action-research” started involving stakeholders: ARCA CAPITANATA organized a public event in a public school, inviting citizen and demo site tenants. The students at the school (attending their last year of study on "wine and food" and "dining and sale services") prepared the buffet and welcomed participants. In this occasion, the mayor of Margherita di Savoia, with the regional assessor of welfare and regional assessor of territorial planning, landscape, urban planning and housing policies, welcomed to the participants and introduced the strong interest of the local community and locale policy to the project actions and results. The public event paved the way to social activities of the projects, highlighting the need of all the community involvement, starting from tenants of Demo site. A “social task force” has been created for each REHOUSE Demo site, after the relevant stakeholders mapping. Regarding the Italian case, they are: tenants, as before mentioned; ARCA CAPITANATA, owner and manager of the building and partner of the project; neighbourhoods; church (owner of an external space useful for tenants and neighbours); nursery school.

3.2. Methodology for energy and indoor behavioural analysis

The methodology here proposed started with a picture of the state of the site from the technical and social point of view, since every energy renovation process, specifically in a social housing, needs to start with the energy audit, structural analysis, analysis of behaviour on energy use and indoor comfort, and social context. In Margherita di Savoia, in occasion to the technical visit sites related to energy audit and structural analysis, social factors have been investigated. The first part of the energy audit (still in progress) represents the state of the building that is going to be renovated.
The building is in a marginal area of Margherita di Savoia, part of a cluster of similar ones, all characterized by problems of physical degradation of the building and social vulnerability of its occupants.

Fig. 1 Model of the building

The demo building has a rectangular footprint with four floors and eight apartments, and it is built in reinforced concrete frame with poor insulation. These constructive specifications cause problems of heat dispersion and housing discomfort due to summer temperatures, inadequate, natural ventilation, old facilities as well as presence of architectural barriers. The heat supply relies on natural gas boilers, while there is not any cooling equipment nor onsite renewable energy production facilities. The first steps of the energy audit (performed with the commercial tool TERMUS) produced a 3D BIM model of the building and a first analysis of energy consumption. The main critical issue has been the data consumption collection because of the lack of some utility bills, therefore energy and methane data were obtained directly by the energy provider. Data reported by TERMUS software detected different situations of energy consumption in each apartment. It focused some apartment the consumption was very low, and far from ordinary consumption of other flats.

Data reported by TERMUS software shows different situations of energy consumption and in some cases anomalous results can be observed (electricity consumption is very low).

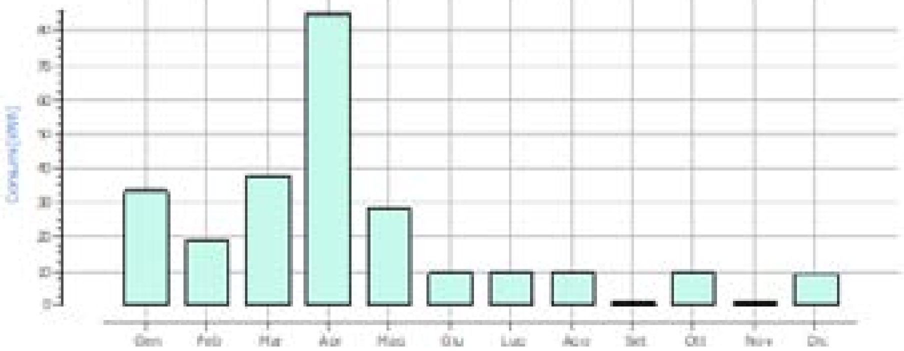

Fig. 2 Diagrams of energy consumption anomalous compared with a usual one of the same building (methane)

The integrated approach, investigating both technical and social aspects, will permit to answer to this anomaly, monitoring real data and end users' behaviours.
The energy audit requires data, but also information on end users' perceptions and needs, this in order to better integrate the innovative technology in modelling the building.
Moreover, this approach aims at integrating further social aspects, for the purposes to support designers of the Renovation Packages to improve the technology and facilitate the technology acceptance. In order to explore and investigate tenants' needs, two meetings in presence were organized to be able to put in relation the social context with the energy audit first step.
Results of households' interviews show that accommodations are generally perceived as cosy, nevertheless the presence of humidity is a common condition. For this reason, windows are open during the day to facilitate ventilation, and dampness affects all the rooms in the accommodations.
In addition to humidity, another phenomenon detected is the presence of drafts, especially near the windows and the entrance doors.
All households have led lamps and appliance in class A.
Nobody uses a thermostat; a switch on/off management system for heating is used. Only two apartments have air conditioner, the others use ventilators. Concerning heating system, radiators (natural gas boiler) are in all the apartments.
Householders expressed satisfaction about natural lighting, however interviewers noted that during the morning, the roller blinds were closed, and lamps were on.
The first interview concerned the knowledge of the tenants (age, employees, etc) and their perception and awareness on the impact of their behaviour (perception on heating, cooling, humidity, light, use of appliances, etc). The basic idea was to understand the grade of satisfaction as well as expectations of the end users, in order to identify needs that can be met thanks to the renovation work, as well as elements for improvement proposals and ideas to share with stakeholders during the next stage of the action (engagement action).
The interviews were useful also to introduce "pills" of knowledge on energy efficiency among

the tenants, asking questions and by explaining the technicians' work. In this way, on one side, useful information on users' behaviour was collected and, on the other side, information on the correct use of electricity was transferred.

Face-to-face meetings have reported needs and expectations related to the neighbourhood. The results will be used not only for traditional "compensatory measures" to increase end-users' acceptance, but also to start a co-design process, thanks to a bottom-up approach, based on the principle that energy efficiency refurbishment of buildings does not only affect indoor comfort and/or energy saving, but it has also an impact on the life quality standard of neighbourhood/city area, from an urban regeneration perspective.

The questionnaire tested in the Italian Demo-site has been translated into English and distributed to the Rehouse partners, in order to collect comparable findings also in the rest of Demo sites.

The questionnaire was divided in 5 sections.

The section A includes specific items to identify the occupant profile (gender, age, employment) and to recognise the apartment features where each respondent lives.

The section B includes items related to indoor air quality and ventilation behaviour, and if this can affect comfort levels. It is mainly focused on energy behaviour and users' habits, by providing, at the same time, simple tips to raise awareness on the importance of lightness, water use, and adequate temperature for heating and cooling.

The section C is about the building characteristics: dampness and drafts presence; acoustic comfort perception, water provision; shading percentage; heating and cooling systems and grade of satisfaction on these.

The section D aims at inquiring knowledge level and features concerning building automation systems.

The section E is a survey on issues such as safety perception, cultural, health and social infrastructures and transportation at neighbourhood/district level.

Findings are summarized and included in a matrix: items of the questionnaire matching with social actions, compensation actions, support to designers and developers of the innovative solution (Renovation packages); key performance indicators, energy audit; communication and information activities.

This methodology approach showed how by actively involving end users by assessing their needs and habits and cross-referencing this data with the technical audits carried out by professionals and building owner requisites made it possible to merge a top-down approach with a bottom-up one in the project's implementation.

Fig. 3 Circle of correlations with main actors of an energy renovation process

4. CONCLUSIONS

The results of this approach in Demo site allow the building owner and designers to plan interventions that meet tenants' needs and not only technical requirements, identifying "non-negotiable" issues for an implementation success: for instance, from technicians' point of view, the need to replace all the frames, even where they have been replaced recently, as well as to remove existing loggias or verandas, or from tenants' point of view, the installation of an elevator. The virtuos cycle explained in the previous paragraph, shows the common perception that the neighbourhood is not safe. Moreover, the need to improve life quality conditions emerged not only for each single accommodation but also at the neighbourhood community level, promoting the creation of freely usable socialization and meeting spaces. The whole process follows the logic of a dialogue aimed at the "acceptance" of a "top-down" technological intervention proposal by the project partners, which however was reformulated, "bottom up approach", thanks to an elicitation of information and proposals obtained both from semi-structured interviews and meetings. The meetings held in the area of the Italian demo site of Margherita di Savoia have been essentially based on this methodological approach, highlighting:

- The "empathic relationship" sought to establish between the recipients of the behavioural investigations, the facilitators and the experts in the action of illustrating the project proposals and above all "listening" to end users' doubts and opinions
- The consequent "active inclusion" (involvement) of the actors (the tenants and the various stakeholders)
- The research and planning action, thus becoming "collective", cannot avoid examining the "complexity" of the intervention and the context in which it will develop.
- All in order to reach a "change" not only in relation to daily energy uses, but also with a view to imagining and planning neighbourhood developments and shared social spaces.

The whole process follows the logic of a dialogue aimed at the "acceptance" of a "top-down" technological intervention proposal by the project partners, which however was reformulated

thanks to an elicitation of information and proposals obtained both from semi-structured interviews and meetings. From this perspective, the action takes the form and value of co-design. (Schuler & Namioka, 1993; Beyer & Holtzblatt, 1998; Kensing, 2003; Kuiper, 2007; De Carlo, 2013).
The aim of the REHOUSE project, and in particular the Italian Demo-Site, is to respond to expressed needs, in a perspective of *social innovation* (Westley, McGowan & Tjornbo, 2017; Hubert, 2010; Mulgan, 2019). All this to achieve a level of "sustainability" of this innovation over time, also thanks to the acquisition of a behavioural change aimed at consolidating profitable use of the innovations introduced. As we have seen, the cognitive and participatory actions can work to strengthen a social group: a simple "collective" thus becomes a "community". This basis can represent the beginning of a social cooperation contributing to spreading more productive behaviours in the field of energy consumption and, more generally, pro-environmental issues. In fact, many of the different "levers" for behavioural change, as codified in the scientific literature, are based, among others, on the assumption of sharing "social norms", which thus become "drivers" of the actions both collective and individual (phenomenon of the so-called "conformism"). Multiple methodologies and techniques were tested, with the aim of achieving behavioural change in the field of energy consumption. (Thaler & Sunstein, 2009; Bertini, Diana, Disi, Di Mario, Corcos & Delli Colli, 2017; Kegan & Laskow Lahey, 2018; Lopes, Henggeler Antunes & Janda, 2019; Medojevic, Medojevic & Delic, 2021).

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5. REFERENCES

1. Barbier R. (2007) *La ricerca - azione*. Roma, Armando
2. Bertini I., Diana M., Disi A., Di Mario C., Corcos S. & Delli Colli S. (2009) *CAMBIAMENTO COMPORTAMENTALE ED EFFICIENZA ENERGETICA - Report Stati Generali Efficienza Energetica 2017*. Roma, ENEA - Agenzia Nazionale Efficienza Energetica.

3. Beyer H. & Holtzblatt K. (1998) *Contextual design: Defining customer-centered systems*. San Francisco, Morgan Kaufmann.
4. Bouzarovski S. (2015) *Retrofitting the City - Residential Flexibility, Resilience and the Built Environment* (p. 121). London. Bloomsbury Publishing.
5. De Carlo G. (2013) *L'architettura della partecipazione*. Macerata, Quodlibet.
6. Hubert A. (2010) *Empowering People, Driving Change: Social Innovation in the European Union*. BEPA – Bureau of European Policy Advisers, Brussels.
7. Kegan R. & Laskow Lahey L. (2018) *Immunità al cambiamento: come liberare nuove potenzialità (in noi e nella nostra organizzazione)*. Milano, Franco Angeli.
8. Kensing F. (2003) *Methods and Practices in Participatory Design*. Copenhagen, ITU Press.
9. Lewin K. (1948) *I conflitti sociali. Saggi di dinamica di gruppo*. Milano, Franco Angeli.
10. Lewin K. (1951) *Teoria e sperimentazione in psicologia sociale*. Bologna, Il Mulino.
11. Lopes M., Henggeler Antunes C. & Janda K. B. (2019) *Energy and Behaviour Towards a Low Carbon Future*. Cambridge - Massachusetts, Academic Press.
12. Medojevic M., Medojevic M. & Delic M. (2021) *An integrated framework of factors affecting energy-related user behaviour*. International Journal of Sustainable Energy, 40:4, 364-388, DOI: 10.1080/14786451.2020.1811280
13. Mulgan G. (2019) *Social Innovation: how societies find the power to change.* Policy Press, Bristol.
14. Petrescu D., Petcou C. & Baibarac C. (2016) *Co-producing commons-based resilience: lessons from R-Urban.* Building Research & Information, 44:7, 717-736, DOI: 10.1080/09613218.2016.1214891
15. Pink S., Fors V., Lanzeni D., Duque M., Sumartojo S. & Strengers Y. (2022) *Design Ethnography - Research, Responsibilities, and Futures*. London, Routledge.
16. Sagaris L., Peñafiel J., Orellana R. & Guajardo M. F. (2023) *Participatory pedagogies enhance engineering education for sustainability*. Educational Action Research, DOI: 10.1080/09650792.2023.2240858.
17. Schuler D. & Namioka A. (1993). *Participatory design: Principles and practices*. Hillsdale, Erlbaum.
18. Stevenson F., Baborska-Narozny M. & Chatterton P. (2016) *Resilience, redundancy and low-carbon living: co-producing individual and community learning*. Building Research & Information, 44:7, 789-803, DOI: 10.1080/09613218.2016.1207371
19. Sunding L. & Ekholm A. (2015) *Applying social sciences to inspire behavioural change in the construction sector: an experimental study*. Construction Management and Economics, 33:9, 695-710, DOI: 10.1080/01446193.2015.1090619.
20. Thaler R. H. & Sunstein C. R. (2009) *Nudge Improving Decisions About Health, Wealth, and Happiness.* London, Penguin Publishing Group.

21. Kuiper G. (2007) Participatory planning and design in the Downtown Eastside: Reflections on Global Studio Vancouver, Australian Planner, 44:2, 52-53, DOI: 10.1080/07293682.2007.9982573.
22. Westley F., McGowan K. & Tjornbo O. (2017) *The Evolution of Social Innovation*. Edward Elgar Press, London.
23. Xiao J. X., Luo M. J. & Li W. (2023) *From the fuzzy front end to the back end: A participatory action research approach to co-design promoting sustainable behaviour*. The Design Journal, 26:1, 32-51, DOI: 10.1080/14606925.2022.2113262
24. Yarrow T. (2016) *Negotiating Heritage and Energy Conservation: An Ethnography of Domestic Renovation*. The Historic Environment: Policy & Practice, 7:4, 340-351, DOI: 10.1080/17567505.2016.1253149

How can energy demand research advance racial justice? The case of the UK

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Abstract

This paper shares findings from research at the intersection of energy demand and racialisation — an under-researched topic in Europe. We sought to understand the reasons for this gap, and identify potential approaches to address it in the UK, through a scoping literature review, semi-structured interviews, and a stakeholder workshop. The scoping literature review identified 36 publications that focused on energy and racialisation. The majority of these were about the United States, used quantitative methodologies, and performed analysis at the city and national-level, especially in the residential sector, and also focused on energy demand. Participants for semi-structured interviews (n=27) and one project workshop (n=45) were identified among energy demand and social justice researchers and practitioners. Interviews covered understanding the current situation (at an experiential and structural level), aspiration (through a pluralistic definition of racial justice), and learning from other disciplines like gender and energy. The workshop was used to obtain feedback on emerging insights. Thematic analysis revealed the following areas for further investigation—(a) Energy services where people demonstrably experience racialisation, namely, built environment, transport, health, and food; (b) Processes through which racialised people are disproportionately impacted by energy system governance, especially with respect to energy demand practices, low-carbon technologies, energy advice services; and (c) Methods to strengthen the evidence's explanatory power in a non-extractive manner. The paper concludes with a call to further research the diverse energy practices and needs of racialised people, thereby challenging assumptions around an archetypal low-carbon energy consumer, and implications for energy justice. **Funding**: This work is funded by the Centre for Research into Energy Demand Solutions (CREDS), supported by a UK Research and Innovation grant [EP/R035288/1].

1. INTRODUCTION

Consequent to the George Floyd protests and the global resurgence of the Black Lives Matter movement in 2020, the Centre for Research into Energy Demand Solutions (CREDS) realised that there was a dearth of research at the intersection of energy demand and racial justice, especially in the context of the United Kingdom, its primary geography of focus. In response, CREDS commenced scoping research to understand this gap and is building towards a research agenda to further racial justice in energy demand research.

While it is important to understand when, what, and how much energy is demanded, it is equally important to understand *who* uses this energy, and *how* they are able to use it. In this research, we focus on how racialisation ascribes 'racial' meaning to people's everyday identities, positions and values, largely through structural and institutional mechanisms. These result in affective as well as material consequences, including unequal access to opportunities and services that disadvantages overall well-being of racialised people (Bonilla-Silva, 2020; Meghji, 2020). At the societal level, racialisation can be experienced as (but not limited to)—

- Adults belonging to ethnic minority groups being more severely affected by the ongoing cost of living crisis (ONS, 2022), and austerity measures that have reduced welfare benefits and discriminate against them (Bhambra & Holmwood, 2018; Edmiston, et al., 2022);
- Unequal healthcare provisioning, especially in the wake of COVID-19 (Camargo, 2020; Public Health England, 2020), thereby impacting their overall well-being;
- Language barriers to obtaining consumer advice and support, as English might not be their first language (Hodges, et al., 2022);
- Households categorised as 'ethnic minority' tending to live in more overcrowded and dilapidated housing conditions (The Health Foundation, 2023), thereby experiencing fuel poverty more severely as 75% of recent migrants (those living in the UK for less than 5 years) are in the private rented sector, which has some of the poorest energy efficiency ratings (Bouzarovski, et al., 2022). Furthermore, one in three homeless people in London being non-white (Gulliver, 2017);
- Racialised communities being situated farther away from access to essential services and public transport options, increasing their risk of transport poverty (Gates, et al., 2019).

Investigating the racialisation of the energy system requires understanding it at a societal level, and specifically, exploring how this might manifest within the energy system. Firstly, who is assumed to be a typical energy user or early adopter of technologies that will aid in rapid decarbonisation, and what does that mean for those who might not fit that assumption in terms of accessing the services and technologies to assist low-carbon practices (Newell, 2021; Middlemiss, 2022)? Secondly, do we understand the diverse and complex energy needs and practices of racialised people? How responsive or inelastic could those practices be to what is considered popularly as low carbon lifestyles (Owen, et al., 2023)? Finally, are existing opportunities to participate in the energy system racialised, thereby contributing to unfair decisions? Could that affect the way problems are defined and solutions are designed? This paper raises these questions, as current research on these topics is limited in scope, contexts and methods, specifically in the UK but also across Europe. It is intended as a framing paper to initiate further conversations and commitment towards anti-racist energy demand research.

2. BACKGROUND: SCOPING LITERATURE REVIEW

We carried out a scoping literature review that focused on publications where race or ethnicity were central themes in exploring research on the various dimensions of energy. The review focused on four broad themes—(a) different dimensions of energy (across demand and supply) and their interaction with racialised factors, (b) energy justice, fuel poverty and just transitions, (c) social theories applicable to energy research (such as energy sociology, structuration, etc.), and (d) the UK's historic landscape of racialisation. This search shortlisted 36 publications, which demonstrated the characteristics illustrated in Figure 1.

Most studies that consider energy and any aspect of racialisation pertain to the United States. The studies are largely focused on the national level, followed by city-level analysis. This can potentially be explained by the focus on the US, where most studies of racialisation focus on inner-city experiences. While it is instructive to draw inspiration from this existing work, it is also important to recognise the differences in the organisation of the energy systems among these contexts, and their histories of racialisation. Quantitative analyses dominate the scoping review sample, being nearly double those of qualitative approaches. We observe an almost equal balance between primary and secondary data, but it is the availability of secondary data that allows for larger scale (such as national-level) quantitative studies. While the broader environmental and climate justice narratives have focused on the extractive nature of the energy system, be it in terms of siting infrastructures, mining or pollution and their impacts on local communities, studies that focus on race and energy are focused on energy demand—in terms of exploring residential energy efficiency around heating and lighting, weatherization/ energy retrofitting/ fabric improvement, or around ability to access energy advice especially in coping with energy poverty. And therefore, we see that this research also focuses to a greater extent on the residential sector, though we should also explore what it means for other sectors with a significant and growing energy demand such as transport.

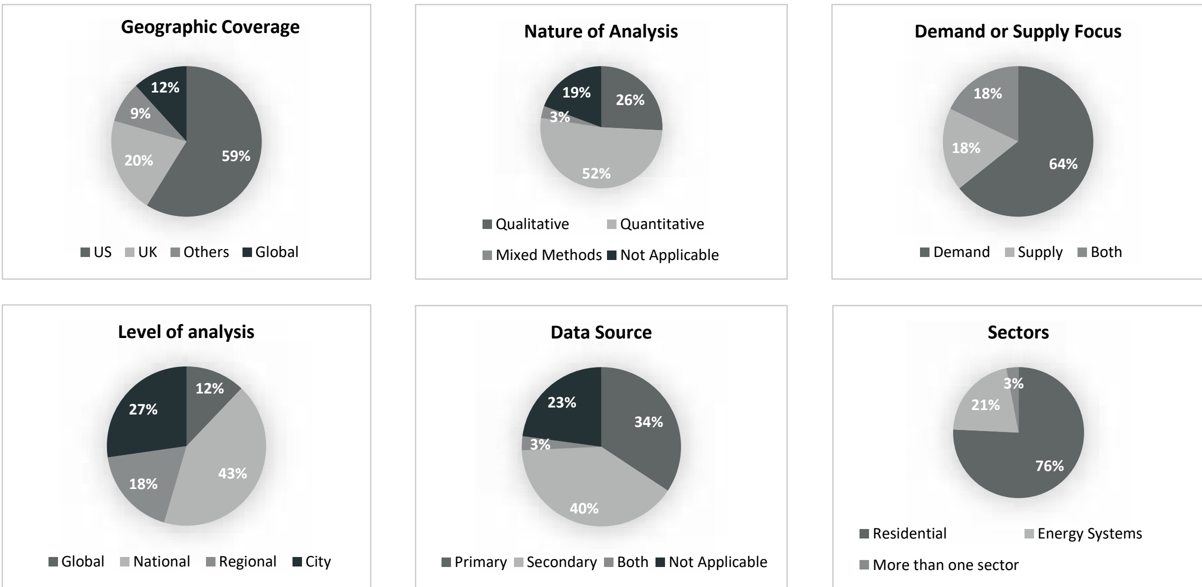

Figure 1: Observations from the scoping literature review of 36 publications discussing energy & racialisation

While there is broad consensus on the dearth of research surrounding the relationship between racialisation and energy demand, specifically in the UK, some of the reasons behind the persistence of this gap include—challenges around bridging research and action across different scales and actors (Forster, et al., 2019; Raslan & Ambrose, 2022), availability of data and its appropriate classification in a manner that is useful for analyses but also non-essentialising (D'Agostino, et al., 2011; Ahmadzadeh, 2021; Bouzarovski, et al., 2022), and a lack of sufficient diversity within the research community to allow for multiple perspectives (Blakelock, 2021; EPSRC, 2022).

Apart from the built environment (Huebner, et al., 2022; Rutten, 2020), and transport (Schwanen, 2018; Gates, et al., 2019; Mattioli & Scheiner, 2022), which are two of the most significant drivers of energy demand (DESNZ, 2023), health (Hernandez, 2016; Camargo, 2020; Huebner, et al., 2022; Race Equality Foundation, n.d.) and food (Reames, 2016; Reames, et al., 2018; Martiskainen, et al., 2021) emerged as areas where there is an acknowledged link but where a need to build further evidence on the relationship between racialisation and energy demand remains. Specifically, within the built environment we require evidence around housing (Gulliver, 2017; D'Souza & Khan, 2021; Raslan & Ambrose, 2022), especially in the private rented sector (Bouzarovski, et al., 2022), and heating and cooling needs (Kidwell & Ogunbode, 2022). Similarly, transport not only considers daily commute (Gates, et al., 2019), but also air travel (Mattioli & Scheiner, 2022), and mobile work (Hopkins & Davidson, 2022). Processes to manage energy demand are also potentially racialised. These include aspects around practices of using and managing energy, accessing energy advice services (Forster, et al., 2019; Hodges, Schmidt, & Becker, 2022; Sovacool & Rio, 2022), acceptance and trust towards low-carbon technologies (Lennon, 2017; Owen, et al., 2023), as well as the overall governance of the energy system (Newell, 2021; Lennon, 2021; Bouzarovski, et al., 2022).

Conceptualising racial justice with respect to the energy system broadly fell under three categories—(1) an extension of the energy justice tenets (Jenkins, et al., 2016; Jenkins, et al., 2020), (2) drawing on the historical contexts of colonialism and racial capitalism in establishing these energy systems (Kothari, 2006; Lennon, 2021; Bhambra & Newell, 2022), and (3) framing around opportunities and ease of accessing services (Creutzfeldt & Gill, 2021; Bouzarovski, et al., 2022; Forster, Hodgson, & Bailey, 2019). Achieving the vision around any of these categories requires explicitly anti-racist approaches with respect to data collection (Ahmadzadeh, 2021), effective engagement among researchers and those who are being researched (Blakelock, 2021; Creutzfeldt & Gill, 2021), robust conceptualisation of social theories in the context of energy demand (Cannon & Chu, 2021; Bouzarovski, 2022; Sovacool, et al., 2023), and corresponding analysis, and principles of political education and engagement (Kapoor, et al., 2022). During the course of this review, the following research questions emerged that became the foundation for further empirical data collection.

Table 1: Research questions

Status-quo	*Agency*: How do we understand the energy use experiences of people and communities who also experience racialisation? *Structure*: What role do organisations play in perpetuating or addressing injustices?
Aspiration	What can racial justice in energy demand look like? What is required to achieve it?
Contexts	What can we learn (or unlearn) from other contexts, movements and agendas?

3. METHODS

The outlined scoping literature review was complemented with semi-structured interviews and a project workshop to corroborate insights from the review, as well as build on them to respond to the research questions identified in Table 1. Empirical data was analysed thematically.

Data collection: Semi-structured interviews (n=27, of whom at least eight respondents had experienced racialisation) were conducted among researchers and practitioners working on energy as well as social justice, across Europe. The respondents were identified through their association with CREDS, and authorship of publications identified in the literature review, followed by a snowball sampling approach. The semi-structured interviews alluded to the three research questions identified in Table 1. Preliminary results were presented in an online workshop in April 2023 to obtain feedback on the emerging findings, and an invitation to further the findings in the participants' respective work—this included 45 participants from research, academia and industry engaged in energy and/or social justice work in the UK and Europe, some of whom had already participated in the interviews.

Data analysis. Empirical data was analysed thematically, using nVIVO. A thematic analysis was identified as the analytical approach, since the objective of the research was to improve our understanding of the research gaps, and identify focus areas to further energy demand research that is anti-racist. The coding tree was developed inductively from the interview data, and further triangulated against the insights from the scoping review. This led to the analytical structure demonstrated in Figure 2. The approach strengthened the insights from the review. For instance, mobile work as a dimension of enquiry did not emerge from the literature, but the racialisation of platform economy-based mobile work in the UK was discovered during the interviews. The workshop was designed around the four enquiries that emerged from the thematic analysis (Figure 2), and formed the basis for the findings presented in Section 4 that were finalised based on the insights and feedback from the workshop.

4. FINDINGS

The analytical enquiry begins with a recognition of the dearth of research linking energy demand and racialisation, in the UK. In responding to the research question on status-quo, the analysis first sought to understand the challenges around why this research gap persists. In the spirit of articulating an agenda on this, the remaining three analytical enquiries adopt a more action-oriented approach—beginning with the energy services where evidence needs to be built and strengthened, understanding the processes within the energy system that further racialisation, thereby speaking to procedural justice, and finally, ways to practice and sustain anti-racist principles in energy research, especially as a research centre established to further energy demand research. This section is structured upon this logic, as shown in Figure 2.

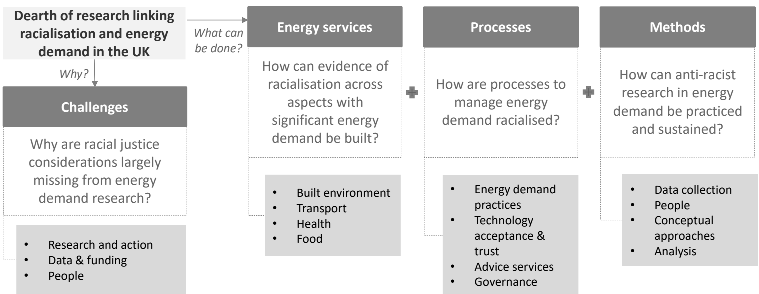

Figure 2: Thematic analysis structure

4.1. Challenges: Why are racial justice considerations largely missing from energy demand research?

Research and action: Linking a systemic issue like racial justice to specific empirical studies on energy use presents a challenge of bridging different scales—linking contemporary lived experiences with historic structural factors. Institutionalised racism within the energy system might not appear obviously associated with everyday experiences of accessing energy services. In circumstances where evidence already exists, it is important to translate the diagnoses into actionable interventions that can be embedded in practice. As observed by an interview respondent: *"We need more intervention studies. Try to change something. What are the impacts of that? Because we often just correlate and don't try to make interventions."* (AES4[1]). Another challenge is the tendency to conflate class and race, with unhelpful hierarchies being created between representation versus redistribution that risks overlooking experiences (Fraser, 1998)—for example, whilst the UK's leadership in fuel poverty research is widely recognised

[1] These are respondent signifiers, AE: Academic (Energy), AES: Academic (Energy & Social Justice), PE: Practitioner (Energy), PS: Practitioner (Social Justice), PES: Practitioner (Energy & Social Justice). The numbers merely signify the sequence in which they were interviewed.

(Bednar & Reames, 2020), it does not translate to a recognition of its racialised nature.

Data and funding: Racism might appear evident in certain aspects of society, thereby making remedial responses such as affirmative action, plausible. However, with respect to energy use it is not obvious, unless the relationship between structural issues and everyday experiences is consciously investigated, such as proactively considering those who might be overlooked in the transition to net zero. As noted by Blakelock (2021), data pertaining to race and ethnicity characteristics (which is what most data on racialisation is usually reduced to) is not collected often, nor across all relevant datasets. This is corroborated by this quote: "*It would mean that we put equal emphasis on the voices of ethnic minorities, as of the typical white household. So that we collect as much data from them as from other parts of the population. And I think that's the part where we have spectacularly failed in the past*." (AES4). Some datasets are too small to conduct statistically significant analysis with adequate de-identification. Furthermore, many respondents opined that limited funding opportunities result in uncoordinated and restricted studies with limited explanatory capacity that might be unable to comprehensively address these research gaps —*"There are small amounts of money out there to do research on this issue. But little pots of money mean that researchers pick up small scale studies.*" (AES8).

People: The energy efficiency community and the energy poverty community might be working towards similar priorities, but those might be parallel efforts because there is insufficient overlap between them. Lack of diversity in these communities also contributes to the perception that transition to net zero energy system is a 'white, middle-class, predominantly male' concern—a constant refrain observed throughout many of the interviews. Labelling those outside this demographic group as 'hard-to-reach' or 'difficult-to-engage' puts the onus of action on already marginalised people rather than the system. The private rented sector, for instance performs very poorly on energy efficiency and contains some of the worst building stock across the UK. This link between energy efficiency, housing and racial justice remains largely unexplored. Some of the reasons for this research gap include (1) the absence of a clear contact person (like a housing or a tenants' association representative), (2) the research design is not considerate to the needs of people and how they could benefit from the research and hence do not have the incentive to participate, and (3) many immigrant tenants are vulnerable to the UK Home Office's hostile environment policy that makes them ineligible for most forms of state welfare support, and might be reluctant to candidly share negative experiences.

4.2. Energy services: How can evidence of racialisation across energy services be built?

Built Environment: Whilst respondents recognised housing as a significant component to investigate, they also reflected that it is important to expand the scope to look at the broader built environment, not just the buildings that people inhabit (which significantly determines their energy use and access to technologies such as installing solar PV or heat pumps or smart meters that can be challenging in multi-storeyed housing projects, where certain racialised people are overrepresented), to have a more comprehensive appreciation of the spaces that people use. The location and quality of housing is determined by several socio-economic factors, which may in turn determine the type of contract that those who are tenants might hold with their energy supplier. Poor housing security and poor-quality building stock makes installing energy demand reduction measures (like insulation) less appealing, leading to higher energy use and costs. This is especially a challenge in the private rented sector—*"If you're in the private rented sector, it's gonna be really hard to get panels on your roof or any of these things that you need to be able to shift your demand and still have access to the energy services that that you need, especially because your tenure is short or uncertain.*" (PES2) Many local authorities, who used to have a more grounded perspective of the buildings in the neighbourhood that needed insulation and the corresponding ability of residents to fund these interventions through their local area action plans, no longer have those powers. Three respondents also brought up the increasing vulnerability to heatwaves being experienced across UK cities, their racialised nature, and its potential to alter the seasonal energy demand profile.

Transport: The interview responses explored the relationship between transport, energy and racialisation beyond the daily commute, and reflected on nuances pertaining to air travel, mobile work, and accessibility of low carbon modes such as active travel. The ability to choose transport modes, and exposure to longer commute time is racialised (thereby increasing the risk of exposure to extreme temperatures and air pollution). Low-emission and active travel are not equally accessible to all members of the population. Living close to public transport increases property prices, crowding out those less able to pay, who are ironically in greater need of public transport. Air travel also varies by different social groups—*"Even families on really low incomes will set aside money to do that international flight every year to go back and see family. That is very different in comparison to a flight to a European weekend getaway.*" (AE3). Another dimension that emerged from the interviews, and was not explicit in the literature is mobile work, those who provide mobility services such as van and food delivery drivers, especially in the context of digitalised platform economies—"*Thinking about mobile work is a clear entryway into thinking about racialised mobility*." (AES5).

Health: Respondents provided an expansive framing to understand the significance and relationship between health, racialisation and energy demand. They recommended not to consider health as merely a dimension requiring energy but also to consider the health outcomes of poor energy use, and how racialised experiences of energy use can contribute to poor health outcomes. Therefore, energy poverty should not be framed merely as an economic problem but one with significant health and well-being implications. Healthcare workers can also act as crucial intermediaries in research involving community engagement.

Food: Respondents recognise that people hold strong cultural ties with food that is important to understand with respect to diverse energy practices. Respondents observed that labour in the food retail sector also tends to be racialised, and its relationship with energy demand requires further attention. Food can also be a way of building trust when engaging with communities.

4.3. Processes: How are processes to manage energy demand racialised?

Energy demand practices: People have complex and diverse energy practices that may not always lend themselves to obvious energy conservation practices or flexible time of use—some tactics to manage energy demand. Respondents corroborated the observation by Hodges, Schmidt, & Becker (2022) that energy users from multi-generational households (largely represented by people from an Asian background (ONS, 2023)) had energy demand profiles that could not always be as flexible—*"It's really about that agency and scope for people to do things differently. I've seen this in behavioural change research, it is assumed that people are constantly picking from a menu. For a lot of people, for a whole set of reasons, that menu is pretty constrained.*" (AES11). This also complicates assumptions and definitions surrounding average household energy use. Simultaneously, energy conservation practices of racialised people as they navigate the energy system, must be recognised, and emulated where appropriate. These could include practices such as switching off heating in rooms that are not occupied. However, we need to be cautious in ensuring that coping mechanisms to overcome hardship are not idealised, because—"*Many a times, trauma can resemble culture."* (PS1).

Technology acceptance and trust: While research recognises the role of public acceptance of technologies to decarbonise, there is not enough work on who constitutes that public. However, there is recognition that different groups engage differently with technologies depending on how easy they are to use, as well as how intrusive they might appear (for example, the technical possibility of smart meters to convert to prepayment meters). Female household members make the majority of the household choices about energy use, but are not always in charge of monitoring energy consumption or paying the bills, especially in the context of increased digitalisation, automation and penetration of smart home technologies. The types of decisions being made in these contexts are different (day-to-day versus one-off decisions) and need to be distinguished from each other, as do the intersections between the different interdependent and relational identities and power that people hold in their lives—*"If we are designing and developing stuff and then putting it out in the world, but we have not talked to and included the people who will ultimately benefit or not from this, that is bound to fail. So the classic example is putting heat systems in people's houses and the control system is built by an engineer or a technical-minded person. It might make sense to them in the lab to know how a thermostat works, but it makes absolutely no sense to the user, who doesn't really need to know that, but does need to know how to set it to be warmer during the weekend.*" (PES3)

Advice services: Many racialised people, especially recent immigrants and asylum seekers, are unaware of ways to access energy advice services that could support their decisions around energy suppliers and choice of competitive tariffs—for instance, deciding between fixed and standard variable tariffs, and which of those might be most suitable given their energy needs and the suppliers' responses to changes in wholesale prices. While energy suppliers are obliged to maintain a Priority Services Register (PSR) service of vulnerable customers (including those with extra communication needs or limited knowledge of English), this does not help those who are unaware of it. People who have experienced discrimination from authorities also feel uncomfortable accessing services, even those they are entitled to receive. Language barriers further complicate this—"*If English is not your first language, you cannot effectively obtain the information you want.*" (PES3). Owing to significant funding constraints, most of the advice support available is for emergency responses, rather than something more continuous.

Governance: The supplier-hub model positions the energy supplier as the primary determinant of consumer needs, and their construction of the 'typical' energy user tends to overlook the diversity of energy users and their needs. Suppliers are obliged to publish quarterly implementation data on their energy efficiency programmes, which includes number of properties insulated, type of insulation, cost, etc., but is silent on the nature of beneficiary households and why they were targeted. This is an example of how policies and interventions could exacerbate racialisation or unequally distribute the costs and benefits of the transition—"*Rather than 'leaving no one behind', we should consider 'who should be taken along first'."* (AES8). Local authorities and community action groups are often the first point of contact for communities. Their responsibilities and power to influence decisions need to be understood.

4.4. Methods: How can anti-racist research in energy demand be practised and sustained?

Data collection: Data collection and processing is political, not value neutral. While it is foundational to building evidence, it has its limits. Respondents acknowledged that it is important to be conscious about who is collecting the data, for what purposes, and whose needs are expected to be met by the research. For example, more systematic, better coordinated research would help to avoid participant research fatigue, and more longitudinal studies would support a more historically-sensitive understanding of the issues, and track their nuances over time. Oversampling the relevant group ensures that the data is representative and can be meaningfully analysed, whilst still protecting anonymity. Moving beyond essentialising categorisations like ‘ethnic minority’ is important to build understanding on the continuous and dynamic process of racialisation– the nuance of this data is still very limited. Properly informed research should ask specific questions, understanding what issues affect which people, so as to recognise the participants’ experiences and not essentialise them within homogenising categories. Harmonising this data between the devolved nations would also help (as ‘ethnic minority’ means different things across the different nations of the UK). Case studies should exemplify a range of experiences rather than selecting reified cases because they might be convenient. It is well acknowledged in energy research that consumers’ levels of agency to make ‘rational’ choices vary. For instance, where one lives, in what kind of house, significantly influences heating and transport ‘choices’. Research about energy user experiences (especially around energy source), type of energy supplier (decentralised/ traditional market-oriented), and type of energy user are relevant in this context. Understanding users’ experiences are crucial to the design of interventions and to inform policy. Linking this experiential data with an understanding of how institutional mechanisms perpetuate exclusion ensures that racialised people are not blamed for practices that actually emanate from such institutions. In some cases, the work may be extremely sensitive, such as groups exposed to higher criminalisation. Where necessary, engaging through trusted intermediaries, such as NHS case workers or community leaders, or shop keepers, is a useful way of reaching them. When doing this work, it is essential legitimate to pay people to compensate them for their time and contribution, acknowledge their involvement by co-producing the research outputs, and it is very important to consider issues of safeguarding, for researchers and their participants.

People: Researchers should acknowledge their positionality when considering an appropriate research design. In some circumstances, the researchers’ relative positions of power should be responsibly applied to highlight and further particular agendas—making one’s normative starting point and position explicit, while acknowledging other approaches, and dimensions (of vulnerability, for example), can be a useful starting point. Consideration needs to be given to the framing of participation and its methods – are citizens’ assemblies and participatory budgeting sufficiently representative, and the appropriate methods to elevate marginalised voices? To be trusted in communities, researchers need to respectfully use community practices and should consider taking bottom-up approaches that work with communities to identify the subject of the research so that it is beneficial to the needs and priorities of the community.

Conceptual approaches: Social theories rooted in a recognition of intersectionality help make sense of the diversity of people’s experiences of energy use, structural privileges and its consequences on their daily lives. This is an opportunity to further embed social theories within energy research. This helps identify which challenges are systemic or specific and, consequently, where best to direct interventions. For example, if income is the predominant challenge, responses could include subsidies and benefit schemes, though mistrust in formal institutions or being ineligible for state support might mean such ‘solutions’ need to be delivered differently, and traditional ‘units’ of analysis such as households and ‘families’ rethought (it is well-known that female-headed, single parent households are one of the most vulnerable to fuel poverty, for example).

Analysis: Like data collection, analysis is also not value neutral. Respondents recognised that the causal explanatory power of most quantitative studies remains limited, and suggested intervention-oriented approaches such as realist evaluations or social-impact assessments to provide useful contributions to this limitation. Qualitative approaches such as discourse analysis were found to be informative in explaining the disjuncture between evidence and ideology. Respondents also recognised that it is the fundamental nature of some evidence to be political. For example, good air quality and access to green spaces are correlated with better health, and there is ample evidence that access to these is racialised. The implication is that by depriving some parts of the community of green spaces, their well-being may be compromised.

5. DISCUSSION AND CONCLUSIONS

This research was envisaged to begin understanding ways to further anti-racist energy demand research. While there are several limitations in conducting this work—ranging from structural (such as participating in the energy system, being dependent on controversial energy infrastructures, and the positionality of researchers), to semantic (negotiating the use of terms like BAME or ethnic minority that are recognised as problematic, but data continues to be collected along these categories)—the paper proposes two approaches as next steps. The first is applying the sociological principle of *transversality* to nuance the relationship between identity and power dynamics, in conducting research of this kind, and the second is the application of a heuristic framework to build upon anti-racist ambition in energy demand research with the caveat of not being teleological and perpetuating epistemic injustices.

It is important to acknowledge and accept that research of this nature is political, and can be uncomfortable. It is important to hold safe spaces, but also engage with the discomfort as part of dismantling systems of injustice, and offering "care across differences" (Eaves, et al., 2023). This should however not compel us to force-fit a singular definition of what anti-racism 'should be'. Racialisation is a dynamic and continuous process, therefore, the objective of this effort is to create analytical space for a pluralistic interpretation, that exists amidst the contradictions and multitudes of the social relations and energy system (Bouzarovski, 2022; Sovacool, et al., 2023). Racialisation persists because of its ability to constantly redefine 'the other' (Meghji, 2020; Meer, 2022). Therefore, as actors engaging with work on racial justice, it is important to resist reductive and essentialising labels such as 'BAME' and 'ethnic minorities', and adopt more flexible ways to understand and articulate the processes of racialisation, and how it impacts identity. A transversal approach could provide a useful starting point to respond to this (Yuval-Davis, 2017; Cannon & Chu, 2021). How do we minimise the risk of homogenising by being sensitive to inter- and intra-group dynamics around power and privilege, and not standardise all characteristics and experiences? This also helps us understand the ways different social divisions are constructed by, and intermeshed with each other, in specific historical conditions. Acknowledging interdependence between various actors, the intersectional nature of their identities, and the relationality of their power and agency vis-à-vis other actors, helps us to challenge unhelpful binaries like 'engaged versus hard to reach' or 'active versus passive energy users', or hold people's identities and powers as a static rather than dynamic relationship (Damgaard, et al., 2022). Future efforts to build on explicitly anti-racist energy demand research should consider transversal politics as a conceptual framework with potential to interpret the differential power positions, differences that engender rather than replace notions of equality, and recognise the layered relationship between identifying with certain social groups, and diversity in their positioning and socio-political values (Yuval-Davis, 1999).

To complement this conceptualisation, with an action-oriented approach, and inspired by works from gender and development, a racial justice 'continuum' (Figure 3) is proposed to articulate and set anti-racist ambition in conducting energy demand research (Kabeer, 1994; UNFPA, 2021). While it is acknowledged that research alone cannot deliver racial justice, a commitment towards ensuring that energy demand research qualifies for the criteria outlined under the 'responsive' category, is a reasonable ambition to begin with. While applying this continuum, it is important to be conscious that the framing is not a teleological vision of achieving racial justice (Seamster & Ray, 2018), and must be interpreted appropriately, as a suggestive scaffolding to think more proactively about anti-racist energy demand research.

Racist	Neutral	Sensitive	Responsive	Racially just
Creates or perpetuates assumptions that discriminate, invisibilise or exclude racialised people's experiences	Ignores racialised differences, needs and power dynamics, and does not allow for building solidarity with other dimensions. "I don't think race is the problem in this case."	Considers race as one among many other factors. Example, adding an indicator on ethnicity, or beginning to collect disaggregated data on ethnicity	Specific action, research or intervention to tackle challenges pertaining to racialisation in a particular context	Address racial injustice and its root causes at a structural level, across all scales of society, institutions and governance

Figure 3: The racial justice continuum (Narayan, 2023)

6. REFERENCES

Ahmadzadeh, Y. (2021, January 27). *Measuring race, ethnicity and ancestry in research: time for new tools.* The EDIT Lab Blog, King's College London.

Bednar, D. J., & Reames, T. G. (2020). Recognition of and response to energy poverty in the United States. *Nature Energy*, 432-439.

Bhambra, G. K., & Holmwood, J. (2018). Colonialism, Postcolonialism and the Liberal Welfare State. *New Political Economy*, 574-587.

Bhambra, G. K., & Newell, P. (2022). More than a metaphor: 'climate colonialism' in perspective. *Global Social Challenges*, 1-9.

Blakelock, E. (2021, March 25). *We need anti-racist fuel poverty policy in the UK.* Medium.

Bonilla-Silva, E. (2020). What makes systemic racism systemic? *Sociological Inquiry*, 513-33.

Bouzarovski, S. (2022). Just Transitions: A Political Ecology Critique. *Antipode*, 1-18.

Bouzarovski, S., Burbidge, M., Sarpotdar, A., & Martiskainen, M. (2022). The diversity penalty: Domestic energy injustice and ethnic minorities in the UK. *Energy Research & Social Science*.

Camargo, A. (2020, December 21). *Delivering health justice*. The Centric Lab

Cannon, C. E., & Chu, E. K. (2021). Gender, sexuality, and feminist critiques in energy research: A review and call for transversal thinking. *Energy Research & Social Science*.

Creutzfeldt, N., & Gill, C. (2021, July 8). *Access to justice for vulnerable people*. Next Energy Consumer.

D'Agostino, A., Sovacool, B. K., Trott, K., Ramos, C. R., Saleem, S., & Ong, Y. (2011). What's the State of Energy Studies Research? A Content Analysis of Three Leading Journals from 1999-2008. *Energy,* 508-19.

Damgaard, C.S., McCauley, D., and Reid, L. (2022). Towards energy care ethics: Exploring ethical implications of relationality. *Energy Research & Social Science.*

DESNZ. (2023). *Digest of UK Energy Statistics (DUKES) 2023: Chapter 1 Energy.* London: Department of Energy Security and Net Zero.

D'Souza, C., & Khan, M. (2021). *Equal Chances | Home Front: Building a New Vision for Social Housing.* London: Fabian Society.

Eaves, L., Gökarıkselb, B., Hawkins, M., Neubert, C., & Smith, S. (2023). Political geographies of discomfort feminism: introduction to the themed intervention. *Gender, Place & Culture*, 517-527.

Edmiston, D., Begum, S., & Kataria, M. (2022). *Falling Faster amidst a Cost-of-Living Crisis: Poverty, Inequality and Ethnicity in the UK.* London: Runnymede.

EPSRC. (2022). *Ethnicity and race inequity in our portfolio.* London: UKRI.

Forster, N., Hodgson, P., & Bailey, C. (2019). Energy advice for Traveller Communities in the context of ethnic & spatial premiums: 'paying the price' for other people's choices. *Journal of Poverty & Social Justice*.

Fraser, N. (1998). *Social justice in the age of identity politics: Redistribution, recognition and participation.* Berlin: WZB Discussion Paper.

Gates, S., Gogescu, F., Grollman, C., Cooper, E., & Khambhaitu, P. (2019). *Transport and inequality: An evidence review for the Department of Transport.* NatCen Social Research/ Dept of Transport.

Gulliver, K. (2017, October 12). *Racial discrimination in UK housing has a long history and deep roots.* Retrieved April 20, 2022, from LSE British Politics and Policy.

Hernandez, D. (2016). Understanding 'energy insecurity' & why it matters to health. *Social Science & Medicine*.

Hodges, N., Schmidt, L., & Becker, D. S. (2022). *Staying warm together: Improving access to energy advice for older and multi-generational South Asian households.* Bristol: CSE.
Hopkins, D., & Davidson, A. (2022). Stories of the gendered mobile work of English lorry driving. *Gender, Place & Culture*.
Huebner, G., Oreszczyn, T., Direk, K., & Hamilton, I. (2022). The relationship between the built environment and subjective wellbeing. *Journal of Environmental Psychology*.
Jenkins, K. E., Stephens, J. C., Reames, T. G., & Hernandez, D. (2020). Towards impactful energy justice research: Transforming the power of academic engagement. *Energy Research & Social Science*.
Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy Justice: A Conceptual Review. *Energy Research & Social Science.*
Kabeer, N. (1994). *Reversed Realities: Gender Hierarchies in Development Thought.* London: Verso.
Kapoor, A., Hood, S., & Youssef, N. (2022). *Confronting Injustice: Racism and the environmental emergency.* London: Runnymede and Greenpeace UK.
Kidwell, J. H., & Ogunbode, C. (2022). *Heatwaves: why UK ethnic minorities are more vulnerable, and what to do about it.*
Kothari, U. (2006). An agenda for thinking about 'race' in development. *Progress in Development Studies*.
Lennon, M. (2017). Decolonizing energy: Black Lives Matter and technoscientific expertise amid solar transitions. *Energy Research & Social Science*, 18-27.
Lennon, M. (2021). Energy transitions in a time of intersecting precarities: From reductive environmentalism to antiracist praxis. *Energy Research and Social Science*.
Martiskainen, M., Jenkins, K. E., Bouzarovski, S., Hopkins, D., Mattioli, G., & Lacey-Barnacle, M. (2021). A spatial whole systems justice approach to sustainability transitions. *Environmental Innovation and Societal Transitions*.
Mattioli, G., & Scheiner, J. (2022). The impact of migration background, ethnicity and social network dispersion on air and car travel in the UK. *Travel Behaviour and Society*. 65-78.
Meer, N. (2022, March 18). *What is the state of racial justice in Britain today?* Transforming Society.
Meghji, A. (2020). Just what is critical race theory, and what is it doing in British sociology? From "BritCrit" to the racialized social system approach. *The British Journal of Sociology*.
Middlemiss, L. (2022). Who is vulnerable to energy poverty in the Global North, and what is their experience? *WIREs Energy and Environment*.
Narayan, U. (2023, July 12). *Guide to racially just energy research.* CREDS Blog.
Newell, P. (2021). Race and the politics of energy transitions. *Energy Research & Social Science*.
ONS. (2022). *Impact of increased cost of living on adults across Great Britain: June to September 2022.* Westminster: Office for National Statistics.
ONS. (2023, May 10). *Families in England and Wales: Census 2021.* Office for National Statistics.
Owen, A., Middlemiss, L., Brown, D., Davis, M., Hall, S., Bookbinder, R., . . . Mininni, G. (2023). Who applies for Energy Grants? *Energy Research & Social Science*.
Public Health England. (2020). *Disparities in the risk and outcomes of COVID-19.* London: PHE.
Race Equality Foundation. (n.d.). *Health and Wellbeing Alliance.*
Raslan, R., & Ambrose, A. (2022). Solving the difficult problem of hard to decarbonise homes. *Nature Energy*.
Reames, T. G. (2016). Targeting energy justice: Exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy*, 549-558.
Reames, T. G., Reiner, M. A., & Stacey, M. B. (2018). An incandescent truth: Disparities in energy-efficient lighting availability and prices in an urban U.S. county. *Applied Energy*, 95-103.
Rutten, K. (2020, December 14). *When will Britain plan for racial justice?* LSE Blogs.
Schwanen, T. (2018). Towards decolonised knowledge about transport. *Nature*.
Seamster, L., & Ray, V. (2018). Against Teleology in the Study of Race: Toward the Abolition of the Progress Paradigm. *Sociological Theory*,
Sovacool, B. K., Bell, S. E., Daggett, C., Labuski, C., Lennon, M., Naylor, L., . . . Firestone, J. (2023). Pluralizing energy justice: Incorporating feminist, anti-racist, Indigenous, and postcolonial perspectives. *Energy Research & Social Science*.
Sovacool, B., & Rio, D. D. (2022). "We're not dead yet!": Extreme energy and transport poverty, perpetual peripheralization, and spatial justice among Gypsies and Travellers in Northern Ireland. *Renewable and Sustainable Energy Reviews*.
The Health Foundation. (2023). *Inequalities in households experiencing housing problems.* Evidence Hub.
UNFPA. (2021). *Gender responsive and/or transformative approaches.* New York: UNFPA, UNICEF.
Yuval-Davis, N. (1999). What is 'transversal politics'? *Soundings*.
Yuval-Davis, N. (2017). Recognition, Intersectionality and Transversal Politics. In Y. Meital, & P. Rayman, *Recognition as Key for Reconciliation: Israel, Palestine, and Beyond* (pp. 157-167). Brill.

A Social Network Approach to Community Energy Participation:

Utilizing Social Network Theory and Analysis to improve initiative success.

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Abstract

This positioning paper argues that a *social network approach* coupled with social network analysis can contribute importantly to creating a more holistic picture of how individual and community characteristics influence participation in *community energy initiatives* (CEIs). First, we introduce the *social network approach* to the research field studying the energy transition and "community energy" in particular. Then, we argue that the *structure* of community social networks connecting (potential) participants might determine whether and how individual and community properties affect CEI participation. We demonstrate how social network theory and analysis methods can be utilized to better understand participation dynamics and how this can aid the implementation of interventions aimed at attracting more participants and increasing their diversity. This is illustrated with empirical findings from our own research. Further, we discuss the connection between research on CEIs and adjacent fields as a foundation for our claims. This approach might have implications for the implementation of community energy and thus help enabling a just and successful energy transition.

1. Introduction

Despite an increasing amount of research on what drives citizen participation in *community energy initiatives* (CEIs), participation dynamics are as yet not well enough understood to enable successful CEI implementation (Germes, Wiekens, and Horlings 2021; Walsh 2021). While researchers scrutinized the potential of CEIs in aiding the energy transition, first findings indicate that lack of acceptance and participation might be a burden to success (Devine-Wright 2011; Germes et al. 2021; Walsh 2021). Consequently, CEIs in the EU struggle with attracting enough community members, which ultimately leads to failure of reaching sustainability goals (Germes et al. 2021; Walsh 2021). Apart from that citizen groups of diverse social, economic, and demographic backgrounds are underrepresented in CEIs, which can lead to local opposition and polarization in the long run (van Bommel and Höffken 2021; Hanke, Guyet, and Feenstra 2021; Hanke and Lowitzsch 2020; Stewart 2021). In this positioning paper we propose that a *social network approach*, rooted in social network theory and utilizing empirical social network analysis (SNA), could importantly improve our understanding of the determinants of CEI participation.

The importance of social network structure for mobilization has been demonstrated in adjacent fields, such as studies of the adoption of technology, and studies of collective action (Borgatti, Everett, and Johnson 2018; Diani and McAdam 2003; Guilbeault and Centola 2021, 2021; Rogers 2003). However, only recently researchers of community energy have begun to highlight the influence of the social context on CEI participation (Fritsche and Masson 2021; Goedkoop 2021; Goedkoop and Devine-Wright 2016; Hargreaves and Middlemiss 2020; Marder et al. 2023) and started to provide empirical evidence underpinning the importance of network structure (Goedkoop, Sloot, et al. 2022a; Goedkoop, Dijkstra, and Flache 2022). While the works of previous scholars that investigated effects of individual and community characteristics on CEI participation provided valuable insights into the underpinnings of CEI participation, we argue that a *social network approach* should receive more attention to achieve a more holistic understanding of local participation dynamics. Simply put, we propose that the social network structure might be a key variable determining whether and how individual and community characteristics affect CEI participation (and hence success). Adopting this approach might not only improve our understanding of CEI participation, but the associated empirical methods of social network analysis (SNA) are valuable tools for designing interventions aimed at improving the implementation of community energy projects.

In the following paragraphs we will first provide some background information on CEIs and introduce previous research on CEI participation. We will then introduce our *social network approach*, provide reasons for why we think such an approach has the potential to both improve our understanding of CEI participation. We will illustrate the power of that approach with examples from our own research. After that we will back up our approach with initial evidence on the effects of social networks on CEI participation and integrate it with adjacent fields of inquiry.

2. Background

Community energy initiatives (CEIs) are bottom up (i.e., citizen-driven) initiatives with common sustainability goals and shared ownership (Bomberg and McEwen 2012; Hamann et al. 2023; Jans 2021). They are also termed renewable or local energy communities (Devine-Wright 2011, 2019; Hanke et al. 2021; van der Schoor and Scholtens 2015), but we stick to CEIs due to the different implicit connotations of other terms (Devine-Wright 2019). CEIs can encompass neighborhood, village and city communities that invest in renewable energy production using green technology. They can be formal or informal arrangements adopting measures from promoting sustainable practices such as insulating homes, investing in warmth pumps and recycling trash on the individual household level to collective projects like community owned solar panel fields or wind turbines (REFs) (Arnould and Quiroz 2022; Goedkoop 2021; Hamann et al. 2023). Often they are founded, owned, and run by local citizens, sometimes with support from local governments or (regional) NGOs and community energy umbrella organizations (Lokale Energie Monitor 2022 2023; Middlemiss and Parrish 2010; Oteman, Kooij, and Wiering 2017). CEIs thus often rely on a volunteer base, sometimes supplemented by (part-time) professional staff in a hybrid model.

The number of CEIs increased throughout Europe in the last decade and the European Commission presents them as an important means to target climate change and enable a just energy transition (Directorate-General for Energy (European Commission) 2019). The purported socially transformative power of CEIs and their potential in aiding the energy transition as well as their more general positive effects on pro-environmental behaviors have also been acknowledged by researchers (Hamann et al. 2023; Hasanov and Zuidema 2018; Middlemiss 2011; Sloot, Jans, and Steg 2017, 2018). To the extent that CEIs are a central component of the energy transition broad CEI participation by all groups of community members is paramount to a successful and just energy transition (Arnould and Quiroz 2022; van Bommel and Höffken 2021; Directorate-General for Energy (European Commission) 2019; Hamann et al. 2023; Hanke et al. 2021).

However, research has shown that CEIs do not always resonate with the public (Devine-Wright 2011; Walker, Wiersma, and Bailey 2014), which is problematic as their success depends on local citizen participation (Devine-Wright 2019). This is also reflected by the number of failed community energy projects that overshadows the number of successful ones in the EU (Walsh 2021). As a result only about 10 GWh (Wierling et al. 2023) of a total energy production of 2785 TWh (Eurostat, EU 2023) is produced through community energy projects in the EU. Furthermore, a recent case study of CEIs in the north of the Netherlands found that most CEIs vanish after some time and those prevailing have only minimal impact in terms of energy production caused by low participation numbers (Germes et al. 2021). National Dutch data supplement and corroborate these findings, indicating that while the number of CEIs increased over the past 10 years and about three in four municipalities harbor a CEI, growth has slowed down recently and less than one percent of the Dutch population participates in a CEI (Lokale Energie Monitor 2022, 2023).

Another reason for stagnant growth and limited impact, is that CEIs struggle with attracting participants from diverse socio-demographic and economic backgrounds (Jesse de Graaff, Anne Marit Popma, and Wieke Meijer 2023). For instance, vulnerable consumers (e.g., those with low incomes or at risk of energy poverty) are often underrepresented and do not profit from CEIs (Germes et al. 2021; Hanke et al. 2021; Heindl, Schüßler, and Löschel 2014; Stewart 2021). This socially and economically biased participation can lead to local opposition to CEI projects (e.g. projects with impact on the local, or subsidies only profiting part of the local community) and political polarization (e.g., "transition for the elites") on the long run (van Bommel and Höffken 2021; Hanke et al. 2021; Hanke and Lowitzsch 2020; Heindl et al. 2014). Such local friction likely undermines the legitimacy of CEIs to act on the behalf of the entire community and diminishes their viability. In this context participation numbers equal success while diverse citizen participation equals justice and success in the long run. Thus, to move away from a "transition for the elites" towards a just energy transition made possible through high civic participation numbers, we need to improve our understanding of CEI participation dynamics among different groups in society: improving our understanding and improving implementation go hand in hand.

To do so, scholars recently proposed to look at the social context in which CEIs are embedded and described CEI participation as a form of *collective action*, while focusing on community characteristics such as *trust, norms* and *identity* and the regional infrastructure (Fritsche et al. 2018; Goedkoop, Sloot, et al. 2022b; Hamann et al. 2023; Hoffman and High-Pippert 2010; Marder et al. 2023; Sloot, Jans, and Steg 2019; Warbroek et al. 2019) rather than just on individual characteristics when scrutinizing CEI participation. This has advanced our understanding of variation in CEI participation as caused by not only individual, but also community and contextual characteristics. However, we propose to go a step further yet, and take a *social network approach* on CEI participation. In a *social network approach*, the structure of networks of social relations between individual actors in the community is the focal point. Via a social network individuals can spread information, sanction undesired behavior, establish norms and coordinate behaviors (Borgatti et al. 2018). Recent evidence indicates that social ties of community members to CEI initiators and community involvement (many ties to other members) indeed predict willingness to participate in CEIs over and above individual attitudes and community characteristics (Goedkoop, Dijkstra, et al. 2022). This resonates in the contributions of several recent studies directing attention to the importance of social relations in the context of community energy and collective climate mitigation behaviors (Constantino et al. 2022; Germes et al. 2021; Hargreaves and Middlemiss 2020). Below, we will therefore introduce what a *social network approach* entails, explain why such an approach could improve both our understanding of CEI participation and the implementation of real-world CEIs, before offering evidence on the effects of social networks on CEI participation. We will then proceed with linking our approach with adjacent fields of inquiry.

3. Introducing a social network approach

A *social network approach* acknowledges that humans (agents) are socially embedded in a network of social relationships and that their behavior and attitudes are influenced by others' behaviors and attitudes, as people do not act in a social vacuum (Flache and Dijkstra 2015; Granovetter 1985; Jackson 2014; Siegel 2009). This theoretical approach is accompanied by a set of powerful *social network analysis* (SNA) methods, which have been applied with great success to many different fields of social inquiry (Borgatti et al. 2018). SNA is a toolbox that enables researchers to visualize and analyze the structures of social relations connecting groups of individuals, organizations, or other (social) entities and describe them at the level of network characteristics. SNA is also used to explain the network structure in relation to social processes which is the basis for theories of social exchange (Dijkstra 2015), social support (Uehara 1990), cooperation (Dijkstra and van Assen 2017), or coordination (Easley and Kleinberg 2010). Particularly pertinent to CEI participation dynamics are social phenomena such as diffusion processes (Anon 2003; Easley and Kleinberg 2010; Rogers 2003) or social influence processes (Axsen and Kurani 2012; Flache, Mäs, and Keijzer 2022), which can be described using a set of nodes representing individual actors, groups, or organizations connected via edges representing social or organizational ties (for a visual representation see figure 1). This analytical approach helps for instance to identify influential actors or clusters of actors based on their structural position in the network (Borgatti and Ofem 2010), which can be crucial information for understanding the spreading of information or behaviors in a community.

4. *A social network approach applied to CEIs.*

A *social network approach* accompanied by SNA methods can be used to examine existing relationships between different (sets of) actors in the community in which a CEI is active. These (sets of) actors include individuals and households, community-based organizations (such as firms, clubs, and associations) and institutions (such as local governments or regional NGOs), and the CEI core organization itself. The types of relationships elicited can include friendship or acquaintance (between individuals and households), membership (between individuals / households and associations), trust (between individuals and institutions, or between individuals), and collaboration (between associations and institutions). Mapping the structure of these relationships in the local community allows the identification of how topological patterns of social ties relate to participation in the CEI and to relevant collaboration between local associations and organizations (Goedkoop, Dijkstra, et al. 2022). This way a *social network approach* increases our understanding of variation in CEI participation within and across communities. It does this by depicting the social structural circumstances under which people do or do not participate as e.g., when having direct social ties to initiators (Goedkoop, Dijkstra, et al. 2022). SNA becomes particularly potent when combined with individual-level data such as SES, household financial resources and individual energy related attitudes, and community-level data such as percentage of homeownership or the local age, income, or educational distribution. That way one can determine cluster of community members from different socioeconomic backgrounds and whether they have ties between each other, which may be crucial for CEI participation (success). Our basic hypothesis is that individual-level and community-level characteristics exert their influence on CEI participant *through* community social networks.

5. *Understanding variation in CEI participation given social network, individual and community characteristics.*

Studying social networks enables researchers to explain phenomena which might be overlooked when only attending to individual or community characteristics. In many social scientific disciplines, human behavior and social phenomena are mainly described as outcomes of individual characteristics such as attitudes, norms, personality, and cognitive resources (Axsen and Kurani 2012; Borgatti et al. 2009). However, there are many behaviors and social phenomena that cannot be properly understood by solely referring to individual characteristics (Borgatti et al. 2009). Thus, research has shown that the spread of adoption behavior, the flow of information and the acquisition of powerful social positions are often explained by the social structure that individuals are embedded in (Axsen and Kurani 2012; Borgatti et al. 2009; Diani 2015; Granha et al. 2022; Hunter et al. 2015; Jackson 2014; Jia et al. 2015; Schafft and Brown 2003). As such social phenomena do often not only depend on individual characteristics and contextual properties, but largely on actors with different traits who are connected to each other through networks (Diani 2015; McAdam 1986). The neglect of such network characteristics can lead to wrong conclusions regarding the associations between individual/community characteristics and the spread of behaviors (Constantino et al. 2022; Jackson 2014). We propose that CEI participation is very much a behavior that cannot be explained by individual and community characteristics alone. Nor can differences in CEI participation between communities be properly understood by looking at community characteristics when not considering the underlying network structure. We illustrate this point by means of an example of two communities located in the northern Netherlands in which social network data were collected (being part of a larger study on community energy initiatives, see Goedkoop, Dijkstra, and Flache 2022 for a detailed account of data collection).

The two communities are villages of approximately the same size (ca. 1400 households) located in the same Dutch province. In both villages a CEI had recently been started by a small group of inhabitants, and the main stated goal of both CEIs was to make their local community "energy neutral" within the next 10 years. Energy neutrality in this context means that *the equivalent* of local energy consumption is generated (preferably locally) in an environmentally sustainable way.[1] Both CEIs were connected to the same community energy umbrella organization (see www.samenenergieneutraal.nl). From a sample of households in both villages, we collected data via questionnaires including different individual, contextual, and network measures. To map the community social networks, respondents listed all local associations (both formal, such as churches, sports clubs, or choral

[1] Dutch law forbids the peer-to-peer trade of energy between households.

associations, and informal, such as book clubs or rock bands) of which they were a member. We also collected data on personal ties and their strength from community members to CEI initiators. These network data allow for estimating sociometric distances between respondents (number of network-steps between citizens) and the local CEI to characterize respondent embeddedness and involvement in the local community (see Goedkoop et al., 2022). Yet, instead of using these social networks to make individual level estimates, we focus on the social network at the community level here to compare both communities.

We construct community social networks on the level of associations as *event-event networks* (see Borgatti et al. 2013, Chapter 13) and identify the position of the CEI in that network. Associations are conceptualized as events because people regularly attend meetings. A tie (edge) between two associations (nodes) thus means that they share at least one member. *Event-event networks* enable us to compare the associations reported by the respondents to the total amount of associations residing in the local community, which gives us an indication of how well the associational life of the local community is represented by our sample. Both community networks are mapped in figures 1 and 2 with the CEI being represented as a magenta-colored node.

When we look at the aggregates of individual and contextual measures, both communities score about the same on all variables (income, pro environmental attitudes, age distribution). However, we know that the CEI in community A died due to a lack of participation, while the CEI in community B flourishes with 356 households currently participating and more than 3000 solar panels installed. Based on the investigated individual and community characteristics this large difference in outcome is hard to understand. Yet, when we look at the social networks, we see that the CEI in the associational network of community A in Figure 1 is virtually disconnected from the rest of the community and not central in the network at all (Figure 1). Further, based on the personal ties of community members to the CEI initiators (not shown in Figure 1) we know that there were barely any strong social ties between the CEI initiators and the rest of the community. This means that while the initiators lacked contact and thus means of social influence and information spread to the rest of the community. This might be a reason for why they failed to convince other community members to join the CEI, and their initiative withered and died.

Figure 1. The associational network of Community A.

Note. The associational networks of community A with a cluster of Initiators that are not well connected to the rest of the community, which likely hindered the spread of participation. The size of the nodes is proportional to the number of members.

In stark contrast to this, the CEI in village B is centrally positioned in the associational network of the community (Figure 2), having many ties to other associations with members of the community. Therefore, the local CEI is in a position from which it could spread information about (upcoming) activities and projects through the local network, but also exert (persuasive and coercive) social influence on other community members to participate in (projects of) the CEI. Further, the central position in the community network enhances the CEI's legitimacy as an organization acting on behalf of the entire community, thus strengthening its bargaining position vis-à-vis local government and other outside organizations. Enhanced legitimacy breeds trust and authority within the community as well (Cook, Levi, and Hardin 2009; De Cremer and Tyler 2007; Hawdon 2008). All this potentially might have contributed to the spread of participation and the success of the CEI in community B.

Figure 2 The associational network of Community B.

Note. The associational network of community B in which the cluster of initiators is rather central and well connected, which can explain the spread of adoption behavior to the rest of the community. The size of the nodes is proportional to the number of members.

It is important to mention that what we present here is no hard evidence nor tested in an experiment. Many arguments above are inferred from social network theory and empirical works on the effects of social network characteristics on information spread, trust and social influence. Therefore, much more research is needed on many more communities to scrutinize possible social structural effects that go beyond individual-level and community-level characteristics. Still, the above example does illustrate how neglecting the social network structure can potentially lead to the wrong conclusions concerning participation dynamics, especially as first empirical findings indicate an effect of social networks on CEI participation (cf., Fleur Goedkoop et al. 2022a; F. Goedkoop et al. 2022). Based on an exclusive focus on either individual or aggregate community characteristics, one may conclude that they are *unrelated* to CEI success or failure. Yet, when taking the *structure* of social networks in the community into account, the conclusion would follow that individual and community characteristics do affect CEI participation but only when the CEI can access other community groups via the social network structure.

6. *Encouraging initial evidence*

Initial quantitative evidence shows that having strong, direct ties to CEI initiators positively relates to one's willingness to participate in CEIs (Goedkoop 2021; Goedkoop, Dijkstra, et al. 2022), over and above the effects of individual sustainability motivation (Goedkoop, Sloot, et al. 2022b). Comparable results were found for networks among farmers concerning the spread of a climate change mitigation innovation (Kreft et al. 2023). Here the researchers found that knowledge residing in the network influenced adoption behavior and that ties to members of the local collective action initiative of farmers increased adoption behavior. As it is known that knowledge spreads and trust resides in social networks (Borgatti et al. 2018; Pretty 2003; Rogers 2003; Schafft and Brown 2003), and both play an important role in CEI participation (Kalkbrenner and Roosen 2016; Sønderskov 2008), similar mechanisms can be expected in the context of CEI participation. Additional evidence comes from the case of widespread solar panel adoption in Germany, which could not be explained without consideration of the social ties between communities (Rode and Weber 2016) and a study taking a meso level approach to explain how local government structure of community energy projects is influenced by the network of low carbon community organizations (Parag et al. 2013).

While this evidence gives first insight into the importance of social networks for CEI participation and its relation to community and individual consumer characteristics, only the studies by Goedkoop et al., (2021; 2022) and Parag et al., (2013) used measures resembling SNA to investigate the structure of local social networks. Therefore, analyzing the social network and relating it to individual and community characteristics when scrutinizing CEI participation remains something that needs to be done (Parag et al. 2013).

7. Linking CEI research to adjacent fields of inquiry and theories

CEI participation is a special case of pro-environmental behavior (Goedkoop 2021) and often conceptualized as a form of collective action or part of a social movement (Fritsche et al. 2018; Goedkoop, Sloot, et al. 2022b; Hamann et al. 2023; Hoffman and High-Pippert 2010; Marder et al. 2023; Sloot et al. 2019; Stern 2000). Much as in other collective action dilemmas CEI participation has properties of both public and private goods (Goedkoop 2021). The public good is the environmental protection afforded by participation in the CEI. Environmental improvements (or rather the partial prevention of further environmental degradation) profit everyone regardless of whether they participate in a CEI. The private aspect lies in the financial gains (such as cheaper energy and less dependence on volatile energy markets) delivered through participation. Hence, CEI participation is neither a purely individual nor a purely collective concern and depends on both individual interests, attitudes and thoughts, and on the social surroundings (Bodin 2017; Goedkoop 2021; Jackson 2005; Siegel 2009)[2].

[2] As any marketeer knows, even purchases of private goods are strongly affected by social influence processes. Social influence on collective good behavior even occurs in contexts where individual costs

A *social network approach* has often successfully been applied in the fields of collective action and diffusion research (Adger 2010; Borgatti et al. 2018; Centola 2013; Diani and McAdam 2003; Siegel 2009). This is especially true for research into environmental issues such as nature resilience, collaborative environmental governance, and resource management (Bodin 2017; Bodin and Crona 2009; Janssen et al. 2006; Jones et al. 2009; Örjan Bodin and Christina Prell 2011; Pretty 2003). In these fields researchers incorporated SNA into their research methods and improved the field's understanding of diffusion and collective action, leading to new insights, theories and policy advice (Bodin, Crona, and Ernstson 2006; Janssen et al. 2006). Integrating theories and the analysis of the social network structure with an analysis of the effects of individual and community characteristics will not only improve our understanding of CEI participation dynamics, but it will also draw out parallels and differences with other fields.

8. Conclusion

CEIs are a crucial and important part of the energy transition (Directorate-General for Energy (European Commission) 2019; Hamann et al. 2023). However, first findings indicated that their current implementation does not bring the desired success due to low participation numbers (Germes et al. 2021; Walsh 2021). In this positioning paper we thus illustrated how a *social network approach* might improve our understanding of why citizens from different backgrounds participate in CEIs. We gave an overview of how to integrate this approach with previous findings regarding individual and community characteristics to create a more holistic picture of CEI participation. Further, we illustrated the practical relevance of integrating SNA into the current research practice to improve the implementation of community energy projects. To back up our claims we reviewed theoretical and empirical literature that highlights the benefits of a *social network approach* and connected it with the literature on CEI participation. We propose that by acknowledging the full social complexity that CEI participation behavior resides in scholars can translate their knowledge into effective interventions that are targeted to the specific context that a CEI resides in. While a *social network approach* has already been applied to other forms of collective action, we think that the strength of such an approach in the context of CEI participation lies its application to improve the implementation of CEIs and increase participation and justice.

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and benefits are easily explicated in monetary terms and sanctioning probabilities for free-riding are low, such as tax evasion (e.g., Alm, Bloomquist, & McKee (2017)).

References:

Adger, W. Neil. 2010. 'Social Capital, Collective Action, and Adaptation to Climate Change'. 18.

Anon. 2003. 'Diffusion Networks'. in *Networks in the Knowledge Economy*. Oxford University Press.

Arnould, Jasmine, and Diana Quiroz. 2022. 'Energy Communities in the EU'. *friendsoftheearthEnergy-Communities-in-the-EU-Opportunities-and-Barriers-to-Financing*. Retrieved (https://friendsoftheearth.eu/wp-content/uploads/2022/09/Energy-Communities-in-the-EU-opportunities-and-barriers-to-financing.pdf).

Axsen, Jonn, and Kenneth S. Kurani. 2012. 'Social Influence, Consumer Behavior, and Low-Carbon Energy Transitions'. *Annual Review of Environment and Resources* 37(1):311–40. doi: 10.1146/annurev-environ-062111-145049.

Bodin, Örjan. 2017. 'Collaborative Environmental Governance: Achieving Collective Action in Social-Ecological Systems'. *Science* 357(6352):eaan1114. doi: 10.1126/science.aan1114.

Bodin, Örjan, Beatrice Crona, and Henrik Ernstson. 2006. 'Social Networks in Natural Resource Management: What Is There to Learn from a Structural Perspective?' *Ecology and Society* 11(2).

Bodin, Örjan, and Beatrice I. Crona. 2009. 'The Role of Social Networks in Natural Resource Governance: What Relational Patterns Make a Difference?' *Global Environmental Change* 19(3):366–74. doi: 10.1016/j.gloenvcha.2009.05.002.

Bomberg, Elizabeth, and Nicola McEwen. 2012. 'Mobilizing Community Energy'. *Energy Policy* 51:435–44. doi: 10.1016/j.enpol.2012.08.045.

van Bommel, Natascha, and Johanna I. Höffken. 2021. 'Energy Justice within, between and beyond European Community Energy Initiatives: A Review'. *Energy Research & Social Science* 79:102157. doi: 10.1016/j.erss.2021.102157.

Borgatti, Stephen, and B. Ofem. 2010. 'Overview: Social Network Theory and Analysis'. *Social Network Theory and Educational Change* 17–30.

Borgatti, Stephen P., Martin G. Everett, and Jeffrey C. Johnson. 2018. *Analyzing Social Networks*. SAGE.

Borgatti, Stephen P., Ajay Mehra, Daniel J. Brass, and Giuseppe Labianca. 2009. 'Network Analysis in the Social Sciences'. *Science* 323(5916):892–95. doi: 10.1126/science.1165821.

Centola, Damon M. 2013. 'Homophily, Networks, and Critical Mass: Solving the Start-up Problem in Large Group Collective Action'. *Rationality and Society* 25(1):3–40. doi: 10.1177/1043463112473734.

Constantino, Sara M., Gregg Sparkman, Gordon T. Kraft-Todd, Cristina Bicchieri, Damon Centola, Bettina Shell-Duncan, Sonja Vogt, and Elke U. Weber. 2022. 'Scaling Up Change: A Critical Review and Practical Guide to Harnessing Social Norms for

Climate Action'. *Psychological Science in the Public Interest* 23(2):50–97. doi: 10.1177/15291006221105279.

Cook, Karen S., Margaret Levi, and Russell Hardin. 2009. *Whom Can We Trust?: How Groups, Networks, and Institutions Make Trust Possible*. Russell Sage Foundation.

De Cremer, David, and Tom R. Tyler. 2007. 'The Effects of Trust in Authority and Procedural Fairness on Cooperation.' *Journal of Applied Psychology* 92(3):639–49. doi: 10.1037/0021-9010.92.3.639.

Devine-Wright, Patrick. 2011. 'Place Attachment and Public Acceptance of Renewable Energy: A Tidal Energy Case Study'. *Journal of Environmental Psychology* 31(4):336–43. doi: 10.1016/j.jenvp.2011.07.001.

Devine-Wright, Patrick. 2019. 'Community versus Local Energy in a Context of Climate Emergency'. *Nature Energy* 4(11):894–96. doi: 10.1038/s41560-019-0459-2.

Diani, Mario. 2015. *The Cement of Civil Society: Studying Networks in Localities*. Cambridge: Cambridge University Press.

Diani, Mario, and Doug McAdam. 2003. *Social Movements and Networks: Relational Approaches to Collective Action*. OUP Oxford.

Dijkstra, Jacob. 2015. 'Social Exchange: Relations and Networks'. *Social Network Analysis and Mining* 5(1):60. doi: 10.1007/s13278-015-0301-1.

Dijkstra, Jacob, and Marcel A. L. M. van Assen. 2017. 'Explaining Cooperation in the Finitely Repeated Simultaneous and Sequential Prisoner's Dilemma Game under Incomplete and Complete Information'. *The Journal of Mathematical Sociology* 41(1):1–25. doi: 10.1080/0022250X.2016.1226301.

Directorate-General for Energy (European Commission). 2019. *Clean Energy for All Europeans*. LU: Publications Office of the European Union.

Easley, David, and Jon Kleinberg. 2010. 'Networks, Crowds, and Markets':

Flache, Andreas, and Jacob Dijkstra. 2015. 'Rationality in Society'. in *International Encyclopedia of the Social & Behavioral Sciences*, edited by J. D. Wright. Elsevier.

Flache, Andreas, Michael Mäs, and Marijn A. Keijzer. 2022. 'Computational Approaches in Rigorous Sociology: Agent-Based Computational Modeling and Computational Social Science'. Pp. 57–72 in *Handbook of Sociological Science*, edited by K. Gërxhani, N. De Graaf, and W. Raub. Edward Elgar Publishing.

Fritsche, Immo, Markus Barth, Philipp Jugert, Torsten Masson, and Gerhard Reese. 2018. 'A Social Identity Model of Pro-Environmental Action (SIMPEA).' *Psychological Review* 125(2):245–69. doi: 10.1037/rev0000090.

Fritsche, Immo, and Torsten Masson. 2021. 'Collective Climate Action: When Do People Turn into Collective Environmental Agents?' *Current Opinion in Psychology* 42:114–19. doi: 10.1016/j.copsyc.2021.05.001.

Germes, Lynette A. M. H., Carina J. Wiekens, and Lummina G. Horlings. 2021. 'Success, Failure, and Impact of Local Energy Initiatives in The Netherlands'. *Sustainability* 13(22):12482. doi: 10.3390/su132212482.

Goedkoop, Fleur. 2021. ‘Involvement in Bottom-up Energy Transitions: The Role of Local and Contextual Embeddedness’. University of Groningen.

Goedkoop, Fleur, and Patrick Devine-Wright. 2016. ‘Partnership or Placation? The Role of Trust and Justice in the Shared Ownership of Renewable Energy Projects’. *Energy Research & Social Science* 17:135–46. doi: 10.1016/j.erss.2016.04.021.

Goedkoop, Fleur, J. Dijkstra, and A. Flache. 2022. ‘A Social Network Perspective on Involvement in Community Energy Initiatives: The Role of Direct and Extended Social Ties to Initiators’. *Energy Policy* 171:113260. doi: 10.1016/j.enpol.2022.113260.

Goedkoop, Fleur, Daniel Sloot, Lise Jans, Jacob Dijkstra, Andreas Flache, and Linda Steg. 2022a. ‘The Role of Community in Understanding Involvement in Community Energy Initiatives’. *Frontiers in Psychology* 12:775752. doi: 10.3389/fpsyg.2021.775752.

Goedkoop, Fleur, Daniel Sloot, Lise Jans, Jacob Dijkstra, Andreas Flache, and Linda Steg. 2022b. ‘The Role of Community in Understanding Involvement in Community Energy Initiatives’. *Frontiers in Psychology* 12:775752. doi: 10.3389/fpsyg.2021.775752.

Granha, Mateus F. B., André L. M. Vilela, Chao Wang, Kenric P. Nelson, and H. Eugene Stanley. 2022. ‘Opinion Dynamics in Financial Markets via Random Networks’. *Proceedings of the National Academy of Sciences* 119(49):e2201573119. doi: 10.1073/pnas.2201573119.

Granovetter, Mark. 1985. ‘Economic Action and Social Structure: The Problem of Embeddedness’. *American Journal of Sociology* 91(3):481–510.

Guilbeault, Douglas, and Damon Centola. 2021. ‘Topological Measures for Identifying and Predicting the Spread of Complex Contagions’. *Nature Communications* 12(1):4430. doi: 10.1038/s41467-021-24704-6.

Hamann, Karen R. S., Maria P. Bertel, Bożena Ryszawska, Brigitta Lurger, Piotr Szymański, Magdalena Rozwadowska, Fleur Goedkoop, Lise Jans, Goda Perlaviciute, Torsten Masson, Immo Fritsche, Tamara Favaro, Annemarie Hofer, Iris Eisenberger, Celin Gutschi, Carla Grosche, Johanna Held, Ursula Athenstaedt, and Katja Corcoran. 2023. ‘An Interdisciplinary Understanding of Energy Citizenship: Integrating Psychological, Legal, and Economic Perspectives on a Citizen-Centred Sustainable Energy Transition’. *Energy Research & Social Science* 97:102959. doi: 10.1016/j.erss.2023.102959.

Hanke, Florian, Rachel Guyet, and Marielle Feenstra. 2021. ‘Do Renewable Energy Communities Deliver Energy Justice? Exploring Insights from 71 European Cases’. *Energy Research & Social Science* 80:102244. doi: 10.1016/j.erss.2021.102244.

Hanke, Florian, and Jens Lowitzsch. 2020. ‘Empowering Vulnerable Consumers to Join Renewable Energy Communities—Towards an Inclusive Design of the Clean Energy Package’. *Energies* 13(7):1615. doi: 10.3390/en13071615.

Hargreaves, Tom, and Lucie Middlemiss. 2020. ‘The Importance of Social Relations in Shaping Energy Demand’. *Nature Energy* 5(3):195–201. doi: 10.1038/s41560-020-0553-5.

Hasanov, Mustafa, and Christian Zuidema. 2018. ‘The Transformative Power of Self-Organization: Towards a Conceptual Framework for Understanding Local Energy

Initiatives in The Netherlands'. *Energy Research & Social Science* 37:85–93. doi: 10.1016/j.erss.2017.09.038.

Hawdon, James. 2008. 'Legitimacy, Trust, Social Capital, and Policing Styles: A Theoretical Statement'. *Police Quarterly* 11(2):182–201. doi: 10.1177/1098611107311852.

Heindl, Peter, Rudolf Schüßler, and Andreas Löschel. 2014. 'Ist die Energiewende sozial gerecht?' *Wirtschaftsdienst* 94(7):508–14. doi: 10.1007/s10273-014-1705-7.

Hoffman, Steven M., and Angela High-Pippert. 2010. 'From Private Lives to Collective Action: Recruitment and Participation Incentives for a Community Energy Program'. *Energy Policy* 38(12):7567–74. doi: 10.1016/j.enpol.2009.06.054.

Hunter, Ruth F., Helen McAneney, Michael Davis, Mark A. Tully, Thomas W. Valente, and Frank Kee. 2015. '"Hidden" Social Networks in Behavior Change Interventions'. *American Journal of Public Health* 105(3):513–16. doi: 10.2105/AJPH.2014.302399.

Jackson, Matthew O. 2014. 'Networks in the Understanding of Economic Behaviors'. *Journal of Economic Perspectives* 28(4):3–22. doi: 10.1257/jep.28.4.3.

Jackson, Tim. 2005. 'Motivating Sustainable Consumption: A Review of Evidence on Consumer Behaviour and Behavioural Change'. *Sustainable Development Research Network* 15.

Jans, Lise. 2021. 'Changing Environmental Behaviour from the Bottom up: The Formation of pro-Environmental Social Identities'. *Journal of Environmental Psychology* 73:101531. doi: 10.1016/j.jenvp.2020.101531.

Janssen, Marco A., Örjan Bodin, John M. Anderies, Thomas Elmqvist, Henrik Ernstson, Ryan R. J. McAllister, Per Olsson, and Paul Ryan. 2006. 'Toward a Network Perspective of the Study of Resilience in Social-Ecological Systems'. *Ecology and Society* 11(1).

Jesse de Graaff, Anne Marit Popma, and Wieke Meijer. 2023. 'Knelpunteninventarisatie energiecoöperaties: knelpunten en kansen voor opschalen | HIER opgewekt'. Retrieved 6 June 2023 (https://www.hieropgewekt.nl/kennisdossiers/knelpunteninventarisatie-energiecooperaties-knelpunten-en-kansen-voor-opschalen).

Jia, Peng, Anahita MirTabatabaei, Noah E. Friedkin, and Francesco Bullo. 2015. 'Opinion Dynamics and the Evolution of Social Power in Influence Networks'. *SIAM Review* 57(3):367–97. doi: 10.1137/130913250.

Jones, Nikoleta, Costas M. Sophoulis, Theodoros Iosifides, Iosif Botetzagias, and Konstantinos Evangelinos. 2009. 'The Influence of Social Capital on Environmental Policy Instruments'. *Environmental Politics* 18(4):595–611. doi: 10.1080/09644010903007443.

Kalkbrenner, Bernhard J., and Jutta Roosen. 2016. 'Citizens' Willingness to Participate in Local Renewable Energy Projects: The Role of Community and Trust in Germany'. *Energy Research & Social Science* 13:60–70. doi: 10.1016/j.erss.2015.12.006.

Kreft, Cordelia, Mario Angst, Robert Huber, and Robert Finger. 2023. 'Farmers' Social Networks and Regional Spillover Effects in Agricultural Climate Change Mitigation'. *Climatic Change* 176(2):8. doi: 10.1007/s10584-023-03484-6.

Lokale Energie Monitor 2022. 2023. ‘Lokale Energie Monitor 2022 | HIER’. Retrieved 6 July 2023 (https://www.hier.nu/LEM2022).

Marder, Fabian, Torsten Masson, Julian Sagebiel, Christina Martini, Martin Quaas, and Immo Fritsche. 2023. ‘Discounting the Future: The Effect of Collective Motivation on Investment Decisions and Acceptance of Policies for Renewable Energy’.

McAdam, Doug. 1986. ‘Recruitment to High-Risk Activism: The Case of Freedom Summer’. *American Journal of Sociology* 92(1):64–90. doi: 10.1086/228463.

Middlemiss, Lucie. 2011. ‘The Effects of Community-Based Action for Sustainability on Participants’ Lifestyles’. *Local Environment* 16(3):265–80. doi: 10.1080/13549839.2011.566850.

Middlemiss, Lucie, and Bradley D. Parrish. 2010. ‘Building Capacity for Low-Carbon Communities: The Role of Grassroots Initiatives’. *Energy Policy* 38(12):7559–66. doi: 10.1016/j.enpol.2009.07.003.

Örjan Bodin and Christina Prell. 2011. *Social Networks and Natural Resource Management : Uncovering the Social Fabric of Environmental Governance*. Cambridge, UK: Cambridge University Press.

Oteman, Marieke, Henk-Jan Kooij, and Mark A. Wiering. 2017. ‘Pioneering Renewable Energy in an Economic Energy Policy System: The History and Development of Dutch Grassroots Initiatives’. *Sustainability* 9(4):550. doi: 10.3390/su9040550.

Parag, Yael, Jo Hamilton, Vicki White, and Bernie Hogan. 2013. ‘Network Approach for Local and Community Governance of Energy: The Case of Oxfordshire’. *Energy Policy* 62:1064–77. doi: 10.1016/j.enpol.2013.06.027.

Pretty, Jules. 2003. ‘Social Capital and the Collective Management of Resources’. *Science* 302(5652):1912–14. doi: 10.1126/science.1090847.

Rode, Johannes, and Alexander Weber. 2016. ‘Does Localized Imitation Drive Technology Adoption? A Case Study on Rooftop Photovoltaic Systems in Germany’. *Journal of Environmental Economics and Management* 78:38–48. doi: 10.1016/j.jeem.2016.02.001.

Rogers, Everett. 2003. *Diffusion of Innovations*. 5th ed. Free Press.

Schafft, Kai, and David Brown. 2003. ‘Social Capital, Social Networks, and Social Power’. *Social Epistemology* 17(4):329–42. doi: 10.1080/0269172032000151795.

van der Schoor, Tineke, and Bert Scholtens. 2015. ‘Power to the People: Local Community Initiatives and the Transition to Sustainable Energy’. *Renewable and Sustainable Energy Reviews* 43:666–75. doi: 10.1016/j.rser.2014.10.089.

Siegel, David A. 2009. ‘Social Networks and Collective Action’. *American Journal of Political Science* 53(1):122–38. doi: 10.1111/j.1540-5907.2008.00361.x.

Sloot, Daniel, Lise Jans, and Linda Steg. 2017. ‘The Potential of Environmental Community Initiatives - a Social Psychological Perspective’. Pp. 27–34 in.

Sloot, Daniel, Lise Jans, and Linda Steg. 2018. ‘Can Community Energy Initiatives Motivate Sustainable Energy Behaviours? The Role of Initiative Involvement and Personal pro-

Environmental Motivation’. *Journal of Environmental Psychology* 57:99–106. doi: 10.1016/j.jenvp.2018.06.007.

Sloot, Daniel, Lise Jans, and Linda Steg. 2019. ‘In It for the Money, the Environment, or the Community? Motives for Being Involved in Community Energy Initiatives’. *Global Environmental Change* 57:101936. doi: 10.1016/j.gloenvcha.2019.101936.

Sønderskov, Kim Mannemar. 2008. ‘Environmental Group Membership, Collective Action and Generalised Trust’. *Environmental Politics* 17(1):78–94. doi: 10.1080/09644010701811673.

Stern, Paul C. 2000. ‘New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior’. *Journal of Social Issues* 56(3):407–24. doi: 10.1111/0022-4537.00175.

Stewart, Fraser. 2021. ‘All for Sun, Sun for All: Can Community Energy Help to Overcome Socioeconomic Inequalities in Low-Carbon Technology Subsidies?’ *Energy Policy* 157:112512. doi: 10.1016/j.enpol.2021.112512.

Uehara, Edwina. 1990. ‘Dual Exchange Theory, Social Networks, and Informal Social Support’. *American Journal of Sociology* 96(3):521–57. doi: 10.1086/229571.

Walker, Benjamin J. A., Bouke Wiersma, and Etienne Bailey. 2014. ‘Community Benefits, Framing and the Social Acceptance of Offshore Wind Farms: An Experimental Study in England’. *Energy Research & Social Science* 3:46–54. doi: 10.1016/j.erss.2014.07.003.

Walsh, Molly. 2021. ‘Governments Are Overlooking a Key Piece in the Climate Puzzle: Community Energy’. *Climate Home News*. Retrieved 7 August 2023 (https://ec2-13-40-238-177.eu-west-2.compute.amazonaws.com/2021/05/24/governments-overlooking-key-piece-climate-puzzle-community-energy/).

Warbroek, Beau, Thomas Hoppe, Hans Bressers, and Frans Coenen. 2019. ‘Testing the Social, Organizational, and Governance Factors for Success in Local Low Carbon Energy Initiatives’. *Energy Research & Social Science* 58:101269. doi: 10.1016/j.erss.2019.101269.

Wierling, August, Valeria Jana Schwanitz, Jan Pedro Zeiss, Constantin von Beck, Heather Arghandeh Paudler, Ingrid Knutsdotter Koren, Tobias Kraudzun, Timothy Marcroft, Lukas Müller, Zacharias Andreadakis, Chiara Candelise, Simon Dufner, Melake Getabecha, Grete Glaase, Wit Hubert, Veronica Lupi, Sona Majidi, Shirin Mohammadi, Negar Safara Nosar, Yann Robiou du Pont, Philippa Roots, Tadeusz Józef Rudek, Alessandro Sciullo, Gayatri Sehdev, Mehran Ziaabadi, and Nahid Zoubin. 2023. ‘A Europe-Wide Inventory of Citizen-Led Energy Action with Data from 29 Countries and over 10000 Initiatives’. *Scientific Data* 10(1):9. doi: 10.1038/s41597-022-01902-5.

Porto Energy Hub: A one-stop-shop for fostering energy action in Northern Portugal

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Abstract

The buildings sector is responsible for around 40% of the final energy demand in the European Union (EU) and about 30% in Portugal. As only around 1% of the EU buildings undergo energy-efficient renovation every year, action is crucial to reach EU's ambitious climate-neutral (net-zero emissions) targets before 2050. However, the fragmentation of the value chain related with buildings' renovation as well as the access to funding are pointed as common barriers to retrofitting as many homeowners perceive these interventions as expensive, complex, and risky due to unstable factors influencing works duration and costs. In Portugal, the poor quality of the building stock (and the urgent need of renovation) associated with the inefficiency of the used heating systems, the common social practices and norms, the energy prices, and the low average incomes, leads the country to be part of the list of EU Member States performing worst in energy poverty. This concerning issue motivated the deployment of the first of its kind home renovation one-stop-shop in the country – the Porto Energy Hub (PEH[i]. Despite being a growing popular concept in some European countries, there is no significant experience of one-stop-shops in Portugal. PEH, currently operating in both physical and online modes in five municipalities of the Porto Metropolitan Area aims to deliver support to homeowners, who which to implement energy efficiency and renewable energy production in their homes. The article presents the main findings arising from the one-stop-shop implementation and discusses both challenges and opportunities for the concept in Portugal.

[i] Porto Energy Hub was developed under the scope of the Horizon 2020 Porto Energy ElevatoR project (grant agreement No 101033708).

1. INTRODUCTION

Recent data indicates that buildings account for around 40% of Europe's total energy consumption (35% in Portugal) and more than 75% of the building stock is inefficient considering current standards (EC, 2020a). As average annual renovation rates are quite low (ca. 1%), actions are needed to accelerate these rates in all EU Member States (MS). According to a 2021 report on the Energy Efficiency Directive, among the 28 MS, Portugal is the EU country in which building renovations are less effective in terms of energy savings, regardless of the level of renovation (light, moderate and intense) (Zangheri, 2021). Buildings' inefficiency has very significant impacts on the energy bills and the thermal comfort of occupants. Indeed, in 2021, Portugal occupied the 5th worst position in terms of the inability in maintaining homes adequately warm, only ahead of Bulgaria, Lithuania, Cyprus, and Turkey (Gouveia, 2022).

There is, therefore, an urgent need for fostering action towards a more swift and robust intervention in the existent EU building stock. However, there are still significant barriers to tackle in this pathway. Renovation decisions are influenced by financial and informational barriers, amongst several other which include daily domestic life practices (Bertoldi et al., 2021). Other authors point out the volatility in prices regarding energy efficient solutions and measures (Ferreira et al., 2016), the lack of guarantees for the effectiveness of these solutions (Felius et al., 2020) and the fact that renovations interventions remain mainly a layered approach, where multiple actors interact in a complex setting over a long period of time, which increases the risk of significant delays and failed procedures (Wilde and Spaargaren, 2019). In this context, the 2018 revision of the EPBD (Directive 2018/844/EU) clearly indicates the need to facilitate access to instruments and advisory tools that can guide and facilitate renovation interventions in the EU territory.

One such instrument that is gaining traction is building renovation One-Stop-Shops (OSS). OSS are described in literature as an innovative approach to promote and motivate energy renovation in buildings. These structures, which typically offer integrated renovation services and solutions for small scale projects. are considered as effective to follow and advise homeowners on the complete journey to a successful home renovation process. Although OSS are somewhat a new approach to renovation services, there are a very diversified range of cases implemented in Europe and different operating models should be distinguished. Bertoldi et al., (2021), for instance, suggests that OSS can be clustered in six types – government-driven, industry-driven, ESCO-based, facilitator type, cooperative type, and store type. These models differ not only on the type of service they provide but also on the business model they assume.

By realising the challenge of building renovation, the European Commission launched the so-called Renovation Wave which, in addition to boost building renovation, is also focusing on energy poverty mitigation strategies. Energy poverty is an increasingly discussed topic in the EU agenda as between 50 and 125 million people are estimated to be unable to afford proper indoor thermal comfort (EC, 2020b). Energy poverty is generally accepted as a situation where people cannot access essential energy services and products (such as heating and cooling) at affordable costs, and it is caused by a combination of low wages, high energy prices and inefficient building conditions (EC, 2023). This phenomenon has health consequences, as well as impacts in wellbeing and ability to fully participate in all societal domains (Horta, 2021).

Several studies based on pilot experiences have suggested that OSS can have a key role in tackling energy poverty, by providing technical, financial, and administrative support and advice to homeowners (Rohrer and Lidmo, 2022; DellaValle, 2022). In this setting, this article presents the implementation methodology and first results of a home renovation OSS implemented in the Northern region of Portugal. It is divided in three main sections. The first one introduced the building renovation challenge. Section 2 presents the context and methodology of the implementation as well as the figures and facts associated with the operation phase of the presented OSS. Finally, the last section presents some of the conclusions of the study.

2. IMPLEMENTING AN OSS FROM SCRATCH

2.1. The context: the PEER project

Portugal has been constantly pointed out as performing poorly in indicators related with energy poverty (Eurostat, 2019). Southern European countries like Portugal face differentiated challenges regarding energy poverty. Several factors contribute to these worrying levels (Horta, 2021), including:

- **Inefficient residential buildings.** Many of the existing buildings were built before 1990 (date of the first thermal regulation in Portugal), and historically, thermal insulation was not one of the priorities when designing new buildings. Therefore, most existing residential buildings do not have any kind of thermal insulation. As a result, among the residential buildings whose energy certificates have already been issued, 69.9% obtained a classification between C and F (on a scale in which A+ is the better one) (ADENE, 2023).
- **Infrastructure and equipment.** In a significant number of EU countries, it is common for dwellings to have centralized heating. In Portugal, however, only a small share of homes (about 13% (INE, 2021)) have this type of system and is restricted to the household scale (while in northern Europe, district heating is frequently used). The use of decentralized heating (e.g., portable electric heaters with low efficiency) results in exceptionally high energy bills, which contributes to a very restrained use of these devices. Also, wood-fuelled fireplaces and stoves are widely used in most homes in Portugal due to their low cost.
- **Social practices, norms, and aspirations.** The culture of southern European countries favours personal adaptive comfort practices (through outerwear, for example) to the detriment of home heating. The main reason for not using more often (or at all)

heating equipment has economic order, normalizing excessive cold or heat in homes, which are perceived as "usual" and socially accepted.

- **Low average incomes and energy prices.** Portugal is characterized by high levels of poverty and economic inequalities. In 2020, 20% of the Portuguese population was at risk of poverty or social exclusion (Eurostat, 2020). On the other hand, energy in Portugal is quite expensive. Despite the market liberalization, in the second half of 2022, Eurostat estimated that Portugal was the 15th EU country with the most expensive electricity and gas for household consumers (Eurostat, 2022a) (Eurostat, 2022b).
- **Literacy of citizens and relevant agents.** In addition to the financial incapacity to carry out renovation works at home, there is also a generalised lack of knowledge about what can be done to improve thermal comfort and which materials and techniques are most suitable for each case. Uncertainty as to the cost-effectiveness and the current outcomes in terms of savings of such investments also holds back action.

Home renovation OSS, including physical and virtual services, may provide an important advice and information centre for both citizens and professionals and boost action. These physical and/or online platforms may provide technical, financial, and legal services and solutions, linking all the interested parties, namely, tenants, property owners, construction companies, funding institutions, and public organizations, raising awareness concerning the energy poverty topic. The concept has been introduced in the revised Energy Performance in Buildings Directive (EU) 2018/844 (EC, 2018) and since then, OSS have been developing across Europe as a way to effectively manage renovation projects by creating and making available useful resources such as reliable and sound information, tools, catalogue of practical policies and measures, training materials, contacts of accredited renovation work companies and dedicated services like accessibility to funding, incentives and other financial mechanisms.

Despite the extensive building renovation needs and the worrying energy poverty context, OSS to support citizens in these matters did not exist in Portugal until recently. To fill this gap and link the buildings' energy efficiency market to citizens while increasing the awareness of all the intervening actors for this issue, in 2021, a Portuguese cluster of entities lead by the Porto Energy Agency proposed the Porto Energy ElevatoR (PEER)[ii] project. With the motto of "*fighting energy poverty by building energy efficiency*", PEER aims at developing a bold renovation program to fight energy poverty, promoting buildings' energy efficiency and self-consumption renewable energy communities, as well as mainstreaming new financial schemes. With a special focus on low-income households, PEER has been providing technical, legal, and economic advice to local authorities of the Porto Metropolitan Area at north of Douro River in renovation projects targeted at municipality-owned social housing districts. Such projects are currently being boosted by the 1º Direito[iii] funding program which, under the scope of the Recovery and Resilience

[ii] https://cordis.europa.eu/project/id/101033708
[iii] https://portaldahabitacao.pt/1.%c2%ba-direito

Program, is fully funding renovation works in social housing buildings. So far, PEER supported a pipeline of investment of around 24 M€ to be executed until 2026.

Besides the support to local authorities, PEER's aims also to develop Porto Energy Hub (PEH), a dedicated OSS aimed at to address one of the most relevant barriers to sustainable, effective, and inclusive building retrofitting: the fragmentation of the building renovation value chain. This fragmentation contributes to the perception citizens have regarding building renovations as complicated and uncertain, mainly due to unstable factors affecting the works' duration and costs. In this setting, PEH gathers, in a single contact point, several services and dimensions involved in building renovations, ranging from information to technical assistance, support in funding application, energy audits (when needed) and legal clarification, providing a comprehensive range service path from the renovation design to the provision of funding.

2.2. Porto Energy Hub: Implementation step-by-step

PEH design and operation followed a three-step approach which resulted from a comprehensive revision on other building renovation OSS implemented across Europe.

To realise what PEH is aimed at, a market gap diagnosis was carried out to understand the features of the existing residential buildings (type, age, renovation needs, energy savings potential, type of improvement needs); the type of people living in these buildings (tenants vs. homeowners and income profiles); and the stakeholders operating in the local home renovation market (e.g., existing services, suppliers, contractors, type of companies and their operation modes). As result of this analysis, the major market gaps PEH needs to circumvent were identified, namely: 1) The lack of a coordinated advice and guidance service for home renovation activities; 2) The difficulty of access to reliable and intelligible information on energy efficiency, renewable energy and funding opportunities; 3) The lack of citizens awareness on energy savings potential; and 4) The lack of financial schemes customized to each case.

As the Portuguese market was proved immature in this topic and supporting entities able to assist citizens throughout the home renovation journey were lacking, the services of a home renovation OSS as PEH were perceived as key to stimulate the market and create an increased renovation interest. Thus, a comprehensive understanding of OSS operation, services and business models was required to start the drafting of PEH operation, leading to the second step of PEH development aimed at choosing the operation mode and corresponding business model. By realising the lack of similar supporting structures in the country, and to ensure a steady and robust design of PEH, a comprehensive review of existing home renovation OSS running across Europe was performed as starting point. This review allowed to learn how successful examples dealt with implementation enablers and barriers and to reflect on the pros and cons of the different possibilities of action, informing the decision on the services to provide, entities to engage and business model to pursue. Based on it, the services to offer and the operation mode were defined.

To implement the foreseen PEH services while reaching the broader population as possible, PEH was created in both online and physical modes: the online mode allows for a better dissemination of information whereas the existence of physical desks brings the citizens closer to the PEER team and gives the project a "face". As most of the people currently is able (and used) to access information through digital means, the project website was defined as a key tool for both information dissemination and the OSS operation as it hosts the survey which allows for a first screening of energy efficiency potential, and which triggers the technical support. Fig. 1 displays how the process is conducted, and the role played by the project website.

Figure 1. PEH operating process.

As several physical hubs may be created in different neighbour municipalities, landing pages tailored with information on each physical desk can be developed. In addition to providing local information, such pages have the purpose to redirect users for the main homepage of the project (https://portoenergyhub.pt/) (1). In the main homepage, users may look for information on technical aspects of energy efficiency measures (best systems and technologies for water heating, insulation, glazing, etc.), existing funding opportunities, and updated legal framework (2). In turn, users have also the opportunity to assess the energy efficiency of their homes by answering an online survey (3).

To ensure a wider outreach of the service, local municipalities were involved and agreed to pilot the implementation of physical desks. The discussion with local authorities on this new service revealed to be valuable as it allowed to fine-tune important aspects of the implementation resulting in a model which can be easily replicated. Taking advantage of this collaboration with local municipalities, physical desks are being created in city facilities where citizens are already used to go to solve other daily issues (e.g., licensing and permitting issues, etc.).

In Energy Hub desks (each municipality can customize the designation of the service, thus, currently Porto, Matosinhos, Valongo, Trofa and Maia Energy Hub desks are in place), municipal staff trained about the objectives and services of the OSS are able to:

- Direct citizens to the information on the project webpage and share the project communication materials and provide basic energy tips and advice;
- Schedule technical meetings with the project staff. This technical meeting is only indicated for citizens who want to proceed with the implementation process of energy efficiency measures in their homes or have doubts on specific questions (funding, legal, etc.). Previously to these meetings, citizens are recommended to complete the diagnosis survey available in the project webpage and which allows to a more appropriate technical follow-up.

After answering the survey, users receive an email with a tailored one-pager (4) which identifies energy efficiency potential, existing and applicable funding opportunities and enables to carry on with the technical support, if required. The rationale behind this simplified document is to provide basic information to users who showed interest in the project, even if they are not willing to continue the support process. This initial assessment of potential can, if desired by the user, trigger the scheduling of a technical meeting (either physically or online) (5). When a technical meeting is scheduled, PEER's technical staff travel to the corresponding Energy Hub desk and carry out the technical appointment, advising citizens on potential energy efficiency measures, available funding programs or issues related to the regulatory framework. When necessary, technical meetings can also lead to site visits carried out by building experts for a more detailed survey of needs and identification of concrete improvement measures (6). Such visits result in a detailed report on the energy and thermal behaviour of dwellings which allows for the prescription of concrete implementation measures and cost estimates, allowing citizens to have a very clear idea of the type of intervention and associated costs (7). To ensure uniformity and the quality of site visits, detailed procedures and report templates were developed by the project. The site visit is expected to provide further technical support to renovation measures implementation and technical solutions prescription.

If users decide to proceed with interventions, the PEER technical team may continue to follow the process which was designed considering the users willing to proceed with the interventions. This follow-up allows to assess the effective impact of interventions. Regardless of the extent of the provided support, PEH users are asked to fill in a satisfaction survey regarding the service, which will allow drawing conclusions regarding adjustments and improvements (8).

2.3. Figures and facts

Figure 2 - Energy Hubs operating in September 2023.

PEH was first presented in the municipality of Porto which, in September 2022, launched the Porto Energy Hub, the first OSS service developed in the scope of PEER. Soon after, on the beginning of November, Matosinhos opened the Matosinhos Energy Hub, followed by the Valongo Energy Hub service launched in March 2023, the Trofa Energy Hub (May 2023) and the Maia Energy Hub (September 2023) (Fig. 2).

From September 2022 to August 2023, through the analysis of the online surveys, the OSS service assessed the potential of energy efficiency improvement of 178 homes, located in several cities across the country but mainly concentrated in the North region: 166 were from the Porto Metropolitan Area, which is covered by the project through the Porto Energy Agency.

From the reports generated from the survey, the following conclusions can be drawn (Fig. 3):

- Most survey respondents were men (60%). Both apartment and detached dwelling owners look for energy advise (48% and 47%, respectively) (Fig. 3a) and 65% of the assessment requests were made by owners/dwellers of more-than-three bedrooms (Fig. 3b), meaning larger homes, which typically are also responsible for a larger energy demand;
- Although most of the assessment requests come from more-than-30-years-old buildings, 38% of the surveys represent homes built after 1990 and therefore, after the first Portuguese regulations on buildings' thermal performance (Fig. 3c). Indeed, 5% of the requests are from residential dwellings built after 2010, which seems to indicate that even newly constructed buildings are not performing exactly as intended in what concerns energy;
- Regarding constructive solutions, single brick wall homes without thermal insulation were the most reported (Fig. 3d), which is in line with the construction standards before the 1990s, whereas insulated walls, both single and double are still relatively scarce (around 29%). In turn, most of the dwellings' state to have double or even triple glazing spans (60%) (Fig. 3e), which seems to indicate that there is a greater tendency to invest in replacing these elements rather than insulating opaque elements (as walls). These stated characteristics for wall and window elements explain the average 27% improvement potential identified.
- In what concerns heating, 43% of dwellings still use either inefficient electric or gas-

based technologies and 16% of respondents still stated to use wood fireplaces or other biomass-based heating system (Fig. 3f). Only 10% of these dwellings already use AC or heat pumps as heating system. For heating systems, a 60% improvement potential was identified, ranging from a 4% potential in a dwelling with insulated walls, tripled glazed windows and heat pump to a 83% improvement potential in double-layered insulated wall dwelling with single glazed spans and wood-based heating system.

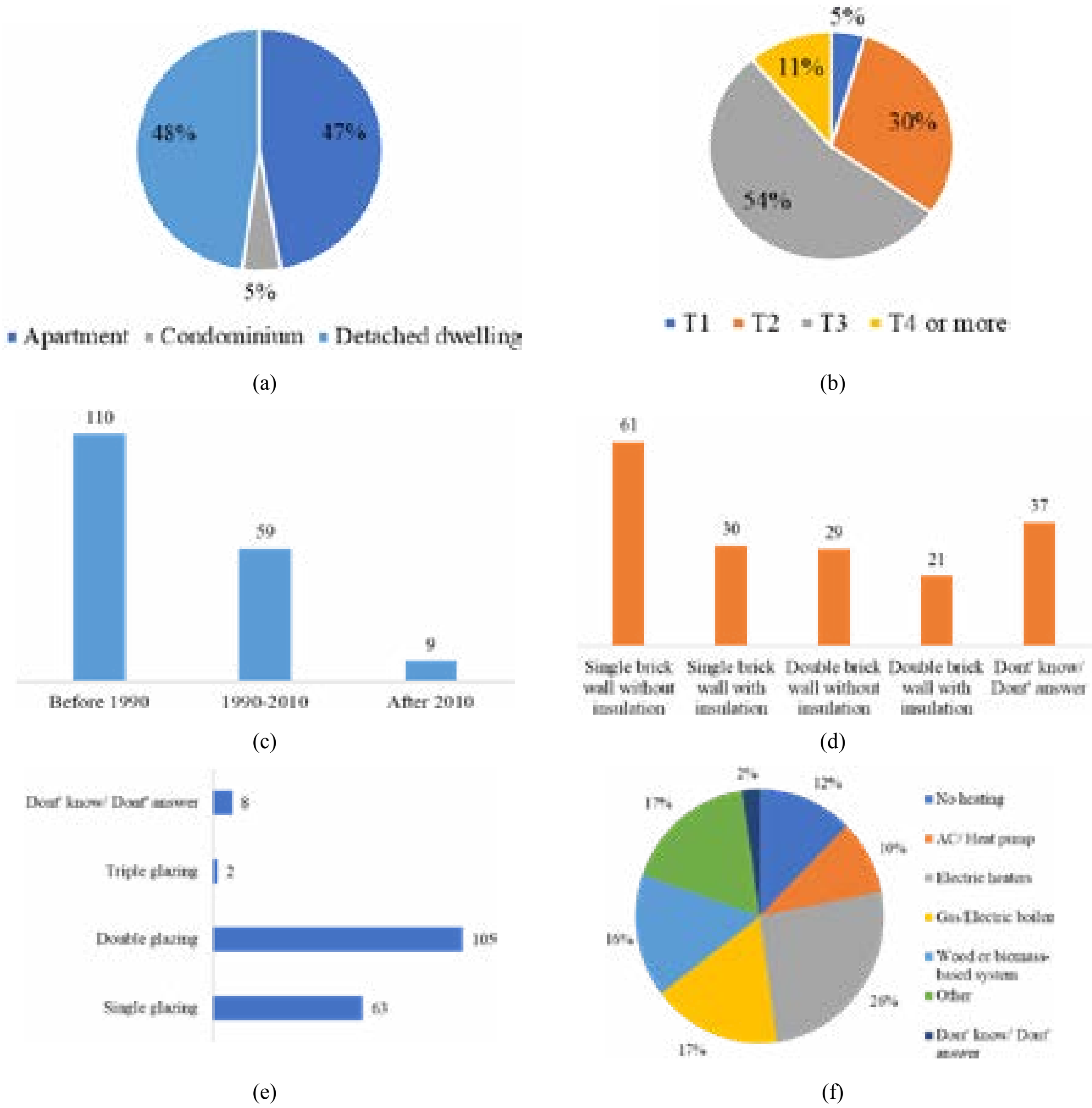

Figure 3. Results from surveys assessment.

From the over 170 assessment surveys, 97 technical meetings were held, either in-person (mostly), online or by phone (Fig. 4a). On these meetings, the balance between users' gender was more balanced: 49% of men requested more detailed advice on energy efficiency measures whereas 51% of women requested and attended these sessions. Also, most of the meetings held so far were related to questions on existing and future funding opportunities (70%) (Fig. 4b) and from these, mixed interventions (35%), window replacement (26%) and insulation (10%) were the most mentioned interventions (Fig. 4c). In addition, meetings were also held to advise on technical measures. Mixed interventions, usually in ongoing renovation settings, windows replacement, insulation features and renewable energy production for self-consumption were the addressed topics (Fig. 5d). Besides funding and technical requirements, clarifications on billing were also provided in several meetings.

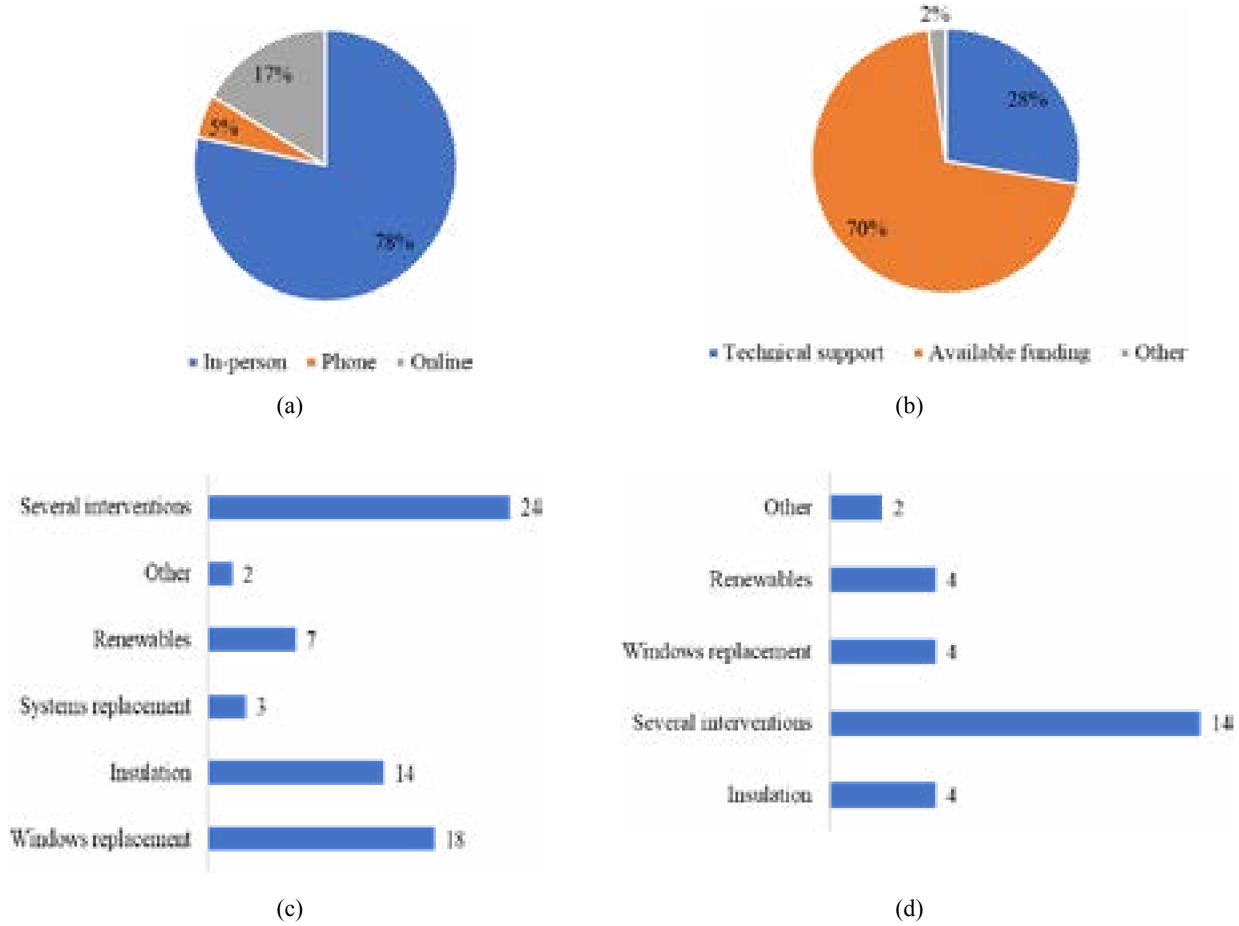

Figure 4. Results from the technical meetings.

3. MAIN CONCLUSIONS AND LESSONS LEARNED

The article summarizes the initial results from the implementation of an OSS in northern Portugal. Despite the characterization of the type of user, dwellings and needed information, the experiment allowed to gain knowledge regarding the contextual factors intervening for a successful OSS implementation. Firstly, there is a significant renovation potential of the built environment, i.e., even when a small measure is implemented, its effect is usually easily noticeable and recognized by the building users. Secondly, an aspect which proved to be key for the successful implementation of PEH was the win-win collaboration with local authorities. Municipalities are trusted entities by citizens and their participation and sponsorship gives the project credibility and security, in addition to allowing a much larger dissemination to other local entities and citizens. Also, the participation of municipalities in the discussion and implementation process of these kind of initiatives builds capacity on their staff and promotes awareness of local authorities regarding the energy topic and funding options. From the project perspective, the collaboration with municipalities allows to split the effort and costs of the service. Lastly, the replication process is highly facilitated by the enabling framework created by the current energy and climate neutrality awareness installed in most European countries. This framework raises the interest of local entities on providing differentiated services to their citizens boosting private investment in home renovation and raising energy literacy.

In turn, the low performance of buildings is complemented by a generalized lack of knowledge of citizens, municipal staff and market players on energy efficiency and renovation processes, which leads to inaction and the dissemination of often contradictory and erroneous information on the benefits of renovation. Additionally, existing information about financing measures and programs is also complex and difficult to translate for regular citizens. Therefore, the role of OSS as PEH is increasingly relevant, especially at the local level, as cities are designing their paths towards the decarbonization of the territory, ensuring that this is done in a sustainable, inclusive, and financially viable way.

REFERENCES

ADENE. (2023). *Statistics - Buildings' energy certificates*. Retrieved from https://www.sce.pt/estatisticas/

Bertoldi, P. B.-K. (2021). *The role of one-stop-shops in energy renovation - a comparative analysis of OSS cases in Europe*. Energy and Buildings. https://doi.org/10.1016/j.enbuild.2021.111273.

EC (2018). *Directive (EU) 2018/844 on the energy performance of buildings and on energy efficiency).* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L0844

EC (2020a). *In focus: Energy efficiency in buildings.* Retrieved from https://commission.europa.eu/news/focus-energy-efficiency-buildings-2020-02-17_en

EC (2020b). *Energy poverty.* Retrieved from https://energy.ec.europa.eu/system/files/2016-

11/enerpoverty_0.pdf#:~:text=Energy%20poverty%20is%20a%20widespread%20problem%20across%20Europe%2C,are%20unable%20to%20afford%20proper%20indoor%20thermal%20comfort.

EC (2023). *Energy poverty in the EU*. Retrieved from Energy: https://energy.ec.europa.eu/topics/markets-and-consumers/energy-consumer-rights/energy-poverty-eu_en

DellaValle, N. C. (2022). Empowering energy citizenship among the energy poor. *Energy Research & Social Science*. https://doi.org/10.1016/j.erss.2022.102654.

Eurostat. (2020). *Income and Living Condition (EU-SILC)*. Retrieved from https://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions

Eurostat. (2022a). *Electricity prices statistics*. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics

Eurostat. (2022b). *Natural gas prices statistics*. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics#Natural_gas_prices_for_household_consumers

Felius, L. D. (2020). Retrofitting towards energy-efficient homes in European cold climates: a review. *Energy Efficiency*. https://doi.org/10.1007/s12053-019-09834-7.

Ferreira, M. A. (2016). Cost-optimal energy efficiency levels are the first step in achieving cost effective renovation in residential buildings with a nearly-zero energy target. *Energy and Buildings*. https://doi.org/10.1016/j.enbuild.2016.10.017.

Gouveia, J. P. (2022). *National Indicators - Insights for a more effective measuring.* Lisboa: Energy Poverty Advisory Hub.

Horta, A. S. (2021). *Policy brief 2021 - Pobreza Energética em Portugal.* Retrieved from https://repositorio.ul.pt/bitstream/10451/48206/1/ICS_AHorta_LSchmidt_PobrezaEnergetica_.pdf

INE. (2021). *Survey on the energy consumption in the residential sector - 2020.* Lisboa: INE.

Rohrer, L. L. (2022). Combating energy poverty in social housing. *Social Green Interreg Group*. https://projects2014-2020.interregeurope.eu/fileadmin/user_upload/tx_tevprojects/library/file_1663935629.pdf.

Wilde, M. S. (2019). Designing trust: how strategic intermediaries choreograph homeowners' low-carbon retrofit experience. *Building Research & Information*. https://doi.org/10.1080/09613218.2018.1443256.

Zangheri, P. C. (2021). *Progress of the Member States in implementing the Energy Performance of Building Directive.* Luxembourg: JRC Science for Policy Report.

SUCCESSFULLY REACHING THE HARD-TO-REACH BY IMPROVING HOME ENERGY ASSESSMENT TOOLKITS WITH THE HELP OF FRONTLINE & COMMUNITY PROVIDERS

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Keywords: Behaviour Change, Field Research Pilot, Hard-to-Reach Energy Users, Energy Poverty, Intermediaries, Vulnerable Energy Users

Abstract *Home Energy Assessment Toolkits (called Whānau HEAT Kits here) have been available to loan from public libraries in e.g. Ireland, Australia, Aotearoa New Zealand, and Canada since the early 1990s. A cross-country comparison and in-depth evaluations of two such interventions by the lead author, however, showed they often fail to achieve their full potential in terms of changing energy-using behaviours, and reaching the most vulnerable. This field research pilot, funded by the NZ government's Support for Energy Education in Communities programme, aimed at improving HEAT kits to target those who need support the most, but who are underserved and often remain hidden from conventional interventions.*

The goal was to show significant and persistent behaviour changes by following a robust scientific process called "The Building Blocks of Behaviour Change". The Whānau HEAT kits were co-designed with community and technical experts to target 44 highly-vulnerable families in the Wellington Region between December 2021 and March 2023. They contained easy-to-use tools such as infrared thermometers, digital hygrometers, shower timers etc. to educate whānau [families] in both their own energy-using behaviours, and their home's energy performance. Trained community and frontline providers were used as all-important Middle Actors to help us identify, recruit and engage low-income whānau with at least three compounding vulnerabilities. The pilot was an unmitigated success, with all households completing all two weeks of behaviour change activities and in-home measurements to receive $500 prize packages that directly targeted the problems they uncovered by using the tools.

1. INTRODUCTION

Current Library HEAT Kit Programmes

The idea for improving HEAT kits for hard-to-reach (HTR) energy users in Aotearoa (NZ) was developed from an earlier research collaboration under the User-Centred Energy Systems Technology Collaboration Programme by the International Energy Agency called "*Task 24: Behaviour Change in DSM*"[1]. The lead author investigated and evaluated HEAT kits on loan from public libraries in Ireland (SEAI, 2018; Rotmann & Chapman, 2018a&b) and Aotearoa (Rotmann, 2018a), and did a cross-country case study comparison of energy saving kit programmes around the world (Rotmann, 2018b&c). A typical HEAT kit contains measurement tools to assess current energy use, or determining / fixing the (in)efficiency of a home's thermal envelope (e.g. digital thermometer/hygrometer); appliances (e.g. plug-in energy monitor); insulation (e.g. thermal leak detector); fridge/freezer (e.g. fridge thermometer); and hot water (e.g. stopwatch and shower bag to measure shower water flow).
Despite the extensive spread of HEAT kit toolkits (a more recent unpublished cross-country analysis found at least 40 examples in five English-speaking countries), scientific investigation of such a popular behaviour change intervention was so far lacking.

We found that these programmes (summarily called "HEAT kits" here, although they have different names in different countries) are often regarded as highly-successful by their programme managers, despite not being able to show any proven behaviour changes by participants (Rotmann, 2018a; Rotmann & Chapman, 2018a). From self-reported surveys, it was found that the overwhelming majority of participants had a positive experience with the kits, and library waiting lists to this day remain long (in Ireland, the energy agency CODEMA has now distributed over 500 kits to libraries around the country, with the backlog causing some libraries to develop their own, inferior copies, Gobnait Ní Néill, *pers. comm.*).

The Irish HEAT kits were found to increase awareness of energy use in the home and a majority of participants reported intentions to act on installing energy-efficient equipment after borrowing the kit (SEAI, 2018). These responses attest to a change in willingness, but not necessarily behaviour (the "intention-behaviour gap", e.g. Connor & Norman, 2022). The novelty of the kit and its range of tools made for an interesting and engaging experience for most users, and almost all stated that they would recommend it to others. Surveys, interviews, and a focus group undertaken with Auckland HEAT kit users showed similarly-enthusiastic and positive feedback (Rotmann, 2018a). However, it was noted that the respondents were already highly-motivated and engaged, and early adopters of energy-efficiency programmes.

[1] https://userstcp.org/task/task-24-phase-2-behaviour-change-in-dsm-helping-the-behaviour-changers/

Reported shortcomings

Despite the positive feedback from programme managers, and self-reported feedback on intended energy actions by HEAT kit borrowers, it was unclear if the kits have actually led to many real (observed) energy behaviour changes. There are several reasons for these shortcomings, which we aimed to address with the improvements trialled here:

- The main metrics for success were numbers of kits borrowed, or waitlists.
- Library staff were not specifically trained to explain the kits / their benefits.
- Surveys, interviews or focus groups were largely answered by highly-motivated and engaged participants with high self-efficacy.
- There were no longitudinal surveys and no follow-up studies on persistence.
- The in-home data was not collected or analysed.
- The kits were unlikely to be borrowed by the most vulnerable households.

Our Aims

The pilot described here researches the value of *Whānau* [family] *HEAT kits,* introduced by a trusted community-based contact, as a tool for hard-to-reach (HTR) households to educate and empower themselves about how to best manage their energy use. An extensive literature review of almost 1000 publications (Rotmann et al, 2020) characterised how complex, heterogenous and numerous (authors estimated that at least ⅔ of energy users in residential and commercial sectors could be regarded as HTR) underserved energy users are, and how problematic the terminology and (lack of) targeted engagement strategies are when policy makers, programme managers and researchers design interventions without a deeper understanding of their subjects' lived experiences - especially of vulnerable populations.

Using the "Building Blocks of Behaviour Change" framework (Karlin et al, 2021), and undertaking *ex post* cross-country case study assessments in eight countries (Mundaca et al, 2023), we found that even though most programme managers utilise some behavioural science methods, they rarely follow a robust scientific "best practice" process (Karlin et al, 2022) when designing and implementing interventions targeting vulnerable populations. Particularly in applied research settings, it was found that inadequate attention was paid to properly defining target audience (sub)segments (low income was usually the main metric used) and behaviours (ibid), even though behavioural strategies and interventions can have different effects depending on the individual or group being targeted (e.g. Lavelle et al, 2015).

Designing and pre-testing interventions with target audiences was also found to be inadequate, particularly when it came to the testing and refining of the intervention content(s) and delivery strategies (Karlin et al, 2022). On a positive note, co-design with community representatives who understood the lived experience of vulnerable populations was relatively common in the cases analysed here (ibid). All analysed case studies and the major HTR literature review by Rotmann et al (2020) revealed **trust** as a critical success factor when engaging vulnerable populations. Building close and trusted relationships with multiple stakeholders - particularly those community providers directly serving the target audience is clearly essential, yet also extremely difficult as they are also HTR and often have similar trust issues around interventions that are designed from the top-down by "experts" in government, industry or academia (Rotmann & Cowan, 2022). Overcoming these barriers and building trusted relationships with community gatekeepers was a major goal in this field research pilot.

These trusted community "Middle Actors" (though they prefer the term "navigators") include those frontline providers working with households from e.g. the health, social support, housing, religious, and financial sectors. Their primary mandate is not necessarily to provide energy advice to their clients, which is why we trained them in the *Home Performance Advisor: Making Energy Work for Whānau*[2] programme designed for community providers, to give them a basic understanding of the intersection of energy behaviours, healthy housing and utility bills. Our goals in this study were to improve library HEAT kits, using a package of interventions, for vulnerable hard-to-reach audiences. Our research questions were as follows:

1. Can library HEAT kits be improved to target vulnerable and HTR households?
2. Is the use of trained community Middle Actors and in-home visits more successful than library loans when targeting those audiences?
3. Does gamification and the provision of tailored prizes improve household energy literacy and lead to persistent behavioural change?

2. METHODOLOGY

The pilot was co-designed, implemented and evaluated using the "*Building Blocks of Behaviour Change*" framework (Karlin et al, 2021). It balances robust behavioural science methodology with real-life best practice, and addresses the many barriers when engaging the HTR. Community Middle Actors (MAs) are already managing extremely complex work with very limited resources, and their (often justified) distrust of authority figures and experts meant they were reluctant to engage or provide access to their vulnerable clientele. Therefore, the research team needed to build trusted relationships first, find ways to work alongside existing programmes, and be responsive to their needs. All community MAs and project partners were duly compensated for their time spent on the pilot, which included the training, identifying and recruiting eligible whānau, and co-designing and pre-testing the kit materials.

[2] https://hpa.arlo.co/w/

2.1. Discover

In the Discover Phase, we undertook landscape (of similar programmes) and stakeholder assessments, to ensure we all agreed on shared goals and objectives for this pilot.

2.2. Define

We also spent some time with our community partners agreeing on eligibility criteria and defining our target audiences and behaviours. Any clients who had any three intersecting vulnerabilities such as: low income, renters, social housing tenants, families with small children or pregnant women, single parents, immigrants and refugees, mentally or physically disabled, elderly, Māori and Pasifika, and anyone stigmatised or criminalised (e.g. formerly homeless, incarcerated, addicts, sex workers) were eligible for receiving a Whānau HEAT kit.

2.3. Design

The kit content was co-designed with community providers and technical experts, including some library HEAT kit programme managers. Several different community providers were approached to undertake the training, help us identify and recruit eligible HTR whānau, and spread the word among their clients about the value of HEAT kits. However, out of over 25 contacted community providers, only four initially agreed to undertake the training and share the HEAT kits with their clients (they all came via already-established personal relationships). The tools were tested with the general public at a Christmas Market at the Sustainability Trust (one of our community partners), and a manual was developed and continually revised following more MA input, to simplify technical jargon, and explain how the tools worked, why and where they were useful, in language aimed at 10-12 year old children. The 2-week Activity Booklet with daily activities was also co-designed and user-tested, and we designed "Power Sucker" stickers for power-hungry appliances, a fridge magnet that explained the simple "3 bucket" concept (see Figure 1), and a recommendation booklet families could keep with top energy-saving tips and links to further subsidies and support programmes.

Figure 1. The "3 buckets" concept explains where energy is used in a house. From left to right: the "healthy" bucket (heating, cooling and ventilating); the "hot water"; and the "lights & appliance" buckets (Source: HPA)

Our tools fell into the 3 buckets in the following way:
1. “Heating / Health bucket”:
- 3 small, digital thermometers / hygrometers to measure temperature and moisture content in the bedrooms and living room
- An infrared surface thermometer to detect temperature changes (thermal leaks)
- A compass to measure where the most solar gain is through windows (North)

2. “Hot water bucket”:
- A shower bag to measure shower flow
- A shower timer to measure how long participants take showers for
- A digital water thermometer to measure how hot water is coming out of the taps

3. “Appliance and lighting bucket”:
- A smart plug to measure how much power appliances use
- An analogue timer to set appliances to turn on/off remotely
- An LED light bulb to show how much brighter these lights are than incandescent

Behaviours that were specifically targeted via stories, quizzes and games in the kit were:
- Noting down and reducing number of showers (Day 1)
- Measuring and reducing the length of each shower (Day 2)
- Measuring hot water (cylinder) ensuring it had the right temperature (Day 3)
- Calculating power use of appliances (Day 4)
- Counting number of different light bulbs in each room (Day 5)
- Unplugging the second fridge/freezer when it’s not in use (Day 6)
- Weatherising an inefficient home with simple tools (Day 7)
- Opening and closing curtains as required (Day 8)
- Dealing with moisture and condensation issues (Day 9)
- Airing and ventilating homes (Day 10)
- Addressing causes for mould (Day 11)
- Quick fixes to reduce power bills (Day 12)
- Do a healthy homes check (Day 13)
- Address leaking hot water pipes (Day 14)

2.4. Deployment

Following successful recruitment via four community Middle Actors (the Sustainability Trust, Dwell Social Housing Trust, and two Pasifika Churches), we completed 44 in-home assessments including pre- and post-interviews, as well as 4-month follow-up calls, to gather valuable monitoring and behavioural data, and better understand participants' lived experience. Households were left with the kits for two weeks, and more than half opted into receiving daily text prompts to complete the 5-10 minutes of daily activities in the Activity Booklet. After two weeks, we collected the HEAT kits, dropped off prizes, and undertook post-intervention interviews based on the "beyond kWh" tool co-developed by Task 24 project partners (Karlin et al, 2015; SCE, 2015), which was previously used to evaluate HEAT kits in Ireland (Rotmann & Chapman, 2018a&b). Completion / engagement was rewarded with up to $500 worth of low-cost solutions that targeted the issues highlighted by HEAT kit assessment tools (such as LED light bulbs, tap aerators, secondary glazing, door snakes, energy-efficient appliances). We initially hoped for 10% full completion rate (all 14 days of Activity Booklet filled out with in-home recorded data), and were very pleasantly surprised!

3. RESULTS & DISCUSSION

3.1. Demographics & Housing

Most of our pilot participants were families with children (66%), followed by family units without children (14%), flatmates, and single occupants (both 10%). Occupant numbers per household are significantly higher ($\overline{x}$=3.7) than the average Kiwi household ($\overline{x}$=2.7), with several households having 5-8 family members living in crowded conditions.
The majority of participants (especially Pasifika and those recruited by Dwell Social Housing) were renters, with only a quarter owning their homes. Aside from the ten families from Dwell, another nine renters came from Kāinga Ora (the government's social housing provider), or transitional housing. The number of bedrooms was also slightly greater ($\overline{x}$= 3) than the average NZ rental home ($\overline{x}$= 2.7), although most (even 3- or 4-bedroom homes) only had one bathroom and were of quite old housing stock (estimated pre-1970). It was unsurprising to find so many substandard houses, as the general housing stock in Aotearoa is one of the worst in the OECD, causing chronic respiratory health issues in large parts of the population, but especially Māori and Pasifika, the elderly, and young children (e.g. Johnson et al, 2018; Howden-Chapman, 2015). Structural and functional overcrowding is known to be a huge issue among Pasifika households (both for cultural and financial reasons; see Statistics NZ, 2018).

3.2. Participant Backgrounds / Energy Lifestyles

We heard a lot of stories about participants' backgrounds that were rather tragic - especially social housing tenants often had experienced significant vulnerabilities, such as homelessness, having to flee war-torn countries, bringing up large families on their own, addiction and mental health issues, and long-term unemployment, as well as serious physical ailments and disabilities. A big theme that came through was how incredibly grateful they were for being provided stable, efficient and decent housing by the social housing providers. They still frequently had some issues with e.g. moisture build-up and leaks, and their perspectives of what constituted “healthy housing” were often based on unhealthy baselines (see discussions about NZ’s unhealthy “pioneer masculine energy culture” by Ambrose & McCarthy, 2019).

A general insight from the pre-interviews was that the HTR participants targeted here often already exhibited quite strong energy conservation behaviours - sometimes to the detriment of their health or wellbeing. The significant stress that utility bills cause led them to prioritise paying those bills over other matters, such as other bills, or buying healthy food. Those who had moved into improved (social) housing described noticeably improved wellbeing, and changed certain lifestyles, such as “treating themselves” to more heating or better eating, and small luxuries. Before moving into social housing, they would have been even harder to reach (hidden), due to distrust, shame, mental health issues, and fear of authorities. Some habits were clearly borne from tradition and upbringing - in the case of some immigrant Pasifika communities, they had little experience with cold winters or even access to reliable electricity systems on the islands. Their children and grandchildren often had to work as their translators, including helping them read and pay their bills.

It is critical to exercise caution when crafting informational messages, particularly for vulnerable populations, to prevent unintended negative impacts on their health and well-being. For instance, research conducted in Aotearoa (Lloyd et al, 2008) revealed that households experiencing energy hardship tended to reduce their energy consumption, even after receiving free insulation upgrades, leading to inadequate home heating. Similarly, in the United States (Hernández, 2016), households facing utility disconnections were observed resorting to unhealthy alternative heating sources such as ovens. These households vigilantly monitored their thermostats and limited heating, often to the detriment of their health and overall well-being - something we originally observed in our whānau too.

3.3. Heating, Appliances and Hot Water

Sixteen of the 44 homes did not have any heating in the bedrooms. The majority were either radiator, electric fans or heat pumps. It was heartening to see only one unflued gas heater in use (as they cause massive indoor air pollution and fire danger). Almost all homes had range hoods in the kitchens, and extractor fans in the bathroom (although one had birds nesting in there!), and most participants reported using them regularly. Only three homes had no mechanical ventilation at all. All homes had fridge/freezer combos, six had chest freezers and only two had a second (beer) fridge. The vast majority of homes had electric water heaters, but only about half of them were insulated. Only three gas water heaters were encountered, and no solar water heaters. Most homes had LEDs or other forms of efficient lighting, though five homes still had old halogen lights, and several self-reported, as part of the HEAT kit activities, old incandescent light bulbs. Curtains were found in most homes (only four had none), but about half of them were inadequate, not long enough, and/or not thermally-lined.

A shocking 76% of homes had mould issues, 67% reported leaks or draughts, and 40% reported damp and cold bedding, especially in winter - even though many of these homes were managed by public and private social housing providers and/or had been through various government subsidy retrofit programmes. We need to continually improve our rental housing stock and keep educating vulnerable whānau on health-related energy behaviours (such as ventilation) - rather than focusing on reducing kWh or carbon emissions.

3.4. Psychographic Findings

Motivations

Most pilot participants stated that *"saving money on energy bills"* was their initial reason for agreeing to partake. They further elaborated on having high electricity bills (especially in winter), wanting to invest in their family and/or their home, or having past issues paying their utility bills. Some participants noted that they had been threatened with their power being cut off. One participant also shared the incredibly tragic story that they could link the passing of a family member due to not being able to pay for heating: *"Heating is very, very important, I lost my mother because we could not afford heating."* This is one of the worst outcomes of the energy poverty crisis, with excess winter deaths from lack of heating, and excess summer deaths from lack of cooling becoming a more and more dire problem, globally, and in Aotearoa (Howden-Chapman, 2015). This affects especially vulnerable whānau, including those suffering disabilities, poor health, the elderly and very young, and is particularly pronounced in low-income private renters (Hales et al, 2010). One participant noted that the power bill was *"the most expensive, but also the most important one to pay!"*

Financial motivations were thus the biggest reasoning and core aspect for over 50% of our participants wanting to engage with the HEAT kit pilot, actively stating that the opportunity to gain up to $500 worth of prizes and learning energy-saving behaviours were the biggest contributors behind their decision-making. For several participants, some of these prizes and ongoing savings on their electricity bills, were literally life-changing improvements. Close to 50% also stated either concerns regarding their personal health, a family member's health issues, or the condition of their home as one of the core deciding factors to borrow the HEAT kit. More than 35% of participants indicated that one or more household members were currently suffering from a health condition that was likely exacerbated or directly linked to the condition of their home. Several participants said that they wanted to know more about the "invisible aspects" like temperature and moisture measurements, and where leaks came from. Some also mentioned that their property was ageing, and they were hoping that the tools would help them identify which repairs they should tackle first, or let their landlord know about. The diagnostic DIY nature of the tools were particularly appreciated by Pasifika. Several participants expressed that their main motivations changed over the 2-week period they were using the kit. The financial benefits were still an important factor, but the idea that they would learn something new every day motivated them to continually interact with the kit, showing that they were good educational tools. Most participants with children remarked on how much they liked the gamified approach to the activities, although adults with no children found some of the games irrelevant. We aim to tailor the kits to different audiences next.

General barriers

We asked participants to give us some of their main barriers in relation to energy-saving behaviours. The highest response (17) was *"I feel I'm already doing all I can"*. Twelve respondents said they were *"too busy or had other priorities"*, and seven said that their *"landlord won't do enough/anything"*. Only four said they didn't have access to enough information, which is notable as most energy-efficiency interventions are information-based.

Tenancy status

The tenancy status of our participants also clearly affected the type of energy efficiency changes and retrofits they could incorporate within their home. Unfortunately, this also affected some of the prizes we were able to provide to households. Some of our most effective devices and tools were unable to be given as they were a permanent alteration to the house (e.g. door seals that needed to be screwed in). In cases like this we provided door snakes rather than door seals. The tenancy status of participants also affected the level of self-advocacy they could invoke. 36% of our participants were in some form of social housing - and we relied on their landlords to identify and recruit them. Trust again was a major issue. These tenants noted very long wait times after notifying their social housing provider of any issues they were having, and that they had to re-enquire about the same issue on more than one occasion before any action was taken. The 38% of participants who were privately renting also said that it could be difficult to advocate for changes within their homes without a positive, trusted and open relationship with their property manager or landlord.

Language barriers

Language barriers were a significant issue, especially in Pasifika and immigrant / refugee communities. Several had English as their secondary language. For ten of our interviews we had to use an interpreter (often their teenage children) to help with the interview process. This is an important consideration for scale-up and future iterations of the kits. They should be translated into different languages, and co-designed to be culturally-appropriate. An even bigger language issue concerns the technical jargon and terminology used in the energy sector.

Changes post-intervention to the health of the home

Most of our insights here are qualitative and anecdotal (although we also tracked measurable improvements in both average temperature and humidity from the in-home measurements over the 2-week period). However, improvements around knowledge on how to live healthier, or use energy wiser, were significant and impressive. *"After two weeks it has now become a lifestyle. I keep trying to keep warm air in, and turning off light switches and wall switches."*

Even more positive was the significant empowerment and self advocacy improvements we could see in some of our social housing tenants in particular. Several used the tools to be able to show their landlords that there were issues in their homes with e.g. leaks, draughts, mould and high moisture content. Many said they would strive to either make their own homes healthier or to move to a healthier home for their whānau. Others mentioned aspirations of home ownership. Some homeowners also mentioned how they now had continued confidence and understanding in their own homes, and knew better where to invest in their homes.

4. CONCLUDING INSIGHTS AND RECOMMENDATIONS

We have shown that the Whānau HEAT kit intervention is applicable to HTR audiences, with the 100% completion rate, the 100% of participants who said they'd recommend the kits to family and friends, and 85% who reported significant improvements in home performance and wellbeing. We believe we have shown in this pilot that using trained community MAs is more successful when targeting vulnerable and HTR audiences than library programmes. The gamification elements of the kits combined with the Activity Booklets were al successful: 85% of whānau still showed behavioural persistence after 3-4 months (we could not measure changes after 12 months as the pilot had finished), and 90% of whānau reported significant bill reductions ($\bar{x}$=$50 savings a month). Recommendations for improvements centre around targeting the kits more towards different audiences (e.g. school children, shared housing, elderly, immigrants, Māori), as well as developing a web-based App to reduce onerousness of data collection and analysis. The single most important recommendation is to continually reach out to, and build trusted relationships with diverse community and frontline providers and Middle Actors. They are the most important key in reaching the hard-to-reach.

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REFERENCES:

Ambrose, A. and McCarthy, L. (2019). Taming the 'masculine pioneers'? Changing attitudes towards energy efficiency amongst private landlords and tenants in New

Zealand: A case study of Dunedin. *Energy Policy,* 126, 165-176.

Conner, M., Norman, P. (2022). Understanding the intention-behavior gap: The role of intention strength. *Frontiers in Psychology* 13. 10.3389/fpsyg.2022.923464

Hales S., Blakely T., Foster R.H., Baker M.G., and P. Howden-Chapman (2010). Seasonal patterns of mortality in relation to social factors. *J of Epidemiol Comm Health*.

Hernández, D. (2016). Affording housing at the expense of health: Exploring the housing and neighborhood strategies of poor families. *J Family Issues* 37(7), 921-946.

Howden-Chapman, P. (2015). *Home truths: confronting New Zealand's housing crisis.* Bridget Williams Books Limited: Wellington.

Johnson, A., Howden-Chapman, P. and S. Eaqub (2018). *A stocktake of New Zealand's housing.* Ministry of Business, Innovation and Employment: Wellington. 87pp.

Karlin, B., Forster, H., Chapman, D., Sheats, J., and Rotmann, S. (2021). *The Building Blocks of Behavior Change: A Scientific Approach to Optimizing Impact*. SCI: Los Angeles.

Lavelle, M. J., Rau, H., & Fahy, F. (2015). Different shades of green? Unpacking habitual and occasional pro-environmental behavior. *Global Envir. Change*, 35, 368-378.

Lloyd, C.R., Callau, M.F., Bishop, T., Smith, I.J. (2008). The efficacy of an energy efficient upgrade program in New Zealand. *Energy and Buildings* 40(7), 1228-1239.

Mundaca, L., Rotmann, S., et al (2023). A Cross-Country Case Study Comparison of How to Engage Hard-to-Reach Energy Users in 8 Countries. *ERSS* 104, 103205.

Parag, Y., & Janda, K.B. (2014). More than filler: Middle actors and socio-technical change in the energy system from the "middle-out", *ERSS*, 3, 102-112.

Rotmann, S. (2018a). *NZ Home Energy Audit Toolkits.* Task 24: Wellington. 82pp.

Rotmann (2018b). *Cross-Country Case Study Comparison of Energy Saving Kit Programmes.* Task 24: Wellington. 35pp.

Rotmann (2018c). *Cross-Country Case Study Comparison Ireland – Database of Energy Saving Kit Programmes*. Task 24: Wellington.

Rotmann, S. & Chapman, D. (2018a). *Evaluation Report for Home Energy Saving Kits: Using Bayesian Modelling to test the "beyond kWh" toolkit*. Task 24: Wellington. 47pp.

Rotmann, S. & Chapman, D. (2018b). Energy Saving Kits – Educating And Empowering End Users? A Cross-Country Case Study Comparison. *BEHAVE conference*.

Rotmann, S. and Cowan, V. (2022). Piloting Home Energy Assessment Toolkits (HEAT kits) to Empower Hard-to-Reach Energy Users. *eceee Summer Study Proceedings*.

Statistics NZ (2018). *Living in a crowded house: Exploring the ethnicity and well-being of people in crowded households.*

Stats NZ (2021). *The Wellbeing Survey: General Social Survey.* www.stats.govt.nz

SEAI (2018). *Home Energy Saving Kits Final Report: Ireland*. SEAI: Dublin. 64pp.

ARE THE MAJORITY OF ENERGY USERS REALLY "HARD-TO-REACH" OR ARE WE NOT TRYING HARD ENOUGH TO REACH THEM?

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Abstract

The Hard-to-Reach (HTR) Energy Users Task by the Users TCP by IEA has delved deeply into characteristics of HTR energy users, and engagement strategies that have worked to reach them in case studies around the world, and via co-designed field research pilots in Aotearoa NZ, Canada and the United States. Main findings were that:

1. *Their numbers were significantly greater than we hypothesised (Rotmann et al, 2020).*
2. *They are an extremely diverse cohort in residential and commercial sectors, and being low-income does not necessarily make them HTR (ibid).*
3. *Top-down designed behaviour change interventions aimed at poorly-characterised energy users have several methodological failings, including a lack of participatory co-design processes (see Karlin et al, 2021; 2022; and Mundaca et al, 2023).*
4. *End user needs and their lived experiences are often poorly understood by intervention designers in government, industry and research sectors, who generally operate from Eurocentric worldviews, privileges and biases.*
5. *Involvement of community middle actors, gatekeepers and navigators is crucial but extremely hard, as they are also often HTR, overworked and undervalued, and suffer from similar levels of distrust in well-meaning intentions of "experts" when it comes to how we acknowledge them, and their communities' data, stories, and suffering.*

In short, it is not marginalised communities who are hard-to-reach, but us, who are not engaging them in ways that suit their needs, instead of ours. By focusing on fixing misperceived symptoms rather than underlying structural and systemic causes of energy injustice, we will fail to achieve a just energy transition for all.

1. INTRODUCTION

1.1. The Energy (Injustice) Crisis

The energy crisis is rapidly unfolding due to the poly[1]- and permacrises[2] of COVID-19, the Russian invasion of Ukraine, inflation and rampant cost-of-living rises, as well as supply shocks around the globe. In addition, collapsing climate and ecosystems are leading to calls to rapidly decarbonise and transition our largely fossil fuel-driven and inefficient energy system. Governments around the world face the trilemma of having to balance energy (in)security with sustainability, whilst also addressing affordability concerns (Hussain et al, 2023). Unfortunately, carbon and energy footprint gaps between the rich and poor keep expanding (Chancel, 2022; Oswald et al, 2020). Furthermore, instead of pursuing a truly "just and fair energy transition" around the globe, the world continues to subsidise fossil fuel production and consumption; a trend that is expected to increase to 7.4% of global GDP by 2025 (Parry et al, 2021). On a positive note, a recent study of 119 countries showed that a reduction in energy vulnerability also facilitates a reduction in greenhouse gas emissions, both directly and indirectly (Liu et al, 2023). The synergistic benefit of these overlapping goals compels us to address the two in tandem (with energy access provision also being an implied goal).

Research (e.g. Bartiaux et al, 2019) highlights the links between inequality, inequity, exclusion, vulnerability and energy injustice in sustainable energy transitions. Energy poverty / vulnerability / hardship is typically driven by energy-inefficient buildings, high energy prices, and low income, resulting in either too cold or hot indoor temperatures or sacrificing other essentials, such as food and health services, to afford adequate warmth or coolth (see detailed analysis and terminology critique in Rotmann et al, 2020). This can cause several detrimental impacts on households and society, with the most significant effect being on physical health, with a close correlation between excess winter deaths, cardiovascular disease, and respiratory problems, as well as mental and social health issues, such as social isolation and anti-social behaviour (especially in children and the elderly).

There are societal groups who experience decreased quality-of-life or disempowerment as a result of sustainable energy transitions in general, and smart grid deployment (Tarasova & Rohracher, 2022), demand-side flexibility (Powells and Fell, 2019), climate mitigation (Hussain et al, 2023), and decarbonisation of heating (Sherriff et al, 2022a), and transport (Sovacool et al, 2023), in particular. It is clear that all of these crises, as well as our current inadequate and often misdirected responses, have hidden, disproportionate and compounding impacts among the poorest, most marginalised and most vulnerable energy users around the globe (Sherriff et al, 2022b; Hussain et al, 2023). Hussain et al (2023) call this polycrisis *"a perfect storm for governments worldwide, which are under tremendous pressure to work out a proportionate response."* They also highlight that the energy transition and energy justice need to take centre stage, and that ignoring the latter has already resulted in further political and economic instability and social unrest.

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[1] polycrisis = the simultaneous occurrence of several catastrophic events

[2] permacrisis = an extended period of instability and insecurity, especially one resulting from a series of catastrophic events (Collins Dictionary's Word of the Year 2022)

Sadly, energy vulnerabilities, inequities and hardship keep growing. The number of people around the world who live without electricity was set to rise by nearly 20 million in 2022, reaching 775 million, the first global increase since the International Energy Agency (IEA) began tracking the numbers 20 years ago. At the same time, while the richest 10% use ~39% of total final energy, the poorest 10% consume only ~2% (Oswald et al, 2020). Likewise, whereas the bottom 50% contribute to 11.5% of global CO_2-e emissions, the richest 10% are responsible for 48% (Chancel, 2022). As the IEA says[3]: *"There is no pathway to net-zero without first achieving universal electricity access."* It may be impossible to achieve universal well-being unless we first address systemic energy, climate and environmental injustice.
Yet it is not only energy users in the Global South who lack access to clean, reliable and affordable energy. Energy Action's Cold@Home project[4] found that some 100 million people across Europe and North America cannot afford to keep their homes comfortable and warm anymore. Sovacool et al (2023) estimate it could be as many as 125 million in the EU alone, with a frightening prediction that high fuel prices could kill more Europeans from inadequate access to heating and cooling than the war in Ukraine. Recent estimates show that total energy costs for households have increased by 63-113% due to the global energy crisis, which has contributed to 2.7-4.8% increase in household expenditures (Guan et al., 2023). In turn, it is also estimated that 78-114 million people may be forced into extreme poverty (ibid). These findings underpin calls (and protest movements, see e.g. Hussain et al, 2023) for asserting that access to affordable and secure energy is a basic human right that should be treated as such, rather than a commodity sold to further entrench systemic inequities and injustice. This is even more the case when we consider that the majority of energy generation and supply infrastructure has been paid for by the tax-paying public, who also continues to subsidise fossil fuel polluters by trillions of dollars every year[5].

1.2. Background to the Hard-to-Reach Energy Users Task

The Users TCP Task on Hard-to-Reach Energy Users[6] ("HTR Task") was initiated in 2019, and Phase 1 finished in September 2023. The shared goal of the Task was to *"to identify, define, and prioritise HTR audiences; and design, measure and share effective strategies to engage those audiences to achieve energy, demand response and climate targets while meeting access, equity, and energy service needs."* The Task has successfully delivered all its stated objectives, including co-designing and testing a research framework called the "Building Blocks of Behaviour Change" (Karlin et al, 2021; Figure 1). It has brought experts from around the world together (Discover); undertaken a massive review of HTR audience and behaviour literature (Define); analysed, in depth, existing programmes tasked with engaging HTR energy users around the world (Design); and developed and successfully field-tested its own research process (Deploy). We provide a summary of the findings here.

3 https://www.iea.org/commentaries/for-the-first-time-in-decades-the-number-of-people-without-access-to-electricity-is-set-to-increase-in-2022
4 https://www.coldathome.today/
5 https://www.eesi.org/papers/view/fact-sheet-fossil-fuel-subsidies-a-closer-look-at-tax-breaks-and-societal-costs
6 https://userstcp.org/hard-to-reach-energy-users-task/

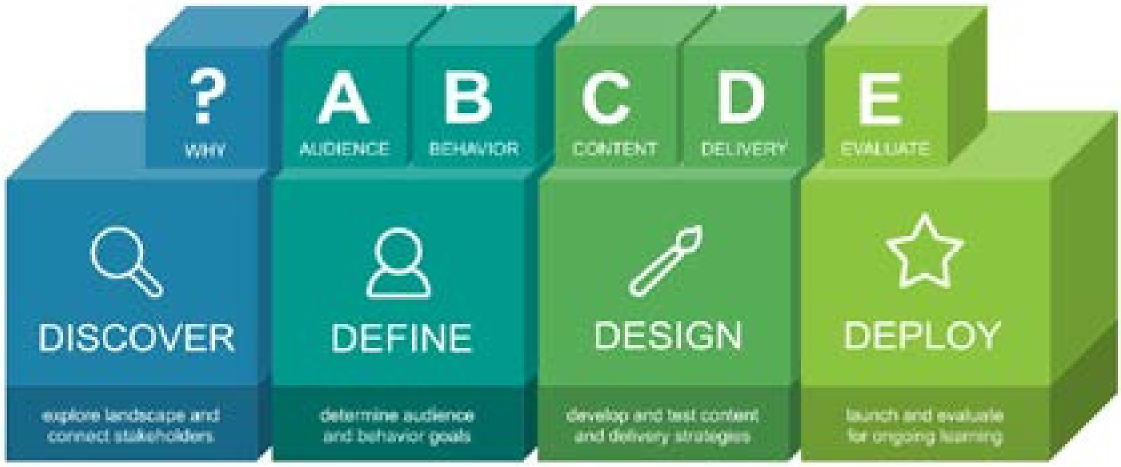

Figure 1. The Building Blocks of Behaviour Change framework (Source: See Change Institute)

The greatest insights stem from undertaking co-funded field research pilots and experiments, with government, industry and community providers in three countries. From this work it became clear that we have only just started to scratch the surface on our understanding of HTR energy users, and how they can be more effectively engaged. We have uncovered many complex problems rather than simple solutions - but we have also started to build invaluable relationships with relevant stakeholders, as well as insights into areas and audience segments that have been largely under-researched and underserved in past approaches, which usually focused on low-income and energy poverty as the primary identifier of the HTR narrative. To overcome the terminology barrier, and to focus on the cause, rather than the symptoms of poverty, addressing energy injustice is the overarching research goal in Phase 2.

2. SUMMARY HIGHLIGHTS OF PHASE 1 RESEARCH

2.1. Literature Review / HTR Characterisation

Following an intensive (almost 1000 publications) review of the literature (Rotmann et al, 2020) in Year 1, we estimate that the majority (at least ⅔, but likely as many as ¾) of households and businesses could be regarded as "hard-to-reach" (HTR), particularly when following our Task's broad definition[7] of this audience group. This assertion is based on HTR audience size estimates in our participating countries from primary (Ashby et al, 2020a&b) and secondary research. This estimate includes the large percentage of vulnerable groups (e.g. minorities, chronically-ill, single parents, elderly, geographically remote), renters and landlords (commercial and residential), small and micro businesses, commercial energy managers and building operators outside of the office sector, and high-income segments. These audiences are critically

[7] *"In this Task, a hard-to-reach energy user is any energy user from the residential and non-residential sectors, who uses any type of energy or fuel, and who is typically either hard-to-reach physically, underserved, or hard to engage or motivate in behaviour change, energy efficiency and demand response interventions that are intended to serve our mutual needs."*

underserved by tailored policies and programmes, and relatively under-researched in the dominant technology-focussed energy efficiency literature.

There is also strong evidence that this number has increased due to the COVID-19 pandemic (Rotmann et al, 2021), which caused extensive vulnerability in households, particularly for renters and (often home-based) small and micro-businesses. These are the people that policy-makers, utility programme managers, and researchers often struggle to engage with, for a variety of reasons. One of the biggest issues is the terminology itself, which seems to put the onus of engagement on those energy users, rather than the "Behaviour Changers" tasked with engaging them. Another is a lack of understanding of the lived experience, barriers and needs of these audiences, and their (lack of) energy and technology literacy.

A very large proportion of energy users might be HTR for one (usually, valid) reason or another. For instance, this characterisation certainly goes beyond low-income households, which is what first comes to mind for most when hearing the term "HTR." In fact, as we learned from the Task, low-income households may be easier-to-reach in certain cases (see Fig 2 below). The more vulnerable these groups become, the more "hidden" they are to policy makers, utility programme managers, and researchers, increasing their chances of falling into deeper hardship (leading to marginalisation, stigmatisation, and ultimately, criminalisation). This is why our second research phase focuses on hidden audiences.

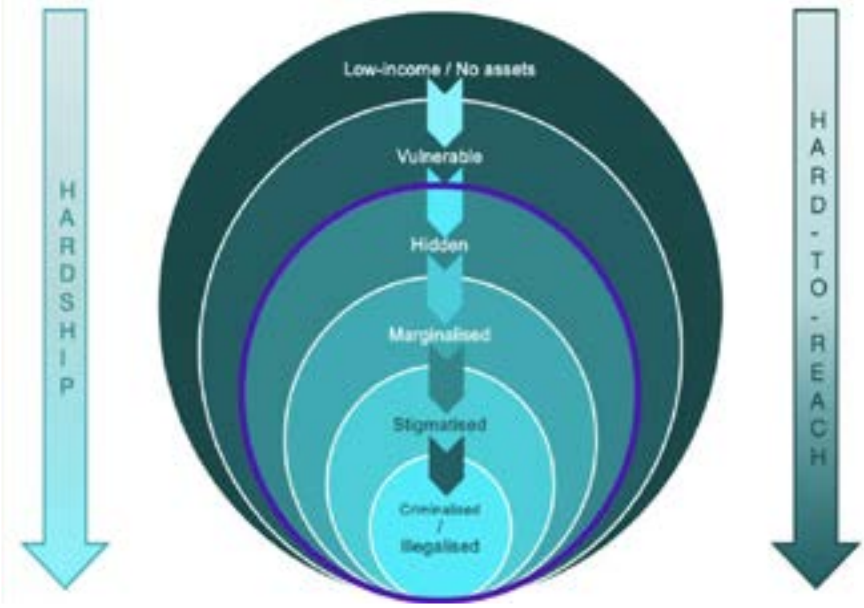

Figure 2: Diagram showing increasing levels of hardship and hard-to-reachness in residential energy users. Purple circle outlines the "hidden" segments.

2.2. Case Study Analyses / Cross-Country Case Study Comparison

The focus for Year 2 was on the engagement strategies and interventions used in a variety of countries, accomplished through case study analyses. The methodology for *ex post* analysis was based on the "Building Blocks of Behaviour Change" framework (Karlin et al, 2021). We analysed each of the 19 case studies from 8 countries (Aotearoa, Canada, Italy, the Netherlands, Portugal, Sweden, the UK, and the U.S.) following the "ABCDE" building blocks–i.e. descriptions of target Audiences and Behaviours, Content and Delivery of engagement strategies and messaging, and Evaluation. We assessed how well each case study followed the four design thinking phases of the framework. Some components, such as clearly defining target audience and behaviour characteristics in the *Define Phase*, and pre-testing messaging content strategies in the *Design Phase*, were less well-developed than others (Karlin et al, 2022). Methods that engaged stakeholders were utilised the most widely.

Karlin et al (2022) showed the importance of placing focus on this initial goal-setting and co-creation process–in some case studies, this step was highlighted as being crucial to their development and/or success. In addition, the case studies also revealed **trust** as a critical success factor, or **distrust** as a significant barrier. Building close and trusted relationships with multiple stakeholders–particularly those community and frontline providers and Middle Actors directly serving the target audience–has become a common and important insight from the reviewed HTR case studies to-date. We consider this to be significant because *building trusted relationships* is critically missing in many energy efficiency and DSM interventions.

We have synthesised all these case studies into a peer-reviewed Cross-Country Case Study Assessment (Mundaca et al, 2023), which supports those findings. From a methodological point of view, this study explored and tested the usefulness of applying the Building Blocks framework in assessing the extent to which interventions employ design and implementation practices that are known to drive behaviour change. Our findings revealed that interventions performed well with respect to the Audience, Behaviour, and Delivery building blocks, but showed room for improvement in the Content and Evaluate blocks.

Overall learnings from the case studies and cross-country case study analysis include:

- The importance of fostering trust from the outset of an intervention
- The value of collecting psychographic data to inform intervention design
- The key role of pre-testing messaging content, even when proposed messages have worked well with other audiences
- The need to consistently incorporate (and follow through on) measurement and evaluation; 84% of included case studies defined a specific behaviour intended to change, but only 10% evaluated whether actual behaviour change had occurred.

2.3. Applying the Building Blocks of Behaviour Change Framework

The author co-developed the Building Blocks of Behaviour Change Framework with our Project Partner, See Change Institute (Karlin et al, 2021; Figure 1). We tested the usefulness of following the standard research framework, which is based on Design Thinking and combined with robust social science methodology (described in detail in Mundaca et al, 2023), in the following ways:

- Using the framework phases to develop the 4-year HTR Task research collaboration
- Using the framework as template (Rotmann et al, 2021) for *ex post* analysis of case study methodologies (Karlin et al, 2022), and cross-country comparisons (Mundaca et al, 2023)
- Using the framework to guide field research pilot development, deployment and evaluation (see Section 2.4).

Discover. During the first phase of programme development, key stakeholders are identified and engaged, and (shared) programme goals are refined via co-creation. This work underpins the collective "Why" a programme is undertaken. An initial landscape analysis can help put the proposed programme or policy in the wider context of similar endeavours. Stakeholder engagement in context with the landscape analysis helps to define and refine the overarching goal of the intervention, which is a critical stage-gate for moving into the Define Phase.

HTR Task deliverables that informed this phase:

- 2019 Expert survey (n=120)
- 2019 Expert interviews (n=50)
- HTR Characterisation report and ACEEE paper (Ashby et al 2020a & b)
- 2020 Literature Review (Rotmann et al, 2020).

Define. The goal of this phase is to define the target Audience and Behaviours for an intervention. The objective is to assess the opinions and thoughts of potential target audiences in an inductive fashion. Gaining insights directly from one's target audience can guide programme planners in selecting strategies or messages that tap into people's motivations and help overcome barriers to action. Moving beyond (often biased) assumptions about how people behave requires collecting relevant insights about the target audience. This phase generates hypotheses and informs methods to test them in the subsequent Design Phase.

HTR Task deliverables that informed this phase:

- 2019 Expert interviews (n=50)
- 2020 Literature Review (Rotmann et al, 2020)
- Audience research during field pilot development (see Section 2.4).

Design. In this phase, the intervention is (co)designed to meet the goals defined in the Discover Phase, and strategies are selected based on insights derived in the Define Phase. A key aspect of the Design Phase also includes the iterative testing and refining of intervention content and delivery strategies. Regardless of the type of intervention, this testing process can help identify pitfalls and shortcomings in an initial research plan.

HTR Task deliverables that informed this phase:

- 2021 Case Study Template (Rotmann et al, 2021)
- 2021 Case Study Analyses (19 case studies from 8 countries, including interviews)
- 2022 Process matters methodology review (Karlin et al, 2022)
- 2023 Cross-Country Case Study Assessment (Mundaca et al, 2023).

Deploy. The final phase involves deployment and evaluation of an intervention to facilitate ongoing learning and optimisation. Successfully defining, designing and deploying an intervention involves establishing measurable key performance indicators (KPIs) at the outset that align with research objectives and have consensus among stakeholders about how they will be measured. This process is both multi-disciplinary and iterative. While the benefits of individual elements are recognised by researchers and practitioners alike, they are often used in isolation rather than as part of a holistic, programmatic, systematic approach. Thus, its unique strength lies in how various methods can work together and inform one another. Evaluation results from the Deploy Phase can inform ideas for intervention optimisation.

HTR Task deliverables that informed this phase:

- Several field research pilots in Aotearoa, U.S. and Canada (see below).

The majority of case study authors in Karlin et al (2022) regarded the Building Blocks framework as a highly-useful framework for exploring ex-post behaviour change. Assessing the Building Blocks framework critically in Mundaca et al (2023) revealed promising results in terms of credibility, confirmability, transferability, and reliability; however, limitations and uncertainties were also present.

2.4. Field Research Pilots

We have also undertaken a significant amount of field research co-funded by government agencies, industry (retailers, generators and distributors), and software companies servicing utilities in Aotearoa, Canada and the U.S. This field research and piloting follows the Building Blocks research process designing, implementing and evaluating targeted engagement strategies and interventions aimed at clearly-identified and characterised segments of target audiences. We engaged the following different audiences in qualitative field research (interviews, focus groups, surveys, multi-stakeholder workshops, and/or in-home interventions):

- **Commercial energy managers and building operators (Canada, 2019):** We designed and piloted a Behaviour, Energy & Sustainability Training ("BEST") course (Rotmann & Karlin, 2020). We tested this in Ontario and aspects of it have been incorporated into *ISO50001 Ready Navigator* training for U.S. government employees since.
- **Commercial energy managers in the MUSH (Municipalities, Universities, Schools & Hospital) Sector (Canada, U.S., 2021):** We undertook focus groups with 40 energy managers, asking specifically about their experience with utilities (Uplight, 2021).
- **Small to medium businesses (SMBs, U.S., 2022):** This research, focusing on their experience with utility rate offerings, did 20 in-depth interviews with SMB owners around the U.S. (Uplight, 2022); we then co-designed and user-tested different SMB rates offers and explainers with them.
- **High & Low-Engagement / High & Low-Income Households (U.S., 2021)**: A nationwide survey was complemented with eight focus groups led by the author.
- **Vulnerable Energy Users (NZ, 2022-23)**: They were identified as low-income with at least three compounding or intersecting vulnerabilities e.g. related to age, minority status, geographic remoteness, or tenancy. We improved on a Home Energy Assessment Toolkit (HEAT kit) intervention, which has been successfully field-tested with 44 households in the Wellington Region by partnering with community and frontline organisations (see Rotmann & Cheetham, this issue).

- **"Hidden" Energy Users (NZ, 2022-23)**: We improved industry customer understanding via workshops, community provider surveys (n=39), frontline customer care staff (n=15) interviews, and empathy interviews with vulnerable customers (n=15).

3. SUMMARY OF CONCLUSIONS FROM PHASE 1

3.1. Challenges & Insights

- Energy users who can be regarded as HTR by those trying to engage them are **much more common** than we initially hypothesised - at least two thirds and possibly three quarters of global energy users fall into this category, according to our estimates.
- These energy users are HTR for **myriad different reason**s, and have very different barriers, needs and motivations, rendering broad-scale or national campaigns difficult.
- Our current methods and approaches to engaging those HTR energy users are still **inadequate** in both their economic feasibility and social / cultural appropriateness.
- We need to do better to **sub-segment audiences**, clearly identify target behaviours, design tailored engagement strategies, and evaluate and re-iterate, as needed.
- In the residential sector, the most common assumption of HTR energy users is that they are **low-income households**. However, focusing solely on low-income energy users leaves out many underserved populations; we should also target:
    - **High-income** / high-consuming energy users
    - The "**squeezed middle**" (non-asset owning mid- to high-income earners), and
    - **Marginalised / vulnerable** energy users
- Among these different groups, who are all HTR for different reasons, we can find further sub-segments (e.g. between marginalised / forgotten; stigmatised / ostracised; and criminalised / illegalised vulnerable groups), which commonly **intersect**.
- **Different engagement strategies** are necessary for each segment.
- Even more complex are non-asset-owning households in the "**squeezed middle**," who are now in danger of becoming the "working poor." They need to be researched and targeted in programmes that currently exclude them (e.g. due to income eligibility criteria).
- In the non-residential sector, the main energy users who are well-researched and understood are those working in **office buildings** and settings. Utilities largely focus their energy efficiency programmes on residential and large commercial & industrial (C&I) customer segments, which means that the 95% of SMBs are largely underserved.
- Another underserved and under-researched non-residential sector is the largely-public, and extremely-complex and diverse Municipalities, Universities, Schools & Hospitals **(MUSH) segment**. Our pilot Behaviour, Energy & Sustainability Training (BEST) course showed how high the appetite was for behaviour change training among energy managers and building operators from this sector (Rotmann & Karlin, 2020).
- These HTR sectors combined are consuming (by far) the largest amounts of energy globally, and are also predominantly (except for the high-income and MUSH segments) renters, adding an additional layer of complexity. More work needs to focus on how to better engage **both tenants and landlords**, in the residential and commercial sectors.

- One important aspect for all these sectors is providing targeted knowledge and **tailored energy education and behaviour change training**.
- Many of these barriers stem from **historic and systemic injustices** arising from the Eurocentric worldview on which our energy, academic and governance systems are built (see Rotmann et al, 2020; Sovacool et al, 2023). It is impossible to achieve energy equity, justice or a "fair and just energy transition" (COP27), without first addressing these interwoven structural inequities. That means delving into the complex and sensitive topic of "decolonisation," or better, "re-indigenisation," in a way that is practical and applicable in the field and actually addresses and mitigates energy injustice.

3.2. Recommendations

Target Audiences:

- Use a co-design process involving practices like journey mapping and ideation workshops with audience representatives can improve understanding of audience characteristics, needs, pain points, and workarounds to barriers to engagement.
- Empathy interviews with the target audience can inform audience characteristics, psychographics, and barriers to engagement.
- A 'lighter touch' approach can be valuable, especially when engaging those who may have had little or no engagement in the past, and who have trust issues.

Barriers:

- More research into better understanding the target audience's barriers to engagement and how to resolve / destigmatise them (e.g. trust, shame or fear) is needed.
- Some households have intersecting and compounding vulnerabilities, making them harder to reach. They need to be approached with particular care / empathy.

Design:

- A 'values-based' intervention design approach can be beneficial. The focus is not on changing individuals' values, but instead shifting away from individual actions and capabilities towards understanding the motivations behind the behaviours.
- Strength-based approaches have proven highly beneficial when engaging Indigenous communities by identifying, recognising, and reinforcing existing skills, interests, and capacity within those communities to engage in better energy management practices.
- Case studies demonstrated the significance of having a single point of contact. A liaison can act as a trusted direct contact for HTR groups, and having a single agency, e.g., oversee the delivery of an intervention can help coordinate efforts from several organisations involved in delivery around shared goals and objectives.

Messaging/Resources:

- Use a suite of publicly-available resources that include insights from programme evaluations and draw from extensive experience via storytelling and case studies.
- Use practical sector expertise on which engagement strategies have the greatest success and how to best optimise content, rather than relying on theoretical insights not tested with HTR audience segments (e.g., most behavioural economics).
- It is valuable to have resources verified by a focus group of individuals of the target audience and to use culturally-appropriate language and imagery. This is especially

critical when engaging minority target audiences, or those with learning disabilities.
- Target communications and messaging through communication channels that the target audience already pursues and utilises is efficient and effective. This necessitates first understanding which channels are already widely used.

Delivery/Trusted Middle Actors:
- 'Middle Actors' and gatekeepers who are already present and trusted in the target community can provide more tailored in-home delivery of advice and interventions, and can promote or widen the referral pathways into greater support for the project.
- Training them is crucial to conduct in-home assessments and tailor support with understanding of underlying engagement barriers in the target community.
- Establishing clear, standardised processes for referral and assessment is beneficial.

Evaluation:
- Informal evaluation activity can be useful as long as it is adequately measured.
- Even with a lack of funding, interventions should have evaluation activity built in from the beginning and throughout the duration. This can help shape the critical stages of programme design and delivery through iterative, data-driven processes.
- There is a need for an in-depth, longitudinal evaluation, as well as more diverse evaluation methods (i.e. not just surveys or interviews but also using gamification and craft-based approaches, especially for mentally disabled and non-English speakers).

4. NEXT STEPS

As more and more energy users - including in the rich Global North - fall into energy hardship, many of them and their plights remain hidden to policy makers, industry programme managers, and researchers. Some aim to remain hidden on purpose, due to often lifelong negative experiences with authorities' attention (e.g. illegalised or criminalised groups), others are hidden / underserved as they are deemed as too complex and difficult to design practical interventions for (e.g. small and micro-businesses), and some are newly-vulnerable groups who struggle with the increasing stigma of status loss (e.g. moving from the "squeezed middle class" to the "working poor"). These energy user segments who are currently hidden and underserved, and whose lived experiences are subject to increasing vulnerabilities, stigma and inequities are the target audience for Phase 2 of the HTR Task. We will focus on the impact of systemic energy injustice, and assess how decarbonisation and transitioning our energy system has the potential to either compound or alleviate these impacts. We will be guided by Indigenous and traditional ecological knowledge, as will be reflected by the disciplinary and/or ethnic backgrounds of our partners.

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5. REFERENCES

Ashby, K., Rotmann, S., Smith, J., Mundaca, L., Ambrose, A., Borelli, S. and M. Talwar (2020a). Who are Hard-to-Reach energy users? Segments, barriers and approaches to engage them. *ACEEE Summer*

Study for Energy Efficiency in Buildings: Monterey.
Ashby, K., Smith, J., Rotmann, S., Mundaca, L. and A. Ambrose (2020b). *HTR Characterisation.* Users TCP HTR Task: Wellington. https://doi.org/10.47568/3XR102
Bartiaux, F., Maretti, M., Cartone, A., Biermann, P., Krasteva, V. (2019). Sustainable energy transitions and social inequalities in energy access: A relational comparison of capabilities in three European countries. *Global Transitions* 1, 226-240.
Chancel, L. (2022). Global carbon inequality over 1990–2019. *Nat Sustain* 5, 931–938.
Guan, Y., Yan, J., Shan, Y. et al. (2023). Burden of the global energy price crisis on households. Nat *Energy* 8, 304–316.
Hussain, S.A., Razi, F., Hewage, K., Sadiq, R. (2023). The perspective of energy poverty and 1st energy crisis of green transition. *Energy* 275, 127487.
Karlin B., Forster H., Sheats J., Chapman D., and S. Rotmann (2021). *The Building Blocks of Behavior Change: A Scientific Approach to Optimizing Impact*. See Change Institute: Los Angeles.
Karlin, B., Rotmann, S., Ashby, K. et al (2022). Process matters: Assessing the use of behavioural science methods in applied behavioural programmes. *Eceee Summer Study Proceedings 2022: Hyéres*.
Liu, Y., Dong, K., Jiang, Q. (2023). Assessing energy vulnerability and its impact on carbon emissions: A global case. *Energy Economics* 119, 106557.
Mundaca, L., Rotmann, S., et al (2023). Hard-to-reach energy users: An ex-post cross-country assessment of behavioural-oriented interventions. *Energy Research & Social Science* 104, 103205.
Oswald, Y., Owen, A. & Steinberger, J.K. (2020). Large inequality in international and intranational energy footprints between income groups and across consumption categories. *Nat Energy* 5, 231–239.
Parry, I.W.H., Black, S., Vernon, N. (2021). *Still Not Getting Energy Prices Right: A Global and Country Update of Fossil Fuel Subsidies. International Monetary Fund (IMF)*. 2021/236. 40pp.
Powells, G., Fell, M.J. (2019). Flexibility capital and flexibility justice in smart energy systems. *Energy Research & Social Science 54*, 56-59.
Rotmann, S., Mundaca, L., et al (2020). *Hard-to-Reach Energy Users: A Literature Review.* SEA - Sustainable Energy Advice Ltd: Wellington. ISBN: 978-0-473-64983-8
Rotmann, S. and B. Karlin (2020). Training commercial energy users in behavior change: A case study. *ACEEE Summer Study on Energy Efficiency in Buildings 2020: Monterey*.
Rotmann, S., Cheetham, E. (this issue). Successfully Reaching The Hard-To-Reach By Improving Home Energy Assessment Toolkits With The Help Of Frontline & Community Providers. *BEHAVE*.
Sherriff, G., Butler, D., Brown, P. (2022a). 'The reduction of fuel poverty may be lost in the rush to decarbonise': Six research risks at the intersection of fuel poverty, climate change and decarbonisation. *People, Place and Policy* 16 (1), 116-135.
Sherriff, G., Ambrose, A,. Butler, D. and Moore, T. (2022b). Editorial – Special Issue: The uneven and increasingly complex dynamics of decarbonisation and energy poverty in the context of unprecedented energy and climate crises. *People, Place and Policy* 16 (1), 1-5.
Sovacool, B.K., Bell, S.E., Daggett, C.,Labuski, C., Lennon, M., Naylor, L., Klinger, J., Leonard, K., and J. Firestone (2023). Pluralizing energy justice: Incorporating feminist, anti-racist, Indigenous, and postcolonial perspectives. *Energy Research & Social Science* 97, 102996.
Sovacool, B.K., Upham, P., Martiskainen, M. et al. (2023a). Policy prescriptions to address energy and transport poverty in the United Kingdom. *Nat Energy* 8, 273–283.
Tarasova, E., Rohracher, H. (2023). Marginalising household users in smart grids. *Technology in Society* 72, 102185.
Uplight (2021). *Getting to Yes with Municipalities, Universities, Schools and Hospitals*. *Research into the MUSH Sector*. Uplight: Boulder.
Uplight (2022). *Six Reasons Why Most SMBs Don't Switch Rates*. Uplight: Boulder.

First steps towards a European algorithm to promote sustainable behavioural changes in citizens.

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Abstract

Achieving a reduction in energy demand and promoting the use of cleaner energy to meet citizens' needs are two crucial actions to incentivize behavioural changes in the population. However, the lack of a tangible indicator to comprehend the impact of our daily energy decisions poses a barrier to creating individual awareness and driving behavioural changes. This study seeks to develop an algorithm for assessing the daily habits of European citizens with the goal of promoting sustainable energy behaviours in households (electricity and heat) and transportation.

The algorithm aims to provide a visual label similar to those used for energy efficiency indicating the extent to which our behaviour aligns with climate objectives. It has been created using open public data published by European Institutions for the 27 member states of Europe. The baseline level of the algorithm has been determined by the average energy consumption per capita in 2015 and is graded to achieve the goals of the European Green Deal by 2030, as outlined in the Climate Pact assessment documents for *the respective sectors. The system has been reviewed by 12 international experts.*

These initial steps pave the way for a standardized information system that can assist citizens in making more informed decisions about their energy consumption. However, improvements are needed to make the system more responsible, which involves adjusting the levels based on socio-economic factors that have been identified as critical when assessing individual behaviour. To accomplish this, we plan to work together with citizens using citizen science methodologies.

1. INTRODUCTION

The global energy system would take 150 years to fully decarbonise with the current rate of decrease in the carbon intensity of energy systems. The cause behind is the fact that the increase in renewable energy generation is still less than the increase in demand, so demand reduction could play a key role in achieving the ambitious climate goals (Barrett, 2022). To implement demand reductions in sectors such as transport and residential, citizens need to make permanent and meaningful changes to their daily lives. This requires a change in behaviour that could be motivated by different methods that can have a relevant impact since it is estimated that a behavioural change in citizens could led up to 19% of carbon emission reductions (Uitdenbogerd, et al., 2007). In the past years, different strategies to trigger and encourage behavioural changes towards sustainability have been designed and studied (White, et al., 2019).

One of the strategies explored by researchers is the enhancement or activation of individual's environmental identity. Studies demonstrate that green identity labelling such as "environmentalist" or "those who care for the environment" is an effective way to strengthen the individuals' self-perception in relation to the environment, which in turn promotes subsequent pro-environmental behaviour. Nevertheless, these identity labels are quite general and lack to the ability to detailly inform citizens on what an "environmentalist" or "green shopper" really entails (Lacasse, 2016; Eby, et al., 2019; Schwartz, et al., 2020; Neves & Oliveira, 2021).

Another strategy to encourage behavioural change is through eco-labelling, where the sustainability-related attributes are shown (White, et al., 2019). Examples include the energy efficiency labels of appliances and carbon emission labels of products, which are familiar to European consumers. Studies show that these eco-labels positively affect individual's consumption choice in many aspects: food or drink products, electrical appliances, or even modes of travel (Neves & Oliveira, 2021; Potter et al., 2021; Kuhn, et al., 2022; Penz, et al., 2017). Most eco-labels today target carbon emissions from products, but to calculate an individual's total carbon footprint from their energy behaviour people typically use a carbon footprint calculator (CFC).

Currently, there is no universally accepted personal or household carbon footprint calculation method. In the absence of such a standard, several non-profits, academics, and companies have sought to develop robust methodologies for measuring and managing personal carbon footprints. Since there are no standards regarding how CFCs should be programmed, very different values can be estimated from similar user behaviours. In many cases, CFC lack adequate contextual information, making it challenging for users to understand their results and how to reduce their carbon footprint effectively. Additionally, some calculators only measure carbon footprints without offering detailed information on alternative choices (Burgui-Burgui & Chuvieco, 2020). Padgett (2008) and Murray (2009) pointed to the wide range of results from different CFCs for the same inputs, and how requested input assumptions are in different formats. Consequently, many calculators tend to consistently underestimate carbon footprints (Birnik, 2013).

A review of 24 online calculators was conducted for this study to assess the common practices used in the calculation of carbon footprint for individuals. The most used categories in carbon footprint apps and programs included home energy, transportation, and food. Nearly one-third of calculators reviewed were country-specific, and not all calculators provided an in-depth methodology report, with only one calculator being open access. Having reviewed these calculators, one of the main questions that come to mind is 'how effective are they in reducing emissions?' Kok & Barendregt (2021) found that calculator users can be divided into two groups with different motivations and needs. For both user groups, calculators increase awareness, and, in some cases, this results in behaviour change. While some studies showed positive results, most interventions included additional elements like focus groups, personalized reduction scenarios or persuasive techniques. One of the biggest challenges of CFCs is getting users to update their data and make sustainable changes in their daily habits. It has been suggested that goal setting and continuous feedback can help engage users in the long term. However, even though research has shown that frequent feedback can help people change their behaviour, e.g. reduce energy use, its extent can vary greatly (Andersson, 2020; Moser & Kleinhückelkotten, 2018; Hurst & Sintov, 2022). Furthermore, Easy-to-take actions can be problematic due to the risk of focusing on incremental changes and efficiency rather than questioning and reconfiguring the unsustainable practice (Salo, et al., 2019).

Policies must address energy behavior change, as relying on social norms alone may not suffice. Understanding the psychological and social factors impacting renewable energy adoption is crucial for effective policies (Zobeidi et al., 2022). Mundaca et al. (2022) emphasize the need for complementary policies with an environmental focus, while Koasidis et al. (2022) highlights the use of monetary rewards to encourage active energy consumption reduction.

The EU-funded AURORA project is creating solar energy communities in five European locations (Denmark, England, Portugal, Slovenia and Spain) through crowdfunding. Its main aim is to engage citizens in the energy transition and evaluate if this leads to behavioural changes. AURORA has developed the first version of an algorithm that evaluates both, the use of cleaner energy and responsible attitudes (efficiency) even if the energy is not as clean as desired for motivating people to become "Near-Zero Emission Citizens". The role of AURORA project is also to promote ad-hoc education through different activities in these energy communities. The algorithm itself does not generate awareness, so it is important that users understand their energy behaviours, these hand-on activities would help to reach the goal of promoting behavioural change among participants.

2. METHODOLOGY

The aim of this study is to create an algorithm that harnesses the impacts of information and green identity, so that it gives more information about one's energy behaviour, much like a CFC does, while ensuring it sparks the individual's environmental identity. With this algorithm, citizens are encouraged to become "Near-Zero Emission Citizens" by reducing the energy consumption and emissions of their daily habits: electricity and thermal consumption, and daily transport. Expected reductions and emissions are according to the average of scenarios indicated in the Assessment Document (European Comission, 2020) of the Green Deal (Commission, 2019). For getting 2015 values we have used public data published by JRC (Koffi, et al., 2017) and for any other data requested in the algorithm public sources are mentioned along the paper.

2.1. Proposed algorithm

According to the European Climate Pact assessment documents, domestic energy consumption should be reduced by 25% and passenger transport energy consumption by 16% by 2030, relative to the levels in 2015 (European Comission, 2020). Here, we propose an algorithm based on the percentages of reduction from 2015 values to achieve the 2030 goals. The proposed algorithm will be country-specific to fit the different energy consumption patterns in European countries and similar to the energy efficiency label, coloured, graded, visual, familiar and understandable, to incentivize users to reduce their consumption and encourage them to act greener in their energy choices.
Table 1 shows the different levels of the proposed algorithm, where the average value (2015) establishes the limit between levels D and E. Users who reduce 25% or more of their residential energy consumption or 16% or more in the case of transports will become "Near-Zero Emission Citizens". On the contrary, level G means an increase of 25% and 16% of the energy consumption in the household and transport sectors from the average value, respectively. It must be noted that these thresholds are not based on any scientific evidence but on our best understanding of psychological factors that help individuals transition from one level to another when introducing small changes. Thresholds must be adjusted using real citizens' data through citizen science methodologies.

Table 1 Limits for the algorithm

Level	Household	Mobility
A+	[< -50% average value]	[< -50% average value]
A	[- 50% of the average value, - 25% average value]	[- 50% of the average value, - 16% average value]
B	[- 25% of the average value, - 10% average value]	[- 16% of the average value, - 9% average value]
C	[- 10% of the average value, - 5% average value]	[- 9% of the average value, - 5% average value]
D	[- 5% of the average value, average value]	[- 5% of the average value, average value]
E	[average value, +5% average value]	[average value, +5% average value]
F	[+5% of the average value, 25% average value]	[+5% of the average value, 16% average value]
G	[> -25% average value]	[> 16% average value]

The algorithm serves to compute and furnish users with a comprehensive label encompassing all their consumption patterns. Subsequently, it segregates detailed information regarding distinct labels pertaining to residential energy (both thermal and electrical) and transportation. These separations will enable users to gain insights into their consumption and emissions across various sectors under examination. In addition, we introduce two distinct labels: one for energy consumption and another for emissions. This dual-label approach is imperative because it necessitates not only a shift towards greener energy sources or transportation but also a reduction in the overall energy consumption associated with daily routines. While an individual might be utilizing clean energy, excessive consumption renders such efforts ineffective in achieving the 2030 objectives. In order to broaden the scope of the project 27 labels among all the EU countries have been created to ensure the accuracy of the algorithm considering the diverse climate conditions and power grids across these regions. Figure 1 illustrates the comprehensive label calculated as the mix for the European Union, and the subsequent section provides a detailed explanation of the calculations involved in generating these labels.

Figure 1 Label for the total energy consumption and emissions for the EU

2.2. Data and calculations

All the databases selected are open-access due to the project's aim to contribute to an open citizen science, where science is available to everyone and the content is updated and accessible.
The baseline levels correspond to 2015 data, as mentioned before. Data for energy consumption comes from the JRC database (Mantzos et al., 2017) and for the carbon footprint calculation, the emission factor (EF) is needed, as shown in Eq. 1. The IPCC defines the EF (IPCC, 2006) as 'a coefficient that quantifies the emissions or removals of a gas per unit activity'.

$$\text{Carbon Footprint (kg } CO_2\text{)} = \text{activity data} \cdot EF_{activity} \qquad (1)$$

The national power grid EF is considered for the calculation of the electricity emissions. For domestic thermal energy consumption, the EF depends on the fuel used for heat production. For the baseline calculation, the EF of the heating fuel most used in each country has been used for the calculation. Finally, for the transport sector, some calculations are needed: the total energy consumption and emissions are divided by the number of inhabitants of the country to obtain the results per capita.

3. RESULTS

The calculations explained above correspond to the baseline values. This section expands on how the first version of the algorithm for the Behavioural Labels has been created.

3.1. Electricity calculation

The carbon footprint of the electricity consumption follows Eq. 2, where the data requested is the household electricity consumption (kWh), the number of people living in the house, and the period tracked of that consumption (days, months, etc.). The EF corresponds to the national power grid EF (kg CO_2/kWh).

$$\text{Carbon Footprint}_{\text{electricity}} = \text{electricity consumption per capita} \cdot \text{EF}_{\text{national power grid}} \qquad (2)$$

Therefore, people who own their renewable installations will be able to deduct the emissions by providing the installed capacity to the algorithm, explained in section 3.4.

3.2. Heating calculation

The carbon footprint associated with thermal consumption is calculated following Eq. 3. Data requested for this calculation is the household thermal consumption (kWh), the number of people living in the dwelling, the type of heating fuel, and the period tracked (days, months, etc.). The different heating fuel EFs for households are shown in Table 2, for both fossil (Koffi B. et al., 2017) and renewable energy sources (solar collectors, geothermal, biomass, etc.) and technologies (district heating, underfloor heating, heat pumps, electric heaters, etc.) (Ntziachristos & Samaras, 2021). The values considered are constant for all countries.

$$\text{Carbon Footprint}_{\text{heating}} = \text{thermal consumption per capita} \cdot \text{EF}_{\text{heating fuel}} \qquad (3)$$

Table 2 Heating fossil fuel and renewable energy sources emission factors

Heating source	Emission factor (kg CO_2/kWh)
Heating oil	0.267
Natural gas	0.202
LPG (liquefied petrol gas)	0.227
Biomass	0.118
Locally-produced biomass	0.000
Geothermal	0.050
Solar thermal	0.040
District heating	0.268

3.3. Transport calculation

The calculation of passenger transport is more difficult than the residential emissions. The carbon footprint for the transport sector is determined by the type of vehicle used (public or private), the energy source (fuel, electricity), and its energy consumption per distance travelled. The calculation follows Eq. 4 where the data requested is the type of vehicle used and the distance (km).

$$\text{Carbon Footprint}_{\text{transport}} = \text{EF}_{\text{vehicle}} \cdot \text{travelled distance} \quad (4)$$

Eq. 4, data from Mantzos, et al. (2017) is adapted to calculate the EFs per capita of passenger transport, which can be found for the EU in Table 3 for private vehicles and Table 4 for public transport. The effect of vehicle occupancy is calculated on the energy consumption and emissions of this sector because when increasing the load of the vehicle, its emissions and consumption increase too, but it results in lower emissions per capita because it is divided by the number of passengers. The calculation for fuel private vehicles is obtained following the approach from the study done by Fontaras et al. (2017) and for the electric private vehicles, the approach follows the study by Weiss et al. (2020).

Table 3 Energy consumption and emission factor per passenger and kilometre for private vehicles (EU data-different sources)

Type of vehicle	Energy source	Vehicle consumption per passenger according to vehicle occupancy (kWh/p-km)					Emission factor per passenger according to vehicle occupancy (kg CO_2/p-km)				
		1	2	3	4	5	1	2	3	4	5
Car	Fuel	0.693	0.363	0.252	0.197	0.164	0.1722	0.0653	0.0475	0.0387	0.0335
	Electricity	0.336	0.171	0.116	0.089	0.072	0.0760	0.0133	0.0093	0.0072	0.0060
	Hybrid-electric	0.452	0.235	0.162	0.126	0.104	0.1073	0.0252	0.0174	0.0135	0.0112
Motorcycles and mopeds	Fuel	0.426	0.229				0.1058	0.0260			
	Electricity	0.136	0,068				0.0307	0.0022			
Bike	Electricity	0.012					0.0028				
	Manual	0					0				
Scooter	Electricity	0.027					0.0060				
	Manual	0					0				

Table 4 Energy consumption and emission factor per passenger and kilometre for public transport (EU data-different sources)

Type of vehicle	Energy source	Vehicle consumption per passenger according to vehicle occupancy (kWh/p-km)			Emission factor per passenger according to vehicle occupancy (kg CO_2/p-km)		
		Almost empty	Average	Nearly full	Almost empty	Average	Nearly full
Bus	Default	0.9901	0.3148	0.1872	0.2428	0.0772	0.0459
	Electricity				0.2238	0.0712	0.0423
	Hybrid-electric				0.2366	0.0752	0.0447
	Diesel				0.2494	0.0793	0.0472
	Alternative fuels				0.2257	0.0718	0.0427
Subway, tram and urban light rails	Electricity	0.1956	0.0622	0.0370	0.0442	0.0197	0.0117
Passenger train	Electricity	0.4474	0.1423	0.0846	0.1011	0.0322	0.0191
	Diesel	0.5491	0.1746	0.1038	0.1449	0.0461	0.0274
High-speed trains	Electricity	0.2737	0.0870	0.0575	0.0619	0.0197	0.0117
Plane	Fuel	423.53 kWh/p			109.622 kg CO_2/p		

For public transport, the level of occupancy is also considered. A normal distribution with the average of passengers per kilometre is calculated from the Mantzos, et al. (2017) data, defining three categories: almost empty (15.9% of occupancy), average, and nearly full (84.1% of occupancy). Energy consumption and emissions are obtained by dividing the energy consumption and emissions per vehicle by the number of passengers according to occupancy (Table 4). Different types of buses have been studied in order for people to find out how the bus is powered (ACEA (2022, March 15)): electric, hybrid electric, alternative fuel (powered by natural gas, LPG, and biofuels), diesel, and the default buses.

3.4. Renewable energy production deduction

The carbon footprint of the photovoltaic (PV) energy production is deduced from the carbon footprint associated with the same energy if this is produced by the national energy production mix, calculated with the EF of the total energy production from Table 5. The carbon footprint obtention for PV energy production follows Eq. 6, where the PV energy production EF (Our World in Data, 2022) is multiplied by this PV electricity produced. Data for this operation should be as up-to-date as possible, and PV energy EF for the generation is the same for all countries (Koffi, et al., 2017).

$$\text{Carbon Footprint}_{\text{energy production}} = CF_{\text{others energy prod}} - CF_{\text{PV energy prod}} \tag{5}$$

$$CF_{\text{PV energy prod}} = \text{Energy produced}_{\text{PV}} \cdot EF_{\text{PV energy prod}} \tag{6}$$

Table 5 Carbon emission intensity of electricity generation

Emission Factor (kg CO_2/kWh)	EU
Energy production	0.226
Photovoltaic electricity production	0.0305

3.5. Total carbon footprint

The final carbon footprint is calculated following Eq. 7 where all carbon footprints (CF) explained previously are taken into account.

$$\text{Carbon Footprint}_{\text{total}} = CF_{\text{electricity}} + CF_{\text{heating}} + CF_{\text{transport}} - CF_{\text{energy produced}} \tag{7}$$

4. DISCUSSION

The algorithm proposed in this research was tested by 45 members of our consortium from different countries: Denmark, Portugal, Slovenia, Spain, the United Kingdom and the European Union to prove its validation and some observations were made. Firstly, thermal data is unknown by many of the users: whether they have electric heating systems and data is included in the electricity bill or they cannot access the thermal data in central heating systems, or they ignore the power source in district heating systems (that is the reason for calculating a default value for district heating). For those cases where the thermal consumption is accounted as electric heating systems, household energy consumption should be considered because the electricity contains the thermal consumption. On the other hand, different transport choices were observed since the main results show that most users use fuel cars as their main transport choice, but other users combine public and private transport using more public vehicles than private ones.

Analyzing the results, a change was made to split level A, referred in our study as the “Near-Zero Emissions” level into level A+ and level A because most users reached level A, and we believe they should be motivated to reduce their energy consumption even if they have already reached the Green Deal goals. Moreover, the reason for not using just one European label and specifying it by country is that the energy consumption patterns depend on the climate conditions of the country and the power grid EF is country-specific due to the energy generated and purchased by the country. Combining primary and final energy in our algorithm can lead to controversy if we consider that people cannot change the primary energy sources supplying the national power grids, as this is a decision made by policymakers. However, we believe that when citizens understand that their label -their environmental impact- is also influenced by decisions made by 'third parties', they will be better equipped to make informed decisions that can influence their country's EF. For instance, they can choose to purchase their electricity/heat from the greenest providers, thereby exerting pressure on their national market to transition more rapidly toward greener energy sources.

Another important point to discuss is the simplification of the calculations. Our main goal is to keep it simple due to the reason of promoting changes in people’s energy behaviours instead of just calculating their carbon footprint without any expected impact. In this regard, we use the same data for old and new cars even if old cars consume more energy than new ones, the same happens with other vehicles choices. We want to create an algorithm that gives users a ranking, tips and suggestions on how to reduce their energy consumption in the household and transport levels and what options they should also follow to reduce their carbon footprint.

Some people are concerned about the use of labels on individuals due to the ethics behind and we are assisted by an International Ethical Board to consider any aspect about their use. Labels can be misused and generate trouble if people see them as classifying users. One aspect of the project deals with ethical use of personal data and citizen labeling. Our solution to this concern about labelling citizens is that the label will be totally personal and confidential, and users will be able to share it with their friends and other users voluntarily. Citizens are encouraged to use the labels to explore their own environmental impact from their energy use and how they can reduce it through simple behavioural changes.

Referring to aviation, the first idea was to not include it because the goal of AURORA is to impact daily habits, but after discussing with the partners of the project, including aviation was a good idea. Another aspect of aviation to note is that this calculation is an average between long-haul and short-haul flights to simplify the calculation because air travel is not part of the daily habits of people’s transportation.

Finally, food or purchases are not considered in the algorithm because the main goal is to influence the daily habits affecting energy directly: this is the energy consumption of our choices in electricity and thermal consumption for our homes and our everyday transportation. These types of current limitations can be avoided into new versions of the algorithm once people are willing to use the label and participate in our citizen science project. One of the questions posed to the 12 international experts was how many data entries we could request from people to keep them engaged in our project. All of them agreed that no more than 15 data entries should be requested and that data entry should be automated in some way to minimize the workload for participants.

5. CONCLUSIONS

Reducing energy consumption and emissions is essential to decarbonize the global energy system and reach the European climate targets. Behavioural change is expected to play a key role in this regard. The algorithm developed in this research will help users to understand their daily habits related to energy consumption and emissions. These behavioural changes will be promoted among users by raising awareness about their energy habits, giving them personalized information, serving as a basis for change. In this process of be conscious and understand the own energy habits, we can facilitate the implementation of necessary changes. But in certain situations, users would not be able to make immediate changes due to personal situations or limited policies. We can conclude that being aware is the first step to behavioural change.

As mentioned throughout this research, data for reference values of average energy consumption are from 2015, aligning with the 2030 goal of reducing consumption from 2015 levels. However, for the footprint calculation, the most recent data is crucial for assessing individual performance accurately. This requires updated national EFs for electricity, heating, transport fuels and renewable sources. These factors change over time, particularly for renewables like PV, where emissions decrease as solar panel production becomes more efficient. Unfortunately, finding public, reliable, and regularly updated sources remains a challenge.

6. REFERENCES

ACEA. (2022, March 15). *ACEA - Driving mobility for Europe*. https://www.acea.auto/fuel-cv/fuel-types-of-new-buses-electric-10-6-alternative-fuels-10-5-hybrid-10-1-diesel-68-8-share-in-2021/

Andersson, D. (2020). A novel approach to calculate individuals' carbon footprints using financial transaction data – App development and design. *J Cleaner Prod*(256), 120-396.

Barret, J., Pye, S., Betts-Davies, S., & et al. (2022). Energy demand reduction options for meeting national zero-emission targets in the United Kingdom. *Nat Energy, 7*, 726-735.

Barrett, J. P.-D. (2022). Energy demand reduction options for meeting national zero-emission targets in the United Kingdom. *Nat Energy, 7*, 726-735.

Birnik, A. (2013). An evidence-based assessment of online carbon calculators. *Int J Greenhouse Gas Control, 326*, 280-293.

Birnik, A. (2013). An evidence-based assessment of online carbon calculators. *Int J Greenhouse Gas Control*(17), 280-293.

Burgui-Burgui, M., & Chuvieco, E. (2020). Beyond carbon footprint calculators. New approaches for linking consumer behaviour and climate action. *Sustainability, 12*(16), 6529.

Burgui-Burgui, M., & Chuvieco, E. (2020). Beyond carbon footprint calculators. New approaches for linking consumer behaviour and climate action. *Sustainability , 12*(16), 6529.

Carbon intensity of electricity per kWh, 2000 to 2020. (s.f.). (Our World in Data), https://ourworldindata.org/grapher/carbon-intensity-electricity?tab=chart

Commission, E. (2019). *Communication from the Commission - The European Green Deal.* Bussels.

Converting Fuel to kWh and CO2e. (s.f.). https://travelifestaybetter.com/wp-content/uploads/2019/02/17-Fuel-Conversion-Rates-to-kWh-and-CO2e.pdf

Eby, B., Carrico, A. R., & Truelove, H. B. (2019). The influence of environmental identity labeling on the uptake of pro-environmental behaviors. *Clim Change, 155*, 563-580.

European Comission. (2020). *Comission Staff Working Document SWD/2020/176: Impact Assesment on Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people.* Brussels.

Fontaras, G., Zacharof, N., & Ciuffo, B. (2017). Fuel consumption and CO2 emissions from passenger cars in Europe – Laboratory versus real-world emissions. *Prog Energy Combust Sci, 60*, 97-131.

Hurst, K. F., & Sintov, N. D. (2022). Guilt consistently motivates pro-environmental outcomes while pride depends on context . *J Environ Psychology, 80*, 101776.

IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories. Vol.1 General Guidance and Reporting. Chapter 1. Introduction to the 2006 guidelines.*

IPCC. (2006). *IPCC Guidelines for National Greenhouse Inventories. Volumen 2: Energy. Chapter 2: Stationary Combustion.*

Koasidis, K., Marinakis, V., Nikas, A., Chira, K., Flamos, A., & Doukas, H. (2022). Monetising behavioural change as a policy measure to support energy management in the residential sector: A case study in Greece. *Energy Policy, 161*.

Koffi, B., Cerutti, A. K., Duer, M., Iancu, A., Kona, ,. A., & Janssens-Maenhout, G. (2017). *Covenant of Mayors for Climate and Energy: Default emission factors for local emission inventories - Version 2017.* http://data.europa.eu/89h/jrc-com-ef-comw-ef-2017

Koffi, B., Cerutti, A., & Kona, A. (2017). *CoM Default Emission Factors for the Member States of the European Union [Internet]. Available from:.* Joint Research Center (JRC). http://data.europa.eu/89h/jrc-com-ef-comw-ef-2017

Kok, A. L., & Barendregt, W. (2021). Understanding the adoption, use, and effects of ecological footprint calculators among Dutch citizens. *J Cleaner Prod, 326*, 129-341.

Kuhn, S., Kutzner, F., & Thøgersen, J. (2022). How to make energy efficiency labels more effective: Insights from discrete choice experiments in Ghana and the Philippines. *Energy Res Social Sci, 84*.

Lacasse, K. (2016). Don't be satisfied, identify! Strengthening positive spillover by connecting pro-environmental behaviors to an “environmentalist” label. *J Environ Psychology, 48*, 149-158.

Mantzos, L., Wiesenthal, T., Matei, N., Tchung-Ming, S., Rózsai, M., & Russ, H. (2017). *JRC-IDEES Integrated Database of the European Energy Sector.* Joint Research Centre (JRC). https://publications.jrc.ec.europa

Moser, S., & Kleinhückelkotten, S. (2018). Good Intents, but Low Impacts: Diverging Importance of Motivational and Socioeconomic Determinants Explaining Pro-Environmental Behavior, Energy Use, and Carbon Footprint. *Environ and Behavior, 6*(50), 626-656.

Mundaca, L., Román-Collado, R., & Cansino, J. M. (2022). Assessing the impacts of social norms on low-carbon mobility options. *Energy Policy, 162*.

Murray, J., & Dey, C. (2009). The carbon neutral free for all. *Int J Greenhouse Gas Control, 3*(2), 237-248.

Neves, J., & Oliveira, T. (2021). Understanding energy-efficient heating appliance behavior change: The moderating impact of the green self-identity,. *Energy, 225*.

Ntziachristos, L., & Samaras, Z. (2021). *EMEP/EEA air pollutant emission inventory guidebook 2019 (1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles).*

Padgett, P. J. (2008). A comparison of carbon calculators. *Environ Impact Assess Rev, 28*(2-3), 106-115.

Penz, E., Hofmann, E., & Hartl, B. (2017). Fostering Sustainable Travel Behavior: Role of Sustainability Labels and Goal-Directed Behavior Regarding Touristic Services. *Sustainability, 9*.

Potter, C., Bastounis, A., Hartmann-Boyce, J., Stewart, C., Frie, K., Tudor, K., . . . Jebb, S. A. (2021). The Effects of Environmental Sustainability Labels on Selection, Purchase, and Consumption of Food and Drink Products: A Systematic Review. *Environ and Behavior, 53*(8), 891-925.

Salo, M., Mattinen-Yuryev, M., & Nissinen, A. (2019). Opportunities and limitations of carbon footprint calculators to steer. *J Cleaner Prod* (207), 658-666.

Schwartz, D., Loewenstein, G., & Agüero-Gaete, L. (2020). Encouraging pro-environmental behaviour through green identity labelling. *Nat Sust, 3*, 746-752.

Uitdenbogerd, D., Egmond, C., Jonkers, R., & Kok, G. (2007). Energy-related intervention success factors: a literature review. *European Council for an Energy Efficient Economy: 2007 Summer Study*, *Proceedings 'Saving energy - just do it!*, 1847-1852.

Weiss, M., Helmers, E., & Cloos, K. (2020). Energy efficiency trade-offs in small to large electric vehicles. *Environ Sci Europe*, 32-46.

White, K., Habib, R., & Hardisty, D. J. (2019). How to SHIFT Consumer Behaviors to be More Sustainable: A Literature Review and Guiding Framework. *J Marketing, 83*(3), 22-49.

Zobeidi, T., Komendantova, N., & Yazdanpanah, M. (2022). Social media as a driver of the use of renewable energy: The perceptions of instagram users in Iran. *Energy Policy, 161*.

INCENTIVIZED ENERGY CONSUMPTION ADAPTION IN PRIVATE HOUSEHOLDS FACING THE ENERGY CRISIS

Results from a Living Lab Experiment

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Abstract
The ongoing energy crisis led to high energy prices and the call for energy savings in the winter months of 2022 to 2023. As the fulfilment of these demands is directly linked to the people's well-being, this challenged many households in the colder months. To analyze the interaction and willingness to reduce one's comfort level with regard to adjusting heating patterns and react to bottlenecks in the electricity supply, a field study was conducted with two tenants living in the living lab Energy Smart Home Lab (ESHL) for a time period of eight weeks. The ESHL combines a smart home with a sophisticated sensor and measurement system. During the experiment, the tenants received calls to action linked to non-economic and economic incentives to adapt their heating and electricity demand. Their reactions were analysed based on a mixed methods approach utilizing the recorded energy consumption data, temperature set points for the heating system, surveys and interviews. The results indicate a typically high motivation to meet the incentivized adaption in heating and electricity consumption, regarding both economic and non-economic incentives. Especially the reduction of the heating demand does not seem to have challenged the tenants too much. They stated not to have lost comfort despite lowering temperature set points significantly. Not all the calls to action, though, were carried out. Notwithstanding the incentive, the main reasons to ignore the electricity calls to action were social gatherings or pre-planned daily schedules, while maintaining comfort levels served as primary justification for increasing heating.

1 INTRODUCTION

The protracted conflict in Ukraine has caused an energy crisis that threatens the German gas supply, and the security of supply of the electricity system (International Energy Agency [IEA], 2023a). Challenges to security of supply are also emerging from decarbonization efforts, including a growing share of renewable energy sources, especially on the electricity supply side, a rise in electrification on the demand side, and bottlenecks within the transmission grid (IEA, 2023b). Many households struggle to fulfill their daily heating and electricity demands due to rising prices and the call for energy savings (Guan et al., 2023; Tollefson, 2022). Fulfilling these demands is directly linked to people's well-being, especially in the colder months. Various studies have assessed the potential impact of the Russia-Ukraine war on energy and food security (Zhou et al., 2023), with a focus on increased household burdens such as increased household energy costs (Kalkuhl et al., 2022), energy insecurity (Cozzi et al., 2022), and poverty (Mahler et al., 2022). They found that despite numerous national subsidy measures to keep energy bills at a manageable level, people may decide to reduce heating or not heating their homes at all as long as possible, regardless of their effects on comfort or health, in order to save heating energy and avoid skyrocketing energy bills (Sgaravatti et al., 2023).

Despite the difficulties faced by consumers, the energy crisis highlights the vulnerability of relying on foreign fossil fuels and offers an opportunity to accelerate the transition toward a more sustainable energy system (IEA, 2022). Multiple nations have responded quickly to the current developments, such as the US Inflation Reduction Act, the EU's Fit for 55 package and REPowerEU, Japan's Green Transformation (GX) program or Korea's aim to increase the share of nuclear and renewable electricity generation (European Commission, 2022; IEA, 2022; The White House, 2023). In speeding up the energy transition, the challenges, such as enabling demand to follow the increasingly volatile electricity supply from renewables, need to be addressed as soon as possible. While the industry sector is already participating in load shifting or shedding in Germany (AbLaV, 2016), limited options exist for private households, comprising so far only dynamic and variable electricity tariffs by a handful of electricity providers (Weigl, 2021). Tariffs that account for energy and power consumption do not exist in Germany so far. To ensure the success of such tariff schemes, it is vital to consider the households' decision process to adopt these tariffs. A household's willingness to engage in variable tariffs may be reduced by the effort to provide load shifting (Schlereth et al., 2018) and unpredictable price developments (Ruokamo et al., 2019). Existing research analyses various economic and non-economic incentives to address the domestic load shifting abilities under real-world conditions, revealing varying results (Alan et al., 2015; Azarova et al., 2020; Bartusch & Alvehag, 2014; Ito et al., 2018; Nilsson et al., 2018; Scharnhorst et al., 2021; Stamminger & Anstett, 2013). Few pilot studies exist, however, that evaluate household acceptance and participation in load shifting or shedding to maintain below a specified power threshold along with a detailed empirical examination (Scharnhorst et al., 2021). Furthermore, the urgency of the energy crisis has not allowed for pilot studies that investigate the incentives and circumstances motivating tenants to prioritize energy savings over comfort. To address this gap, we conducted a field study in the Energy Smart Home Lab (ESHL), where two tenants lived for six weeks, receiving various calls to action to alter their heating and electricity consumption behavior in response to different economic and non-economic incentives.

Hence, our study approach is two-fold: First, to assess the tenant's reaction and engagement with calls to action on their room heating behavior and second, how the tenants respond to various incentives designed to induce demand response behavior. This leads to the following research questions:

I. *To what extent are tenants willing to lower room temperature set points to comply with a given incentive?*
II. *What incentives and other factors influence the tenants' willingness to comply with load shifting or shedding?*

2 MATERIALS AND METHODS

This Section describes the experimental setup in the Energy Smart Home Lab, as well as the experiment design. We further elaborate on the participants' demographics and present the measuring and sensor system, the empirical methods applied for data collection and analysis.

2.1 The Energy Smart Home Lab

The Energy Smart Home Lab (ESHL) located on the Karlsruhe Institute of Technology (KIT) campus, is a fully operational smart home and living lab with integrated sensor and measurement systems. The 60 m² space includes a combined living and kitchen area, two bedrooms, and a bathroom, accommodating up to two tenants simultaneously. Tenants can adjust temperature set points in 0.5 °C increments for the living room and bedrooms through a dashboard. Further details on the ESHL setup are available in (Scharnhorst et al., 2021).

2.2 Experiment design

We used various calls to action along with economic and non-economic incentives to elicit the tenants' responses and behavioral changes. Regarding heating, we introduced calls to action to lower room temperatures for a pre-determined time (several days) to reduce the heating demand. For electricity demand, we implemented load shedding or shifting during designated hours. Economic incentives involved monetary rewards for compliance and penalties for non-compliance. Non-economic incentives tapped into tenants' environmental and societal values.

In September 2022, Germany's national energy conservation regulation came into effect, enacting a maximum room temperature of 19 °C in public workplaces (Federal Cabinet, 2022). Private households are not required to abide by this law, but it gives them the option of voluntarily providing energy savings by suspending contractual obligations of residential tenancies to maintain a specific minimum temperature to avoid damage (such as mold or frost) inside the rented asset (EnSikuMaV, 2022). To decrease the chance of mold formation, the federal environment agency advises not allowing room temperatures to fall below 16 to 18 °C and maintaining room temperatures between 19 to 20 °C (during the day) throughout the heating period of 2022-2023 (Moriske et al., 2017; Umweltbundesamt [UBA], 2022a, 2022b). We designed the experiment accordingly, starting with a reference period without any calls to action, followed by four heating calls to action lasting four to seven days.

Table 1 - Overview of calls to action incentivizing the adjustment of temperature set points

No.	**Incentive E: economic N: non-economic**	**Proposed set point temperature [°C]**	
		Day (6 am -10 pm)	***Night (10 pm – 6 am)***
I	N	No given set point, voluntary reduction of heating. Advice to not set below 16 °C.	
II	E	No given set point, voluntary reduction of heating, compensation starts below 21 °C, lower bound 16 °C.	
		Automatic set points:	
III	E	19 °C	16 °C
IV	N	19 °C	16 °C

Tenants were encouraged to set room temperatures below 21 °C for energy savings, with the first call appealing to their moral values and the second offering monetary rewards (Table 1). Calls to action III and IV automatically set the temperature set points to 19 °C at daytime and 16 °C at night. While the tenants could always manually adjust these set points, deviations from the initially set temperature resulted in either compensation or cost to the tenants in terms of economic incentives. The compensation or cost for saved or excess heating energy, respectively, is calculated as follows:

$$c = s\, c_{ng}\, f \sum_{t=1}^{n} \Delta T_{sp,t}\, E_t \tag{1}$$

With

c: compensation or cost in Euro

$\Delta T_{sp,t}$: deviation of set point temperature from 21°C for computing the compensation or the set point temperature from 19 °C for computing the cost of additional energy consumption

E_t: heating energy consumption in kWh

s: heating energy saving in % per °C

c_{ng}: cost of natural gas in €/kWh

f: scaling factor

t: respective time interval

By lowering the temperature to 19 °C during the day and 16 °C at night, the second economic incentive aimed to assess the tenants' unwillingness to pay and reduce the financial gain they had thus far obtained. If there was a positive deviation from these temperature specifications, the extra energy use would be charged. Calls to action were employed to evaluate tenants' load flexibility, involving specific time intervals and power thresholds. These actions, referred to as "grid bottlenecks," required the load not to exceed 2 kW or 3 kW for three hours, with a compensation of 6 Euros (3 Euros per tenant) or non-economic incentives. These intervals were typically scheduled during peak load periods, such as mornings and evenings. Compensation was calculated based on the electricity rates during the study, which amounted to 0.44

Euro/kWh (Bundesverband der Energie- und Wasserwirtschaft [BDEW], 2023). On average, a two-person household in Germany consumes 2000 kWh of electricity annually, translating to an hourly use of 0.228 kWh and an hourly cost of 0.10 €/kWh (Weißbach, 2021). For the six-hour duration of the call to action, this equated to 1.37 kWh or 0.60 €. To provide substantial but not excessive compensation for the six-week experiment, this value was scaled up by a factor of 10, following a similar approach used in prior studies (Faruqui & Sergici, 2011; Kato et al., 2016).

2.3 Demographics of participants

The two tenants, a male and a female, shared an apartment in the ESHL, both being German KIT students. Their participation in the study was entirely voluntary and not related to any mandatory degree requirements in their academic fields.

2.4 Measuring and sensor system

The power demand of every device in the building was monitored with a temporal resolution of one second during the experiment. The thermal power flow to the buildings' radiators was measured with a temporal resolution of two minutes to account for the heating consumption.

2.5 Empirical methods

Regular interviews were conducted to acquire a deeper insight into the motives and reasons for the tenants' behavior. One interview was conducted before the calls to action were sent, two interviews were conducted during the residential period, and one in-depth interview was conducted following the experiment.

2.6 Limitations

With a household comprising two persons, we recognize that the sample size of the experiment is very limited. Therefore, our findings may not be applicable to other households. However, the study design, as well as the findings may be used for reference, when designing experiments with a larger sample of households to acquire representative results.

3 RESULTS

In terms of both economic and non-economic incentives, the results demonstrate a general strong motivation to fulfill the incentivized adaption in heating and electricity consumption. However, not all of the calls to action were followed through on.

3.1 Lowering the heating set point

In the initial week with no calls to action, set points remained below 21 °C except for bedroom 2, which increased to 21 °C on December 12 at 12 a.m. During the first call to action, the tenants met the non-economic incentive by keeping the set points considerably below 21 °C. In response to the second call to action, all rooms remained below 21 °C, earning them 9.5 € in compensation. Tenant B was absent on weekdays, during the working hours, due to an internship in the first half of the experiment.

"Now I have set the temperature in my room to 18.5 °C when I am not at home during the day, but I know if I would sit and work at my desk all day, it would feel a bit fresh." (Tenant B, interview 2, translated from German)

Tenant B noted that the lower room temperatures in the bedroom were acceptable since most activities took place in the living room in the evening. Following voluntary set point reductions during the first two calls to action (I and II), calls to action (III and IV) all gave default set points of 19 °C during the day and 16 °C at night. Figure 1 depicts the third call to action (III), including the set points, measured indoor and outdoor temperatures, and heating demand. The set points in both bedrooms were lowered below the upper limit of the call to action, which is an interesting reaction given that this behavior was not monetarily rewarded. Neither tenant stated their intention to behave in this manner throughout the interviews. The main room's set point was only ever raised from 19 to 20 °C on January 22 in the morning. The excess heat cost of increasing the temperature set point by 1 °C was calculated for the time period of the active set point morning to evening (10 pm) on 22 January, and amounted to 1.4 Euro.

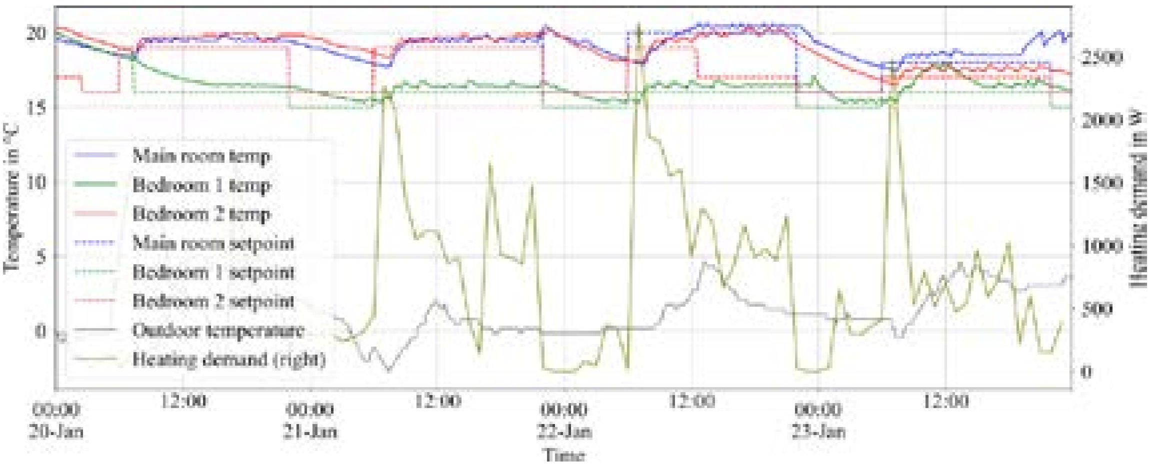

Figure 1 - Temperature et points, measured indoor and outdoor, temperature in °C, as well as heating demand in W for the heating call to action III

The set point was decreased the next day to 18 °C so no further cost for excess heating occurred. Tenant A described the temperature in the main room as:

"For me, this is still comfort temperature. I think we still have 19 °C in the living room, and with a sweater or something similar, this is totally acceptable." (tenant A, interview 2, translated from German)

Call to action IV was unsuccessful, as the bedroom 1 set point temperatures, initially below the target, were adjusted, with daytime increasing by 1.5 °C and nighttime by 1 °C. Out of the four calls to action, two went unmet in the final third of the residential phase, with no comments from the tenants during interviews, leaving the motive for overriding and raising temperatures unknown. Call to action III, with economic incentives, posed comprehension challenges due to a lack of detailed information on the incentive, eventually prompting a temperature increase, possibly due to discomfort, and then a 2°C reduction the following day. The fourth non-economic call to action did not lead to a reduction in temperature. Factors like decreased activity or falling outside temperatures could have played a role. This contrasts with the tenants' claims of efficient heating management and adaptability during the interviews. The absence of direct feedback on the dashboard, unlike electricity-related actions, may have made heating-related calls to action less prominent for the tenants.

3.2 Flexibility provision in electricity consumption

On eleven days, the tenants received calls to action for flexibility in the event of a grid bottleneck. Table 2 shows four calls to action related to economic incentives and seven to non-economic ones.

Table 2 - Calls to action to shift or reduce load in specific time intervals

No.	**Incentive E: economic N: non-economic**	**Duration 3 hours per interval 2 intervals per day**		**Incentive achieved (Y: yes, N: no)**
1	N	6 am – 9 am	6 pm – 9 pm	N
2	N	6 am – 9 am	6 pm – 9 pm	N
3	E	6 am – 9 am	6 pm – 9 pm	Y
4	E	6 am – 9 am	6 pm – 9 pm	Y
5	N	9 am – 12 pm	9 pm – 12 am	Y
6	N	12 pm – 3 pm	5 pm – 8 pm	Y
7	N	8 am – 11 am	8 pm – 11 pm	Y
8	E	12 pm – 3 pm	5 pm – 8 pm	Y
9	E	8 am – 11 am	8 pm – 11 pm	N
10	N	12 pm – 3 pm	5 pm – 8 pm	N
11	N	8 am – 11 am	5 pm – 8 pm	N

The tenants responded to the call to action six times, achieving three out of four economic incentives and receiving 18 Euros in compensation. Figure 2 illustrates successful load shifting.

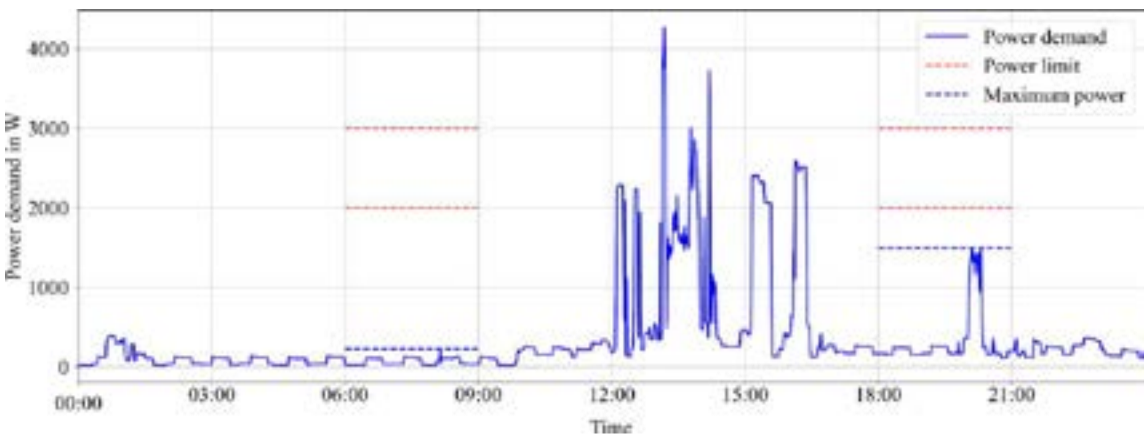

Figure 2 - Call to action representing successful load shifting by the tenants of the Energy Smart Home Lab

Interviews revealed diverse reasons for the remaining five call-to-action failures. The first grid bottleneck call to action encountered a dashboard programming error, falsely indicating a threshold breach at 4 pm, though the interval started at 6 pm. This led the tenants to believe they had already failed, causing them to disregard the threshold. The subsequent call to action, occurring on a Sunday, was unintentionally ignored, as Tenant B had scheduled the washing machine to run at a peak of 2.15 kW, coinciding with the action's start. On two other days (the 9th and 10th grid bottleneck call to action), tenant B declared not to have had another time slot available that day to transfer activities such as running the dishwasher or the tumble dryer. The last grid bottleneck was breached due to the ‘apple pie incident’.

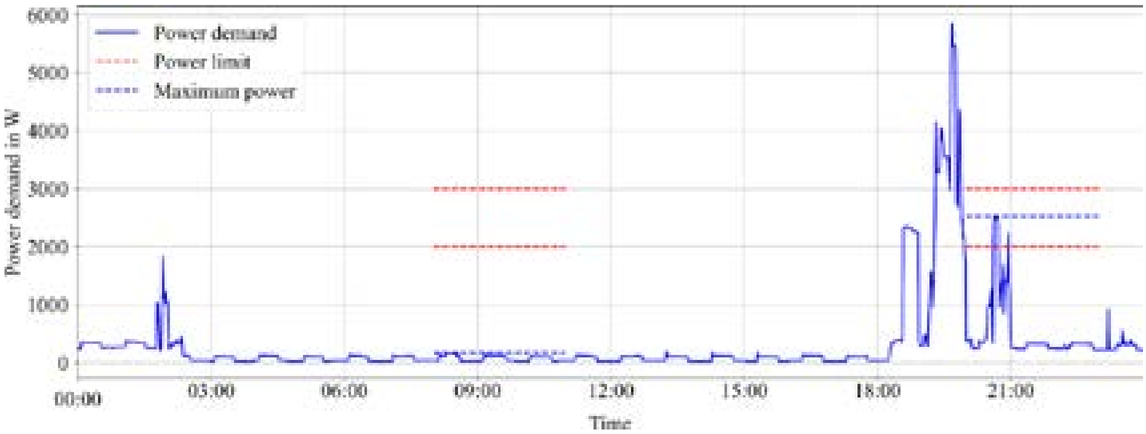

Figure 3 - Call to action 11 representing failed load shifting in the second time interval of the grid bottleneck by exceeding the 2 kW threshold with a peak power of 2.5 kW

Tenant A intended to bake an apple pie, preheating the oven before 5 pm (the threshold start time) to finish baking the apple pie with the oven switched off, and utilizing the residual heat during the interval. Because of growing doubts about the plan's feasibility, the oven was restarted, forcing it to reach its peak power of 2.1 kW and surpassing the 2 kW power threshold (Figure 3). Tenant A stated that regardless of the economic or other sorts of incentives presented, they were generally interested in following the calls to action:

“For me, the financial incentive had no bearing and I always attempt to follow through on the calls to action.” (Tenant A, interview 3, translated from German)

Tenant B, on the other hand, contended that transferring load under bottleneck conditions would be motivated more by economic rather than non-economic incentives. Both sides acknowledged the challenges associated with the timing of the bottlenecks, citing kitchen usage (e.g., the stove and oven) as the main impediment, particularly in the evenings:

“The hours between 6 and 9 am and 6 and 9 pm are challenging when one is the entire day away. To prepare meals in the morning and set the oven to cook so that dinner is ready when one arrives home requires a lot of forethought and effort.” (Tenant B, interview 3, translated from German)

Four of the five failed calls to action, featured non-economic incentives, while one involved economic incentives. Because seven non-economic and only four economic incentives were tested, and since both tenants would, ultimately, influence the decision of the one household they represented, it is impossible to say with certainty whether the economic or non-economic incentives worked better. Though findings suggest a preference for economic incentives, tenant responses were significantly influenced by contextual factors, such as the presence of guests.

3.3 Guidelines for future experimental designs

From the lessons learned during this experiment, we derived the following guidelines to support and improve future experiments in living labs that examine comfort levels and energy consumption behaviors of residential consumers:

1. Start with a reference period (without incentives)
2. Check for economic, as well as non-economic incentives
3. Check for compensation, as well as cost schemes
4. Account for temperature change inertia (e.g., long-term residential phase of at least eight weeks, incentive schemes over multiple days)
5. Adequate user interface for real-time feedback and easy interaction
6. Adequate data gathering equipment
7. Adequate sample size

Starting with a reference period is crucial to enable tenants to acclimate to the new living conditions and establish their daily routines. This period enables unaltered observation of energy consumption, facilitating adjustments to planned incentives. If early observations reveal e.g. deviations from standard load profile, incentive timing should be adapted. Recognizing the significance of non-economic incentives, studies emphasize that household decisions are not solely economically driven (Parrish et al., 2020). Real-time feedback empowers tenants to monitor and improve their energy consumption behavior.

4 CONCLUSIONS

In a two-month field study, two occupants resided in the Energy Smart Home Lab and received calls to action involving economic and non-economic incentives to adjust their electricity and heating demand. Analysis of recorded data, encompassing electricity and heating demand along with temperature settings, was supplemented by regular interviews to uncover motivations for their behaviors. The results indicate a genuine willingness to conform to incentivized changes in energy consumption, encompassing both economic and non-economic incentives. Lowering heating demand did not significantly disrupt the tenants' comfort, but during the final third of the study, temperature settings were raised despite continued claims of compliance with heating calls to action, indicating a preference for comfort over incentives. Not all of the calls to action on electricity consumption were heeded, as well. Some calls to action for electricity usage were ignored due to social commitments, pre-existing schedules, or unnoticed notifications. As this study examined only one household, its findings may not be universally applicable, necessitating further research with a more diverse sample for representative results.

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5 REFERENCES

Alan, A. T., Ramchurn, S. D., Rodden, T., Costanza, E., Fischer, J., & Jennings, N. R. (2015). Managing energy tariffs with agents. In K. Mase, M. Langheinrich, D. Gatica-Perez, H. Gellersen, T. Choudhury, & K. Yatani (Eds.), *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers - UbiComp '15* (pp. 1551–1558). ACM Press. https://doi.org/10.1145/2800835.2801626

Azarova, V., Cohen, J. J., Kollmann, A., & Reichl, J. (2020). Reducing household electricity consumption during evening peak demand times: Evidence from a field experiment. *Energy Policy*, *144, Article 111657*, Article 111657. https://doi.org/10.1016/j.enpol.2020.111657

Bartusch, C., & Alvehag, K. (2014). Further exploring the potential of residential demand response programs in electricity distribution. *Applied Energy*, *125*, 39–59. https://doi.org/10.1016/j.apenergy.2014.03.054

Verordnung über Vereinbarungen zu abschaltbaren Lasten (Verordnung zu abschaltbaren Lasten - AbLaV) (2016). https://www.gesetze-im-internet.de/ablav_2016/BJNR198400016.html

Bundesverband der Energie- und Wasserwirtschaft. (2023). *BDEW-Strompreisanalyse Jahresbeginn 2023*. https://www.bdew.de/service/daten-und-grafiken/bdew-strompreisanalyse/

Cozzi, L., Wetzel, D., Tonolo, G., & Hyppolite II, J. (2022). *For the first time in decades, the number of people without access to electricity is set to increase in 2022: Commentary*. https://www.iea.org/commentaries/for-the-first-time-in-decades-the-number-of-people-without-access-to-electricity-is-set-to-increase-in-2022

European Commission. (2022, May 18). *REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition* [Press release]. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

Faruqui, A., & Sergici, S. (2011). Dynamic pricing of electricity in the mid-Atlantic region: econometric results from the Baltimore gas and electric company experiment. *Journal of Regulatory Economics*, *40*(1), 82–109. https://doi.org/10.1007/s11149-011-9152-5

Federal Cabinet. (2022). *Additional energy-saving measures approved.* The Federal Government | Bundesregierung. https://www.bundesregierung.de/breg-en/issues/energy-saving-measures-2078510

Verordnung zur Sicherung der Energieversorgung über kurzfristig wirksame Maßnahmen

(EnSikuMaV), 2022. https://www.bmwk.de/Redaktion/DE/Downloads/E/ensikumav.pdf?__blob=publicationFile&v=4

Guan, Y., Yan, J., Shan, Y., Zhou, Y., Hang, Y., Li, R., Liu, Y., Liu, B., Nie, Q., Bruckner, B., Feng, K., & Hubacek, K. (2023). Burden of the global energy price crisis on households. *Nature Energy*, 1–13. https://doi.org/10.1038/s41560-023-01209-8

International Energy Agency. (2022). *World Energy Outlook 2022 shows the global energy crisis can be a historic turning point towards a cleaner and more secure future*. https://www.iea.org/news/world-energy-outlook-2022-shows-the-global-energy-crisis-can-be-a-historic-turning-point-towards-a-cleaner-and-more-secure-future

International Energy Agency. (2023a). *Global Energy Crisis: How the energy crisis started, how global energy markets are impacting our daily life, and what governments are doing about it*. https://www.iea.org/topics/global-energy-crisis

International Energy Agency. (2023b, February 21). *The global energy crisis is driving a surge in heat pumps, bringing energy security and climate benefits - News*. https://www.iea.org/news/the-global-energy-crisis-is-driving-a-surge-in-heat-pumps-bringing-energy-security-and-climate-benefits

Ito, K., Ida, T., & Tanaka, M. (2018). Moral Suasion and Economic Incentives: Field Experimental Evidence from Energy Demand. *American Economic Journal: Economic Policy*, *10*(1), 240–267. https://doi.org/10.1257/pol.20160093

Kalkuhl, M., Flachsland, C., Knopf, B., Amberg, M., Bergmann, T., Kellner, M., Stüber, S., Haywood, L., Roolfs, C., & Edenhofer, O. (2022). *Effects of the energy price crisis on households in Germany: Socio-political challenges and policy options*. Berlin, Germany. Mercator Research Institute on Global Commons and Climate Change (MCC) gGmbH. https://www.mcc-berlin.net/fileadmin/data/C18_MCC_Publications/2022_MCC_Effects_of_the_energy_price_crisis_on_households.pdf

Kato, T., Tokuhara, A., Ushifusa, Y., Sakurai, A., Aramaki, K., & Maruyama, F. (2016). Consumer responses to critical peak pricing: Impacts of maximum electricity-saving behavior. *The Electricity Journal*, *29*(2), 12–19. https://doi.org/10.1016/j.tej.2016.02.002

Mahler, D. G., Yonzan, N., Hill, R., Lakner, C., Wu, H., & Yoshida, N. (2022). *Pandemic, prices, and poverty*. https://blogs.worldbank.org/opendata/pandemic-prices-and-poverty

Moriske, H.-J., Szewzyk, R., Tappler, P., & Valtanen, K. (2017). *Leitfaden zur Vorbeugung, Erfassung und Sanierung von Schimmelbefall in Gebäuden*. Bonn. https://www.umweltbundesamt.de/sites/default/files/medien/421/publikationen/uba_schimmelleitfaden_final_bf.pdf

Nilsson, A., Lazarevic, D., Brandt, N., & Kordas, O. (2018). Household responsiveness to residential demand response strategies: Results and policy implications from a Swedish field study. *Energy Policy*, *122*, 273–286. https://doi.org/10.1016/j.enpol.2018.07.044

Parrish, B., Heptonstall, P., Gross, R., & Sovacool, B. K. (2020). A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response. *Energy Policy*, *138*, Article 111221. https://doi.org/10.1016/j.enpol.2019.111221

Ruokamo, E., Kopsakangas-Savolainen, M., Meriläinen, T., & Svento, R. (2019). Towards flexible energy demand – Preferences for dynamic contracts, services and emissions reductions. *Energy Economics*, *84*, 104522. https://doi.org/10.1016/j.eneco.2019.104522

Scharnhorst, L., Sandmeier, T., Ardone, A., & Fichtner, W. (2021). The Impact of Economic and Non-Economic Incentives to Induce Residential Demand Response—Findings from a Living Lab Experiment. *Energies*, *14*(2036). https://doi.org/10.3390/en14082036

Schlereth, C., Skiera, B., & Schulz, F. (2018). Why do consumers prefer static instead of dynamic pricing plans? An empirical study for a better understanding of the low preferences for time-variant pricing plans. *European Journal of Operational Research*, *269*(3), 1165–1179. https://doi.org/10.1016/j.ejor.2018.03.033

Sgaravatti, G., Tagliapietra, S., Trasi, C., & Zachmann, G. (2023, February 27). *National fiscal policy responses to the energy crisis*. https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices

Stamminger, R., & Anstett, V. (2013). The Effect of Variable Electricity Tariffs in the Household on Usage of Household Appliances. *Smart Grid and Renewable Energy*, *04*(04), 353–365. https://doi.org/10.4236/sgre.2013.44042

Tollefson, J. (2022). What the war in Ukraine means for energy, climate and food. *Nature*, *604*(7905), 232–233. https://doi.org/10.1038/d41586-022-00969-9

Umweltbundesamt. (2022a, September 22). *FAQ: Absenkung der Raumtemperatur in Herbst und Winter*. https://www.umweltbundesamt.de/themen/faq-absenkung-der-raumtemperatur-in-herbst-winter

Umweltbundesamt. (2022b, December 16). *Richtiges Heizen schützt das Klima und den Geldbeutel*. https://www.umweltbundesamt.de/umwelttipps-fuer-den-alltag/heizen-bauen/heizen-raumtemperatur#unsere-tipps

Weigl, B. (2021, June 16). Variable und dynamische Stromtarife: Wann Du Strom verbrauchst, ist entscheidend für seinen Preis. *Finanztip*. https://www.finanztip.de/stromtarife/variable-stromtarife/

Weißbach, A. (2021). *Stromverbrauch 2 Personen: Durchschnitt & Kosten*. https://www.co2online.de/energie-sparen/strom-sparen/strom-sparen-stromspartipps/stromverbrauch-2-personen-haushalt/

The White House. (2023, February 14). *Inflation Reduction Act Guidebook*. https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/

Zhou, X.-Y., Lu, G., Xu, Z., Yan, X., Khu, S.-T., Yang, J., & Zhao, J. (2023). Influence of Russia-Ukraine War on the Global Energy and Food Security. *Resources, Conservation and Recycling*, *188*, 106657. https://doi.org/10.1016/j.resconrec.2022.106657

Exploring Narrative Elements in Climate Policy Discourse: Enhancing Policy Acceptance for Consumption Changes

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Keywords: climate communication, narratives, policy acceptance, qualitative analysis

Abstract

Effective climate communication is crucial for gaining support for policies aimed at achieving sustainable change. This qualitative study analyses narratives surrounding climate policies for consumption changes, focusing on enhancing policy acceptance. Through an analysis of 25 articles from three Dutch news websites (nos.nl, ad.nl and volkskrant.nl), the study explores narrative elements contributing to effectiveness (i.e., policy acceptance). We find that articles recognize climate change as a relevant issue but often lack a specific rationale behind why it is considered a problem. Articles differ in terms of the perceived disadvantaged parties, which vary between the climate, citizens, or businesses, as well as the depicted opponents, such as humanity or wealthier consumers. Despite the articles discussing policy pros and cons, clear solutions are absent. In addition, the articles often present economic prosperity versus climate action dichotomy. Predictors of policy acceptance (effectiveness, fairness, impact on lives) receive limited attention. Fear-inducing imagery emphasizes economic consequences rather than climate change itself. Common climate delay arguments include concerns about fairness, well-being, and the demand for policy perfection, potentially hindering support for climate action. To enhance policy acceptance we suggest providing narratives that emphasize the predictors of policy acceptance, clarify policy effectiveness and fairness considerations, and highlight positive impacts.

1. Introduction

1.1. Background

In recent years, the necessity of addressing climate change and advancing towards a sustainable society have gained prominence on a global scale, compelling governments and policymakers worldwide to take decisive actions. Climate goals have been enforced in both the climate and coalition agreements of the Dutch government (Rijksoverheid, 2019; 2021a). Until now, this transformative movement has mainly centred around the energy transition – an extensive shift from fossil fuel reliance to the adoption of renewable energy sources. However, the release of the latest Intergovernmental Panel on Climate Change (IPCC) report in 2022 has refocused attention on a less-explored aspect of climate action: the reduction of indirect energy consumption through behavioural changes.

Ambitious climate policies, such as those directed at indirect energy consumption, require adaptation and change from both citizens and businesses. Often, however, people tend to resist change, especially when they feel that their freedom to make choices is restricted by others (i.e., reactance; e.g., Glifford, 2011; Gifford, Kormos, & McIntyre, 2011; Ma, Dixon, Hmielowski, 2019). Therefore, finding effective strategies to gain public support for these policies has become essential (Anderson, Böhmelt, & Ward, 2017; Rhodes, Axsen, & Jaccard, 2014). It is widely acknowledged that the acceptance of policies aimed at mitigating climate change constitutes a critical prerequisite for their successful development, implementation, and execution (Drews & van den Bergh, 2016; Hoogerwerf, Arentsen, & Klok, 1993). In response to this challenge, Dutch municipalities, regions, and umbrella organizations are increasingly seeking effective narrative strategies for communicating climate policies and explaining their necessity (LCNK, 2022; NPRES, 2021; NVDE, 2021).

To address this issue, in the current study, we explore the essential elements of narratives and analyse 25 articles from three prominent Dutch news websites: nos.nl, ad.nl and volkskrant.nl.

1.2. Narratives

Narratives, within the realm of scientific literature, are multifaceted constructs. While their definitions may vary, they share common threads. Primarily, narratives are characterized as socially constructed stories that imbue meaning into events and experiences, ultimately guiding actions and preferences (Böhm, Pfister, Salway, & Fløttum, 2019; Chabay, Koch, Martinez, & Scholz, 2019; Fløttum & Gjerstad, 2017; Soutar & Mitchell, 2018; van der Leeuw, 2020).

In climate communication and associated policy discourse, the complexity of effective communication cannot be overstated (Moser, 2010; Stoknes, 2014). Climate scientists struggle with conveying their research findings more effectively (UCL, 2014). Despite years of sounding the alarm, tangible progress toward climate goals remains insufficient (IPCC, 2022). The Intergovernmental Panel on Climate Change (IPCC), responsible for synthesizing scientific knowledge on climate change, recognizes the pressing need for improved communication. They view narratives as a means to foster a shared understanding of our environmental reality, how we envision securing our livelihoods in a desirable future, and what actions are required to collectively reach this future (IPCC, 2022).

1.3. Objectives

The primary goal of this research is to gain insight into the narratives surrounding climate policies focused on changes in consumption behaviour as they manifest in articles published on specific news websites. This research seeks to address a twofold mission. Firstly, to comprehensively examine the prevalent narratives within these articles, decoding the underlying storylines that animate the discourse on climate policy and consumption behaviour changes. Secondly, to scrutinize these narratives through the lens of effectiveness, discerning the specific elements that contribute to their persuasive power.

To guide our study effectively, we have formulated two core research questions: 1) What narratives or storylines regarding climate policies aimed at consumption behaviour changes are recurrent in articles featured on three of the most widely-read Dutch news websites? 2) What elements within these narratives or storylines contribute to their effectiveness in communicating climate policies intended to alter consumption behaviour?

2. Methods

2.1. Selection of Media Sources

To gain insights into narratives prevalent on the most widely-read Dutch news websites and those resonating among the broader population of news readers, we considered which news websites had the highest readership and their alignment with political preferences. Based on our findings, we selected the following news websites for our analysis: nos.nl (Nederlandse Omroep Stichting; NOS), ad.nl (Algemeen Dagblad; AD), and volkskrant.nl (De Volkskrant).

A study conducted in 2021 revealed that NOS had the largest reach among news websites, with a daily readership of 23.9% of individuals aged 13 and above (Commissariaat voor de Media, 2022). NU.nl ranked second with a reach of 17.7%, followed by AD at 13.9% and De Telegraaf at 11.2%. With a daily reach of 8.1%, RTL Nieuws secured the fifth position, while De Volkskrant ranked sixth with a reach of 3.1% (Commissariaat voor de Media, 2022).

It is important to note that climate communication is perceived through the lenses of cultural identity and political orientation. Research by the Pew Research Center (2018) suggests that readers of NOS and NU.nl generally hold politically centrist views, while AD, RTL Nieuws, and De Telegraaf readers tend to lean more toward the political right. On the other hand, readers of De Volkskrant tend to have left-leaning political orientations. Additionally, polling conducted by De Hond in 2019 revealed that half of the AD readers tend to vote for center to right-oriented parties, while half of the readers of De Volkskrant prefer centre to left-oriented parties.

2.2. Selection of Articles

The selection of articles was based on their relevance to three policy events aimed at altering consumption behaviour, which we refer to as "policy events". These three policy events are:

1. **Proposal to investigate a meat tax**: On March 29, 2022, Minister Henk Staghouwer (Agriculture) sent a parliamentary letter to the Dutch House of Representatives, regarding an investigation into the potential implementation of a meat tax.
2. **Flight cuts at Schiphol Airport**: On June 16, 2022, reports surfaced in De Telegraaf, citing sources in The Hague, that Schiphol Airport was instructed to reduce its number of flights. This was officially confirmed by Minister Harbers of the Ministry of Infrastructure and Water Management on June 24.
3. **Proposal to introduce a personal carbon budget**: On August 3, economist Barbara Baarsma proposed the introduction of a personal carbon budget as a means to address carbon emissions.

For each of these policy events, we established a specific time frame, encompassing the period from the date the event became public up to two weeks thereafter. Articles falling outside of this time frame were excluded from our analysis, as we argue that such articles do not directly respond to the respective policy event. To identify relevant articles, we used the Dutch search terms "meat tax", "Schiphol" or "shrinkage Schiphol", and "carbon budget" or "CO_2-budget" or "Baarsma". Only written articles, excluding videos or live blogs, discussing the specified policy events were considered for inclusion in our analysis. Please see Table 1 for the number of selected articles per news website and policy event.

Table 1. Number of selected articles per news websites and policy event.

	NOS	**De Volkskrant**	**AD**
Meat tax	N=2	N=3	N=4
Flight cuts Schiphol	N=4	N=5	N=5
CO_2-budget	N=0	N=1	N=1

2.3. Analysis Approach

To facilitate the analysis of the chosen articles and enable informed assessments of their influence on public support for each policy event, we first developed an analytical framework based on scientific literature. After that, two researchers conducted a content analysis employing this framework. In order to enhance the interrater reliability of the analysis, the first six articles were initially independently analysed by the researchers, and then cross-compared.

Table 2 provides a summary of all variables included in our analysis framework, along with brief descriptions of each variable. For a detailed explanation of the development of this analysis framework, please see Appendix A.

Table 2. Analysis framework.

Element	Description
Setting	What is the reason for this article? These are the three different policy events.
Subject (hero)	Who or what wants to achieve the solution to the problem described?
Object (goal)	What does the subject (hero) want to achieve? Focus on the main goal(s).
Helper	Who or what helps the subject (hero)? This cannot be the solution to the described problem.
Opponent (villain)	Who or what causes the problem and/or hinders the subject (hero) from reaching the object?
Sender	Who or what initiates action so that the subject (hero) wants to reach the object (before the subject (hero) sets out)?
Receiver	Who or what experiences negative consequences from the problem and/or benefits from the subject achieving the object?
Plot/storyline	What happens in the narrative and what is the problem being outlined?
Moral (solution)	What is the message and solution to the problem described?
Writing style (narrative or factual)	Is the writing style of the article factual or narrative?
Perceived effectiveness	Is it made plausible that the policy is effective?
Perceived fairness	Is it made plausible that the policy is fair?
Impact on own life	Is it described whether the direct and indirect effects of the policy on one's life are positive or negative?
Fear appeal	Is a fear appeal (i.e., an appeal to fear) used?
Response efficacy	Is confidence created in the solution to the problem? (this is what makes a fear appeal effective)
Hope appeal	Is a hope appeal used (i.e., a positive future outlined)?
Individualism	Is responsibility shifted to individuals (e.g., consumers or citizens)?
Whataboutism	Is responsibility being shifted to others who have a larger carbon footprint?
The free-riders excuse	Is responsibility being shifted to others who have no intention of reducing their emissions, causing us (e.g., as the Netherlands) to experience disadvantages?
Technological optimism	Is it argued that disruptive changes (such as mitigation measures) are not necessary, because of the great potential of future technologies?
All talk, little action	Is it argued that disruptive changes (such as restrictive measures) are not necessary because ambitious goals have already been set, leading to action (i.e., “we are already doing enough”)?
Fossil fuel solutionism	Is it argued that disruptive changes (such as restrictive measures) are not necessary because fossil fuels are part of the solution?
No stick, just carrots	Is it argued that disruptive changes (e.g., restrictive measures) are not necessary

Element	Description
	because society responds only to supportive and voluntary policies?
Policy perfectionism	Is it argued that only perfectly crafted solutions are going to work? Or that further research/exploration of other possibilities is needed?
Appeal to well-being	Is it written that the policy is at the expense of people's well-being or society as a whole (such as negative economic consequences)?
Appeal for social justice	Are the policies seen as socially inequitable (i.e. burdensome on certain social groups)?
Change is impossible	Is it argued that change is impossible and therefore policy makes no sense?
Doomism	Is it argued that change is impossible and therefore policy makes no sense?

3. Results

In this chapter, we present the results of the content analysis, examining each policy event through the lens of our analysis framework. In section 3.1, we first provide the narrative that emerges across all three news websites, after which we describe the main differences between the news websites based on the variables of our analysis framework. We repeat this process for each policy event. In section 3.2, we discuss the writing style, determinants of policy acceptance, the role of fear appeals and response efficacy, the usage of hope appeals, and the usage of climate delay and acceleration arguments. For example quotes from the analysed articles that support our findings, please see the endnotes.

3.1. Similarities and differences between news websites

3.1.1. Meat tax

A common narrative that emerges about the meat tax across all three news website is: *Consumers need to reduce meat consumption to live more sustainable and healthier lives. However, Minister Staghouwer's proposal to investigate a meat tax faces political opposition. Parties like VVD and CDA swiftly distanced themselves from the idea, but it is not just them; opposition parties like PVV, SP, JA21, Denk, and BBB also reject the notion of a meat tax.*

The news websites mainly differ in the entities or individuals described as receivers. The analysed articles of De Volkskrant depict the climate as a receiver, while AD and NOS articles also describe low-income groups and consumers as receivers. [1,2,3]

3.1.2. Flight cuts Schiphol

A common narrative that emerges about the flight cuts at Schiphol across all three news website is: *Schiphol Airport does not meet the requirements for noise pollution, nitrogen and particulate matter. The government sees no way out and therefore decides that the maximum number of flights allowed at Schiphol must be reduced. The responses to this decision, from parties cited in the articles, are mixed. Local residents and environmental organizations* *welcome the measure, but also feel that it does not go far enough. On the other hand, economists, airlines and Schiphol Airport express discontent with the decision.*

The difference among the news websites is notable in terms of the entities described as receivers. The analysed AD articles frequently describe Schiphol and KLM as receivers, while NOS and De Volkskrant emphasize the necessity of complying with noise, nitrogen, and particulate matter requirements, highlighting Schiphol's inability to adhere to these rules.[4,5,6] In De Volkskrant, the environment and local residents are presented as the receivers, while Schiphol is portrayed as the opponent. Furthermore, the role of the government as the subject is questioned. While the decision to downsize essentially makes the government a subject since they are proposing a solution to the described problem (flight cuts Schiphol), articles in De Volkskrant suggest that the government may have a hidden agenda.[7,8] In the analysed NOS articles, the flight cuts are also described as a challenging decision due to Schiphol's position as a job engine for the Dutch economy.[9,10]

3.1.3. Carbon budget

No articles regarding the carbon budget were found on the NOS website. A common narrative that emerges in the analysed articles of De Volkskrant and AD is: *We all emit too much CO2, both consumers and businesses. We need to consume less and we need to go green. This will require radical change.*

The plots in the analysed articles about the carbon budget start with the problem that our consumption patterns are causing too much damage to the climate. In both articles, "we" are portrayed as the opponent.[11,12] However, there is a difference in how wealthier individuals are portrayed within the news website. The columnist of the De Volkskrant writes that the wealthier individuals, the biggest consumers, are not being adequately addressed and portrays them as the root of the problem, thereby marked as opponents.[13] In the AD article, all consumers are opponents, with no differentiation among them.[14] The AD columnist takes a stance favouring a personal carbon budget as a noteworthy solution towards significant change, while the columnist of De Volkskrant leans toward addressing the biggest climate polluters, given concerns about potential adverse effects of the personal carbon budget on low-income groups.[15]

3.2. Analysis framework

3.2.1. Writing style

NOS articles are written in a more succinct and straightforward manner, with hardly any signal words. They are not written from an 'I' or 'we' perspective, with lack of specific emotional appeals.[16,17] In contrast, AD articles utilize signal words, emotional expressions, and incorporate quotes and statements from a variety of individuals, such as citizens, experts, or members of a specific union or association.[18] Finally, articles of De Volkskrant make use of both writing styles.[19] [20]

3.2.2. Determinants of policy acceptance

3.2.2.1. Meat tax

There are differences in the determinants of public acceptance described by the three news websites. The analysed articles of De Volkskrant emphasize the expected effectiveness of the meat tax, while the AD articles predominantly emphasize its ineffectiveness.[21,22,23] The analysed NOS articles barely discuss this aspect.[24] There is no explanation given why this policy saves the climate. Regarding the fairness of the meat tax, both NOS and AD articles focus on the perceived unfairness of the measure towards low-income groups, which is also referred to as distributive fairness (i.e., the burdens of a meat tax fall mainly on low incomes).[25,26] In contrast, one of the analysed articles of De Volkskrant articles mentions compensations of the unfairness towards low-income groups and another one frames the meat tax as 'reasonable pricing'.[27,28] Besides that, the articles of De Volkskrant place more emphasis on the positive effects of the policies on one's life and society.[29,30,31] For example, while the analysed articles of De Volkskrant emphasize the positive health effects of the meat tax, the NOS and AD articles also highlight the increasing cost of groceries and the limitation of freedom in food choices. Nonetheless, the specific reasons behind the positive health effects of the meat tax, as in the reduced meat consumption, remain unclear.

3.2.2.2. Flight cuts Schiphol

The effectiveness of flight cuts at Schiphol to mitigate noise pollution and environmental damage is rarely discussed across all three news websites. Only one of the analysed NOS articles mentions the ineffectiveness of the measure, whereas one article of De Volkskrant briefly notes that the measure does not go far enough to contribute to solving the described problem.[32,33] AD articles primarily focus on the impact of the measure on noise pollution and express doubt about its effectiveness, with no mention of limiting environmental damage. Residents are quoted expressing doubts about the sufficiency of the measure to reduce noise pollution.[34] The fairness of this measure is not addressed in any of the analysed articles. Only AD articles touch upon concerns about whether people are still allowed to go on vacation, though these questions are left unanswered.[35,36] The negative effects of the flight cuts at Schiphol primarily revolve around economic damage to society and the potential increase in airfare, or the removal of (holiday) destinations. Positive effects mainly relate to reduced noise pollution for residents. These effects are described in both AD and NOS articles, while articles of De Volkskrant do not address the consequences of the flight cuts at Schiphol Airport.

3.2.2.3. Carbon budget

The expected effectiveness of a carbon budget is criticized in the De Volkskrant, whereas the AD article does not address this aspect.[37] Concerning the fairness of a carbon budget, the article of De Volkskrant argues that companies should also be held accountable alongside consumers and suggests that the rich are advantaged, necessitating compensation for low-income individuals.[38,39] In contrast, the AD article is less explicit about the fairness of the measure, but mentions the need for restrictions in harmful consumption patterns.[40] Concerning negative and positive effects of a personal carbon budget, the article of De Volkskrant emphasizes the negative effects on privacy of the measure.[41] Additionally, it conveys the message that life will be less comfortable.[42] Similarly, the AD article mentions that certain luxuries will no longer be feasible.[43] Positive effects of a carbon budget are either mentioned cynically or inferred from the fact that otherwise the climate will change rapidly.[44,45]

3.2.3. Fear appeals

The analysis of fear appeals indicates that the analysed articles predominantly focus on the negative consequences of policy measures rather than invoking fear related to climate change itself. While there are limited mentions of fear appeals, they primarily revolve around the adverse impacts of various policy measures, such as potential price increases for goods or plane tickets and potential harm to low-income groups.

For the meat tax, fear appeals are found in articles of De Volkskrant and AD. These fear appeals revolve around economic concerns, suggesting negative economic consequences for the population.[46,47,48] Regarding the flight cuts at Schiphol, discussions within all three news websites primarily revolve around the negative economic consequences of the flight cuts.[49,50] In the context of the carbon budget, the article of De Volkskrant uses a fear appeal related to ethics and privacy, while the AD article highlights the fear of the negative consequences for the climate.[51,52]

3.2.4. Response efficacy

The analysed articles primarily focus on the negative consequences of policies rather than climate change itself. Therefore, we will discuss whether the articles provide potential solutions to mitigate these negative consequences of the policies so that the policies can still be implemented and solve the problem of climate change, indicating high response efficacy.

3.2.4.1. Meat tax

No fear appeals are used in the analysed NOS articles. AD articles mainly present the meat tax as bad idea, indicating low response efficacy.[53] In contrast, De Volkskrant articles are positive about the meat tax and suggest that the rising meat prices will be compensated by a lower VAT on vegetables and fruits, indicating high response efficacy.[54]

3.2.4.2. Flight cuts Schiphol

All three news websites imply an inevitability of the flight cuts at Schiphol. On the one hand, fear is aroused by emphasizing the economic consequences of the flight cuts; on the other hand, there is also a clear message that the flight cuts are unavoidable.[55,56,57] The response efficacy to mitigate the mentioned disadvantages of the flight cuts at Schiphol is thus low.

3.2.4.3. Carbon budget

The article of De Volkskrant on the carbon budget describes various objections to this measure, including the ineffectiveness of it and the negative consequences for privacy. However, an alternative solution is offered: taxing environmental damage.[58] Although it is not explained why and how this resolves privacy concerns, a solution is provided which increases response efficacy. According to the AD article, the carbon budget is the best solution to prevent *"[...] the climate from rapidly going down the drain."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022), resulting in high response efficacy, even if the measure is not presented as particularly pleasant.[59]

3.2.5. Hope appeals

The analysis reveals minimal use of hope appeals in the articles. In a NOS article about the flight cuts at Schiphol, a bit of hope is provided by a quote from the minister: *"'We are ending the tolerance. Schiphol must operate within the rules,' the minister stated. 'We will prioritize addressing noise pollution for the residents.'"*("Harbers: krimp Schiphol is 'onvermijdelijke stap', einde aan gedogen overlast" NOS, 24 June 2022). In an article of De Volkskrant about the flight cuts at Schiphol, hope is embedded in the idea that there is still time for the Dutch to address the nitrogen crisis comprehensively.[60]

3.2.6. Climate delaying and accelerating arguments

The presence of arguments that either delaying or accelerating climate action was quantitatively examined. Delaying arguments are based on Lamb et al. (2020), while accelerating arguments are the inverse of delaying arguments, such as "the policy promotes greater justice" (inverse appeal to social justice) or "technology will not solve it for us" (inverse technological optimism). In total, 18 delaying argument and 20 accelerating argument are mentioned. Please see Appendix B for a detailed overview per delaying and accelerating argument.

The delaying argument that is mentioned most often is about the injustice of policy (n = 8), namely that people with lower incomes will be affected by the various measures.[61,62] Arguments that our well-being declines and that policy must be perfect are mentioned 6 times respectively. The appeal to well-being is often linked to economic interests.[63,64] The argument that policy must be perfect is mostly given by emphasizing the need of further research to find good solutions.[65,66]

The two accelerating arguments mentioned most frequently are that the policy measure can increase well-being (n = 7) and that individuals do not have to do it alone (n = 7). The well-being argument relates to reducing noise for residents near Schiphol Airport.[67] Regarding the argument that individuals do not have to do it alone, the articles mention that there are (also) other parties responsible for solving the problem.[68,69]

4. Discussion

The primary objective of this study was to gain insight into climate narratives in the Netherlands concerning consumption-altering government policies. To achieve this, we examined narratives on three different news websites (NOS, AD and De Volkskrant) related to three different policy events: Minister Henk Staghouwer's proposal to investigate a meat tax, the government's decision to cut flights at Schiphol Airport, and Barbara Baarsma's proposal to introduce a personal carbon budget.

The results of our content analysis reveal a shared starting point in these narratives, emphasizing that “something” must be done to address climate change-related issues or to prevent harm to the environment. However, the narratives lack in providing a clear explanation of why these policies are necessary and how they resolve the issue at hand. Furthermore, the consequences of inaction are not clearly articulated, leaving readers without a full understanding of the potential repercussions if significant changes are not made.

Besides that, the articles explore both the advantages and disadvantages of the selected policies, revealing varying viewpoints among different parties regarding the required actions to combat climate change. Some articles do not provide clear conclusions or solutions, which could be due to journalistic principles aiming to present multiple perspectives. To address this, a constructive journalism approach could be considered, which emphasizes solutions alongside challenges.

The results also show that the narratives often present a dilemma: preserving our economy and prosperity versus saving the climate. The articles tend to focus on the economic threats posed by these policies, including concerns about job losses, increased product prices, and reduced luxuries. This framing suggests that addressing climate change inevitably harms our economic well-being. Whether this choice is accurate and whether addressing climate change will indeed lead to financial and job-related issues is not part of the current research. However, we argue that presenting this dichotomy may not foster support for climate change initiatives.

Moreover, different news websites depict various parties as receivers (victims). For instance, in articles from De Volkskrant about the meat tax, the climate is portrayed as the receiver of benefits, while in articles from the AD and NOS, low-income groups and consumers are also depicted as receivers. These variations in the depiction of receivers and opponents can create confusion regarding who holds responsibility for reducing emissions.

The writing style varies among the three news websites. NOS articles are characterized by a purely factual and objective style, while AD articles adopt a more narrative approach, often incorporating first-person and collective pronouns, as well as emotional expressions. Articles of De Volkskrant make use of both factual and narrative writing styles. These differences suggest that AD articles may be more memorable, comprehensible, and persuasive than NOS articles.

4.1. Limitations and future research

This study has several theoretical and methodological limitations. To address these limitations and enhance the understanding of climate policy narratives, future research should consider the following: (1) Investigate how narratives affect diverse audiences with varying values and worldviews in order to take into account the subjectivity of narratives; (2) analyse the effectiveness of different narrative styles, including framing, using experimental methods to gain more insights into the persuasive power of narratives; (3) explore the long-term effects of different narrative styles, including hope and fear appeals, through longitudinal research; (4) conduct large-scale quantitative research to assess the prevalence of specific narrative elements in climate policy narratives on news websites on a larger scale; and (5) compare climate narratives across various media channels, including print, television, and social media, to understand how different platforms shape public perceptions.

5. Conclusion

The current research uncovers various narrative elements in climate policy discourses related to changes in consumption behaviour. While narratives play a crucial role in shaping public perceptions of climate policy, there is room for improvement in how they are framed. Emphasizing policy effectiveness, highlighting positive aspects, and clarifying roles and responsibilities can contribute to greater public support for climate policies. Further research and experiments are necessary to refine climate policy narratives and enhance their impact on different audiences.

References

Anderson, B., Böhmelt, T., & Ward, H. (2017). Public opinion and environmental policy output: a cross-national analysis of energy policies in Europe. *Environmental Research Letters, 12*(11), 114011.

Armbruster, S. T., Manchanda, R. V., & Vo, N. (2022). When are loss frames more effective in climate change. *Sustainability, 14,* 7411.

Baker, L., & Stein, N. (1978). *The development of prose comprehension skills.* Center for the Study of Reading Technical Report.

Bergquist, M., Nilsson, A., Harring, N., & Jagers, S. C. (2021). Determinants for Accepting Climate Change Mitigation Policies: A Meta-Analysis. *Nature Climate Change, 12*, 235–240.

Bevan, L. D., Colley, T., & Workman, M. (2020). Climate change strategic narratives in the United Kingdom: Emergency, Extinction, Effectiveness. *Energy Research & Social Science, 69,* 101580.

Bigsby, E., & Albarracín, D. (2022). Self- and response efficacy information in fear appeals: A meta-analysis. *Journal of Communication, 72*, 241-263

Böhm, G., Pfister, H.-R., Salway, A., & Fløttum, K. (2019). Remembering and Communicating Climate Change Narratives – The Influence of World Views on Selective Recollection. *Frontiers in psychology, 1026.*

Bruner, J. (1986). *Acts of meaning.* Harvard: Harvard University press.

Bushell, S., Buisson, G. S., Workman, M., & Colley, T. (2017). Strategic narratives in climate change: Towards a unifying narrative to address the action gap on climate change. *Energy Research & Social Science,* 39-49.

Commissariaat voor de Media. (2022). *Mediamonitor 2022.* Retrieved from mediamonitor.nl: https://www.mediamonitor.nl/publicaties/

Chabay, I., Koch, L., Martinez, G., & Scholz, G. (2019). Influence of narratives of vision and identity on collective behaviour change. *Sustainability, 5680.*

Chadwick, A. E. (2014). Toward a theory of persuasive hope: Effects of cognitive appraisals, hope appeals, and hope in the context of climate change. *Health Communication, 30,* 598-611.

Chadwick, A. E. (2015). Bridging the divide between positive and negative: The effectiveness of hope and fear appeals in climate communication. *The Conference on Communication and Environment* (pp. 11-14). Boulder: IECA

Dahlstrom, M. F. (2014). Using narratives and storytelling to communicatescience with nonexpert audiences. *Proceedings of the national academy of sciences,* 13614-13620.

De Kluizenaar, Y., Carabain, C., & Steenbekkers, A. (2020). *Klimaatbeleid en de samenleving. Een korte samenvatting van inzichten uit het sCP-onderzoek op het vlak van duurzame samenleving.* Den Haag: Sociaal en Cultureel.

Dreijerink, L. J., & Klösters, M. W. (2021). *Wat is het maatschappelijk draagvlak voor klimaatbeleid? Onderzoek naar beleidsopties van de studiegroep Invulling klimaatopgave Green Deal.* Petten: TNO

Drews, S., & van den Bergh, J. C. (2016). Public views on economic growth, the environment and prosperity: Results of a questionnaire survey. *Global Environmental Change, 39*, 1-14.

Fløttum, K., & Gjerstad, Ø. (2017). Narratives in climate change discourse. *Wiley Interdisciplinary Reviews: Climate Change,* e429.

Gifford, R. (2011). The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation. *American psychologist, 66*(4), 290.

Gifford, R., Kormos, C., & McIntyre, A. (2011). Behavioral dimensions of climate change: drivers, responses, barriers, and interventions. *Wiley Interdisciplinary Reviews: Climate Change, 2*(6), 801-827.

Graesser, A. C., & Ottati, V. (1995). Some evidence, questions, and challenges. In R. S. Wyer Jr., *Advances in social cognition, Vol. 8. Knowledge and memory: The real story* (pp. 121-132). Hillsdale: Lawrence Erlbaum Associates, Inc.

Grasser, A., Golding, J. A., & Long, D. L. (1991). Narrative representation and comprehension. In R. Barr, M. L. Kamil, P. B. Mosenthal, & P. D. Pearson, *Handbook of Reading Research* (pp. 171-205). Hillsdale: Lawrence Erlbaum Associates, Inc.

Greimas, A. J. (1966). *Structural semantics : an attempt at a method.* Lincoln: University of Nebraska Press.

Hamann, S. (2001). Cognitive and neural mechanisms of emotional memory. *Trends in Cognitive Sciences,* 394-400.

Hoogerwerf, A., Arentsen, M. J., & Klok, P. J. (1993). Om een aanvaardbaar beleid. *Een studie over de maatschappelijke acceptatie van overheidsbeleid.* Universiteit Twente-CBOO.

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

Jones, M. D., & McBeth, M. K. (2010). A Narrative Policy Framework: Clear Enough to be Wrong. *Policy Studies Journal,* 329-353.

Lamb, W. F., Mattioli, G., Levi, S., Roberts, J. T., Capstick, S., Creutzig, F., . . . Steinberger, J. K. (2020). Discourses of climate delay. *Global Sustainability,* 1-5.

LCNK. (2022, juni 22). *Narratief Klimaat en Energie.* Retrieved from Landelijk Communicatie Netwerk Klimaat: https://www.lcnk.nl/nieuws/2246303.aspx

Li, S.-C. S., & Huang, L.-M. S. (2020). Fear appeals, information processing, and behavioral intentions toward climate change. *Asian Journal of Communication,* 242-260.

Ma, Y., Dixon, G., & Hmielowski, J. D. (2019). Psychological reactance from reading basic facts on climate change: The role of prior views and political identification. *Environmental Communication, 13*(1), 71-86.

Mar, R. A., Li, J., Nguyen, A. T., & Ta, C. P. (2021). Memory and comprehension of narrative versus expository texts: A meta-analysis. *Psychonomic Bulletin & Review,* 732-749.

McBeth, M. K., Shanahan, E. A., & Jones, M. D. (2005). The Science of Storytelling: Measuring Policy Beliefs in Greater Yellowstone. *Society & Natural Resources,* 413–29.

Moser, S. C. (2010). Communicating climate change: history, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change,* 31-53.

Moser, S. C., & Dilling, L. (2004). Making Climate HOT. *Environment: Science and Policy for Sustainable Development,* 32-46.

Ney, S. (2006). *Messy Issues, Policy Conflict and the Differentiated Polity: Analysing Contemporary Policy.* Vienna: LOS Center for Bergen: Doctoral Dissertation.

Ney, S., & Thompson, M. (2000). Cultural Discourses in the Global Climate Change Debate. *Society, Behaviour, and Climate Change Mitigation,* 65–92.

NPRES. (2021). *Vertel het grotere verhaal.* Retrieved from Inzichten uit het RES-proces die uitzicht bieden: https://www.res-oneren.nl/4-vertel-het-grote-verhaal

NVDE, V. d. (2021). *Essay: Naar (betere) samenwerking tussen gemeenten, projectontwikkelaars en energiecoöperaties.* NPRES. Retrieved from https://regionale-energiestrategie.nl/Nieuws/2006215.aspx

O'Neill, S., & Nicholson-Cole, S. (2009). “Fear won't do it”: Promoting positive engagement with climate change through visual and iconic representations. *Science Communication, 30,* 355-379.

Pew Research Center. (2018, November 30). Retrieved from https://www.pewresearch.org/global/fact-sheet/informatieblad-opvattingen-over-nieuwsmedia-en-politiek-in-nederland/

Prins, R., Avraamidou, L., & Goedhart, M. (2017). Tell me a Story: the use of narrative as a learning tool for natural selection. *Educational Media International,* 20-33.

Rijksoverheid. (2019). Klimaatakkoord. Accessed Augustus 01, 2023, from https://www.klimaatakkoord.nl/klimaatakkoord

Rijksoverheid. (2021a). Omzien naar elkaar, vooruitkijken naar de toekomst – Coalitieakkoord 2021-2025. Accessed Augustus 01, 2023, from https://www.rijksoverheid.nl/documenten/publicaties/2022/01/10/coalitieakkoord-omzien-naar-elkaar-vooruitkijken-naar-de-toekomst

Rhodes, E., Axsen, J., & Jaccard, M. (2014). Does effective climate policy require well-informed citizen support?. *Global Environmental Change*, *29*, 92-104.

Soutar, I., & Mitchell, C. (2018). Towards pragmatic narratives of societal engagement in the UK energy system. *Energy reserach & social science,* 132-139.

Spiro, R. J., & Taylor, B. M. (1987). *On investigating children's transition from narrative to expository discourse: The multidimensional nature of psychological text classification.*

Stoknes, P. E. (2014). Rethinking climate communications and the "psychological climate paradox". *Energy Research & Social Science, 1,* 161-170.

Stone, D. (2002). *Policy Paradox: The Art of Political Decision Making, Revised Edition*. New York: W. W. Norton.

Tannenbaum, M. B., Hepler, J., Zimmerman, R. S., Saul, L., Jacobs, S., Wilson, K., & Albarracín, D. (2015). Appealing to fear: A meta-analysis of fear appeal effectiveness and theories. *Psychological Bulletin, 141*, 1178-204.

UCL. (2014). *Time for change? Climate change reconsidered*. UCL Policy Commission on Communicating.

van der Leeuw, S. (2020). The role of narratives in human-environmental relations: an essay on elaborating win-win solutions to climate change and sustainability. *Climatic Change,* 509-519.

Verweij, M., & Thompson, M. (2006). *Clumsy Solutions for a Complex World: Governance, Politics, and Plural Perceptions.* Houndmills, U.K.: Palgrave Macmillan.

Witte, K., & Allen, M. (2000). A meta-analysis of fear appeals: Implications for effective public health campaigns. *Health education & behavior, 27*(5), 591-615.

Appendix A

A narrative consists of several elements

Based on narrative literature (McBeth, Shanahan, & Jones, 2005; Ney, 2006; Ney & Thompson, 2000; Stone, 2002; Verweij & Thompson, 2006), Jones and McBeth (2010) developed the so-called Narrative Policy Framework (NPF), which claims that policy narratives consist of one or more of the following elements:

- **Setting**: the space and context in which the story takes place and the (unspoken/implicit) assumptions of the narrative;
- **Characters**: subjects (those who contribute to the solution to the problem), receivers (those who suffer negative consequences from the problem) and opponents (those who cause the problem);
- **Plot or storyline**: a description of the problem and how characters' actions play out over time;
- **Moral**: the message and solution to the problem described.

Similar to Bevan and Colley (2020), we argue that a greater complexity in character analysis is needed. Therefore, instead of simplifying key roles to heroes, victims and villains, we distinguish the following six characters, based on Greimas's Actantal Schema (1966, as cited in Bevan, Colley, & Workman, 2020, p.14):

- **Subject**: wants to achieve the object;
- **Object**: the goal the subject wants to achieve;
- **Helper**: the force that helps the subject achieve the object;
- **Opponent**: hinders the subject from reaching the object;
- **Sender**: helps the subject to reach the object;
- **Receiver**: benefits from the subject reaching the object.

The writing style of a narrative

Narratives are easier to understand than, for example, scientific facts or descriptive texts (Bruner, 1986, as cited in Mar, Li, Nguyen, & Ta, 2021, p.733; Dahlstrom, 2014). Research on the effects of narratives on the learning process has shown that the narrative form enhances memory and comprehension. For example, through questionnaires, classroom observations, and interviews with students and teachers, Prins, Avraamidou, and Goedhart (2017) demonstrated that narratives about the topic of natural selection are easier to understand than factual/ descriptive texts in a textbook. Furthermore, a recent meta-analysis of experiments investigating memory and/or comprehension of narrative and descriptive texts (e.g., essays, textbooks, or manuals) found that narratives are easier to understand and remember than descriptive texts (Mar, Li, Nguyen, & Ta, 2021).

Based on these differences between narratives and descriptive texts, researchers have developed various theories to explain why the narrative form enhances memory and comprehension compared to descriptive texts. In the literature, four theoretical explanations can be found:

1. **Narratives resemble daily experiences**: Narratives mirror our everyday experiences (Bruner, 1986; Grasser, Golding, & Long, 1991, as cited in Mar, Li, Nguyen, & Ta, 2021, p.733). People perceive daily life as a series of causally ordered events centred around personal goals, with encountering and overcoming obstacles to these goals resulting in emotional experiences. This structure aligns with that of narratives. Additionally, the content of narratives can relate to our daily experiences when elements like friendship, interpersonal conflicts, love, and separation from loved ones appear in a narrative.
2. **Narratives have a historical significance**: Narratives have played a prominent role in human history (Grasser, Golding, & Long, 1991; Graesser & Ottati, 1995, as cited in Mar, Li, Nguyen, & Ta, 2021, p.734). Before the ability to write, stories formed the basis of traditions. By retelling stories about traditions, human memory was the only means to preserve traditions.
3. **Early exposure to narratives**: We are exposed to stories from a very young age, often before we can speak or read (Baker & Stein, 1978; Spiro & Taylor, 1987, as cited in Mar, Li, Nguyen, & Ta, 2021, p.734).
4. **Narratives elicit emotions**: Narratives evoke emotions, making it easier for us to remember the stories (Hamann, 2001).

We therefore included the variable writing style in our analysis framework to examine how the article reads: factual or narrative.

Determinants of policy acceptance

Depending on the goal of the narrative, there are a number of content elements that need to be addressed. In this case, we look at narratives surrounding climate policies and argue that these narratives contribute to (the absence of) policy acceptance. Based on earlier research, we know that support is determined by the following factors (Dreijerink & Klösters, 2021):

- **Perceived fairness**: The extent to which policy is perceived as fair influences the level of support for it. The fairer the policy is perceived, the greater the support.
- **Perceived effectiveness**: When people believe that policy is effective in achieving its intended goals (i.e., contributing to climate change mitigation), there is more support for it.
- **Perceived effects on one's own life**: Support is higher when individuals expect that the policy will have a positive impact on their own lives.

Perceived fairness has been shown to have the most significant impact on policy acceptance (Bergquist, Nilsson, Harring, & Jagers, 2021; Dreijerink & Klösters, 2021). This primarily pertains to the fairness of distributing the benefits and burdens of specific policies. For example, if local residents are entitled to a share of the financial proceeds from wind turbines, this is known as distributive justice (Straver et al., 2017). Distributive justice not only concerns the distribution among groups of citizens, but also between citizens and the industry (De Kluizenaar, Carabain, & Steenbekkers, 2020). Additionally, trust in the policymakers, such as governments, is important (Bergquist, Nilsson, Harring, & Jagers, 2021). Furthermore, the more concrete a policy measure is, the clearer people understand its consequences for their own lives. The more positive the consequences, the greater the policy acceptance (Dreijerink & Klösters, 2021).

We therefore included the variables perceived fairness, perceived effectiveness and perceived effects in our analysis framework to examine whether a narrative aims to generate support of climate policies.

Urgency and fear

Balancing climate change narratives is challenging, as they must inspire urgency without overwhelming audiences with doom and gloom. Research suggests that solely sowing fear about climate change can backfire, leading to disengagement and hopelessness (Bushell et al., 2017; Moser & Dilling, 2004; O'Neill & Nicholson-Cole, 2009). In health research, fear appeals appear to promote behaviour change when coupled with clear, feasible action plans that boost self-efficacy (belief in one's ability to act) and response efficacy (belief in the behaviour's effectiveness; Witte & Allen, 2000). Recent meta-analyses highlight the significance of emphasizing response efficacy (Bigsby & Albarracín, 2022) and reveal that fear appeals can work when efficacy statements are included, problem severity is described, and one-time behaviours are recommended (Tannenbaum et al., 2015). The results of Li and Huang's (2020) study in climate communication align with these findings, indicating that high fear appeals, coupled with high efficacy (self and response), can lead to intentions for climate action. Furthermore, a loss-frame combined with self-efficacy and response efficacy generates support for policy and willingness-to-pay. The combination of fear with hope and confidence, leads to deeper message processing (Armbruster et al., 2022).

Since this study focuses on policy measures we do not include self-efficacy in our analysis framework. We rather focus at the presence of fear appeals and the degree of confidence created in the solution to the problem (response efficacy).

Hope

Unlike fear appeals, hope appeals aim to inspire feelings of hope. This is a future-oriented emotion that individuals experience when a future outcome aligns with their goals, is probable but not certain, is considered important, and is expected to lead to a better future (Chadwick, 2014). This concept is similar to offering actionable solutions (self-efficacy) and increasing confidence in problem-solving (response efficacy). Research by Chadwick (2015) on the persuasive effects of hope appeals in climate communication indicates that hope appeals lead to a greater intention to discuss climate change and its mitigation with others. In her study, hope appeals were presented to participating students through a text that linked climate protection to health and financial goals, aligning with the students' aspirations. The text described how a better future could be achieved by protecting the climate, emphasizing the likelihood of success, and showcasing global climate action.

In our analysis framework, we chose to include hope appeal as outlining a positive future.

Climate delay arguments

Lamb et al. (2020) compiled a list of arguments known as “climate delay arguments.” These are arguments commonly found in climate narratives and revolve around contemporary debates on what actions should be taken, how quickly, who is responsible, and how costs and benefits should be distributed.

Lamb et al. (2020) defined 12 climate delay arguments grouped into four themes:

1. **Surrender**: Assuming that it is not possible to mitigate climate change.
    a. *Doomism*: “All mitigation measures we take are insufficient and too late. Catastrophic climate change is already inevitable. We must adapt or leave our fate in the hands of God or nature.”
    b. *Change is impossible*: “Any measure to effectively reduce emissions would contradict the current way of life or human nature and is thus impossible to implement in a democratic society.”
2. **Emphasize the downsides**: Emphasizing the disadvantages of climate policy.
    a. *Appeal to social justice*: “Climate measures will incur high costs. Vulnerable members of our society will suffer, and hardworking people cannot enjoy their vacations.”
    b. *Appeal to well-being*: “Fossil fuels are necessary for development. If we abandon them, we condemn the world's poor to hardships and deprive them of their right to modern livelihoods.”
    c. *Policy perfectionism*: “We should only pursue perfectly worked-out solutions supported by all parties involved; otherwise, we waste limited opportunities for approval.”
3. **Push non-transformative solutions**: Assuming that disruptive change is unnecessary.
    a. *No stick, just carrots*: “Society will only respond to supportive and voluntary policies; restrictive measures will fail and should be abandoned.”

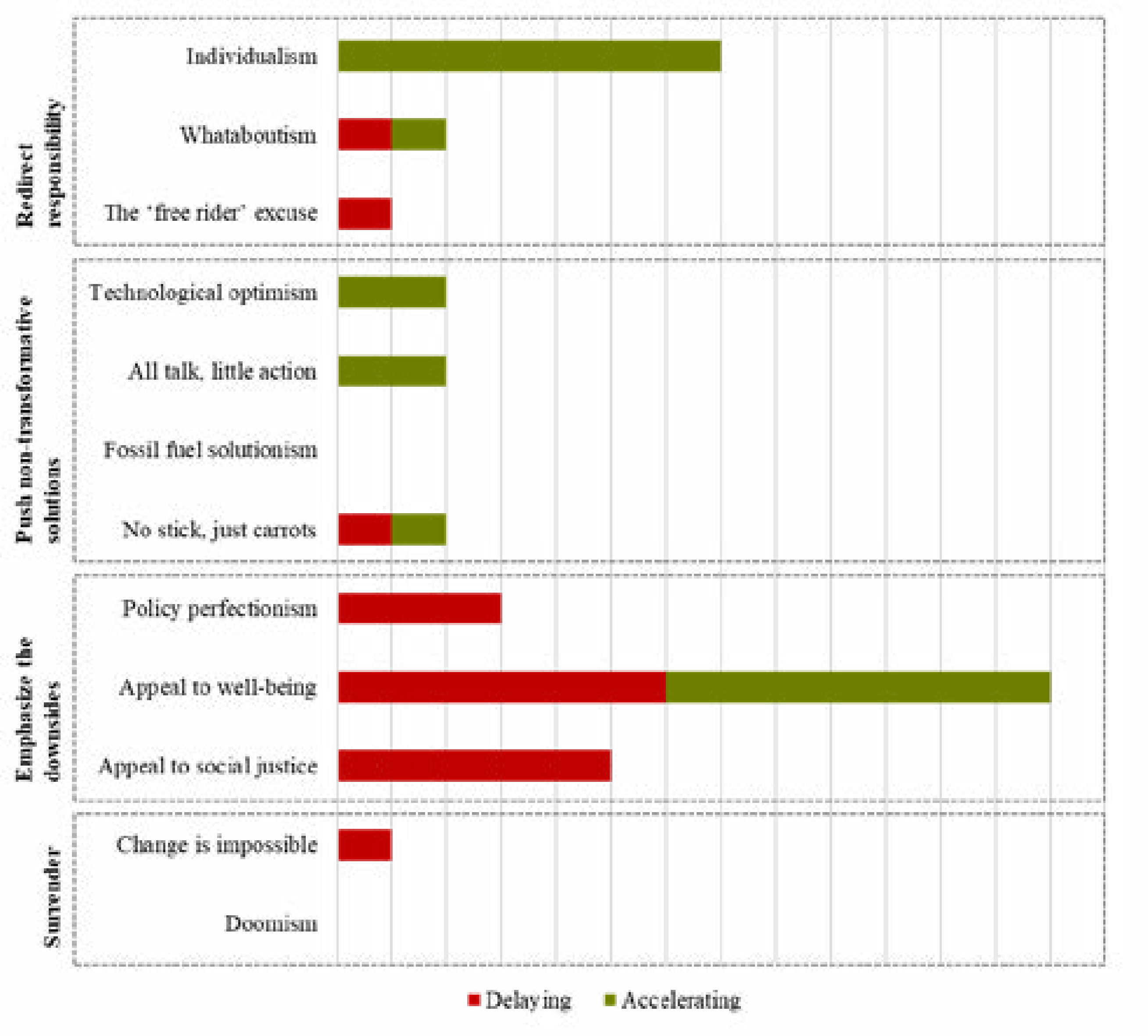
b. *Fossil fuel solutionism*: “Our fuels are becoming more efficient and serve as a bridge to a low-carbon future.”
c. *All talk, little action*: “We are world leaders in addressing climate change. We have adopted ambitious goals and declared a climate emergency.”
d. *Technological optimism*: “We should focus our efforts on current and future technologies, which will unlock significant potential for addressing climate change.”

4. **Redirect responsibility:** Arguing that someone else should take action first.
   a. *The ‘free rider’ excuse*: “Reducing emissions will weaken us. Others don't really intend to reduce their emissions and will take advantage of that.”
   b. *Whataboutism*: “Our CO2 footprint is trivial compared to [...]. Therefore, it makes no sense for us to take action, at least until [...does].”
   c. *Individualism*: “Individuals and consumers are ultimately responsible for taking measures to address climate change.”

Since these climate delay arguments impede urgent climate action or support for climate policies, an effective climate narrative ideally avoids these arguments. We therefore included these arguments in our analysis framework to check whether they appear in the analysed articles. We also check whether the inverse of the argument occurs, as an “accelerating” argument.

Appendix B

Figure 1. Number of delaying and accelerating arguments in the 25 analysed articles in NOS, AD and De Volkskrant.



[1] *“The higher price, which indeed has support, is based on including all the real costs of meat production in the price the consumer pays. Because a fair farmer's wage, reducing animal suffering, and the impact of meat consumption on climate, the environment, and biodiversity loss are currently not factored into the price, but they should be.”* (“Opinie: Belasting op vlees is hoognodig om biodiversiteit op aarde te redden” Volkskrant, 3 April 2022).

[2] *“Staghouwer writes to the Dutch Parliament that he wants to encourage people to eat less meat without restricting their freedom. If the government does not want a chicken fillet or ribeye to become a luxury item, such a levy cannot be too high. Consequently, it is inherently ineffective and only impacts the poorest. This is unfair and especially undesirable in a time when consumers are already dealing with rising prices. The government would be better off making healthy meat alternatives more affordable.”* (“Vleestaks helpt het milieu amper maar dupeert wel de armsten” AD, 30 March 2022).

[3] *“According to JA21 MP Eppink, we are 'heading towards a culinary dictatorship.' He believes that the government should not determine what someone can or cannot eat. Like many other opponents in the opposition, he thinks that the meatball should remain affordable for the average person. [...] D66 MP De Groot thinks it's a good idea to conduct research. 'Eating less meat saves the climate and nature.' He receives support from GroenLinks and the Party for the Animals.”* (“Ruime Kamermeerderheid tegen vleestaks, coalitie verdeeld” NOS, 30 March 2022).

[4] *“The government would like to reduce the maximum number of flights at the airport, currently half a million, by 10 percent. But the consequences could be much greater than the 50,000 flights currently under consideration, says aviation economist Rogier Lieshout, who has conducted multiple studies on the effects of downsizing for Schiphol and KLM, the largest user of the airport. [...] Studies on the economic importance of Schiphol show that the airport, depending on the definitions, generates 60,000 to 90,000 jobs and adds 4 to 8 billion euros in economic value. Indirectly (due to suppliers or companies establishing themselves here based on a major airport), at least 50,000 jobs and 3 billion euros in added value are attributed to that transfer network. According to SEO research agency, the loss of that hub function results in an annual welfare loss of over 600 million euros.”* (“Vluchten schrappen? Sommige bestemmingen zullen verdwijnen en tickets worden duurder” AD, 17 June 2022).

[5] *“The airport emits not only too much nitrogen but also too many particulates and noise pollution. The nuisance to local residents is said to be the main reason the airport must significantly reduce the number of flight movements. [...] Not only noise pollution plays a role. At the end of 2021, it leaked that the previous government was very concerned about the results of the nitrogen calculations around Schiphol. According to confidential legal advice to the government, the airport does not qualify for the necessary nature permit without radical measures. Such a permit has not been available since 2019, making Schiphol, in essence, operate illegally.”* (“Kabinet snijdt in Schiphol: luchthaven moet 10 procent krimpen, overlast voor omwonenden belangrijkste reden” Volkskrant, 16 June 2022).

[6] *“For years, you've been furious with the audacious Schiphol, thinking it could do whatever it pleased, lying and deceiving, knowing that there was always a Hague lobby protecting the airport.”* (“Een schokkend, ongelooflijk plan: Schiphol gaat krimpen, met zeker 10 procent”, Volkskrant, 16 June 2022).

[7] *“And suddenly they're gone, Schiphol's growth ambitions. Disappeared into thin air. The government wants to reduce the number of flight movements to 450, maybe even 420 thousand. A miracle! [...] Perhaps there's*

something else, and he [Minister Harbers] has an alternative plan in mind, involving Lelystad, Rotterdam/The Hague, or Maastricht. Schiphol, downsizing, and nothing else, I can't quite believe it." ("Een schokkend, ongelooflijk plan: Schiphol gaat krimpen, met zeker 10 procent" Volkskrant, 16 June 2022).

[8] *"This represents a significant political trend shift. In recent decades, despite hesitations in The Hague, Schiphol usually received permission to continue growing. The previous minister, Harbers' party colleague Cora van Nieuwenhuizen, agreed in 2019 to a ceiling of 540 thousand flight movements in the coming years."* ("Kabinet snijdt in Schiphol: luchthaven moet 10 procent krimpen, overlast voor omwonenden belangrijkste reden" Volkskrant, 16 June 2022).

[9] *"There is no escaping a structural reduction in the number of flights from Schiphol. The government is working on drastic measures because the airport does not meet the requirements for noise pollution, nitrogen, and particulate matter."* ("Ook op langere termijn fors minder vluchten vanaf Schiphol, vanwege milieueisen" NOS, 16 June 2022).

[10] *"Employers' organization VNO-NCW also says that emissions need to come down faster and noise pollution needs to be reduced more quickly. 'But we are really shocked by the decision to shrink Schiphol,' says chairperson Ingrid Thijssen. Thijssen is concerned about Schiphol's global network of direct flights. 'This is where you're taking the axe. It's one of the few things that still make the Netherlands attractive for entrepreneurs, to stay here, to become more sustainable here, or to come here.'"* ("Krimp Schiphol: 'Historisch maar nog niet genoeg'." NOS, 24 June 2022).

[11] *"So we are doing pretty much the wrong way in this country, [...]."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[12] *"It is a given that we have to make sacrifices."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[13] *"This is fundamentally unfair and, moreover, ineffective. One percent of the world is responsible for over half of aviation emissions. We should limit these frequent flyers instead of facilitating them."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[14] *"In that sense, I am in favor of Barbara Baarsma's idea, the chief economist of Rabobank. She suggested today once again that it is high time for everyone to have a personal CO2 budget."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[15] *"How we will fairly distribute the burdens of climate policy will be the question of our time. It is a given that we have to make sacrifices. Who will bear the brunt will be the subject of significant contention. On the global stage but also nationally. [...] To limit the most frequent flyers, you can introduce a surcharge on plane tickets that increases as you fly more often - an idea from Milieudefensie. At the same time, the government, as often promised, could finally tax wealth more heavily. With the proceeds, labor taxes could be reduced (an immediate incentive to work more - I'm looking at you, labor shortage), which would slightly alleviate the higher prices, which lower-income groups are particularly affected by."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[16] *"To achieve sustainability in the food chain, he wants to 'explore a broad mix of instruments.' 'First, we'll gather all the information; only then will we draw conclusions,' he said. The research will also examine the*

socioeconomic effects of a meat tax on people with low incomes." ("Ruime Kamermeerderheid tegen vleestaks, coalitie verdeeld" NOS, 30 March, 2022).

[17] *"The government is investigating whether a tax on meat can encourage people to eat less meat. It is also examining the feasibility of such a levy. It is one of the ideas from the evaluation of the food policy from 2016 to 2020."* ("Kabinet onderzoekt belasting op vlees, consumentmoet minder vlees gaan eten" NOS, 29 March 2022).

[18] *"Get out of here with your meat tax. Don't touch my steak! Stay away from my meatball! For a significant portion of the Dutch population, meat has an emotional value, according to Hans Dagevos, a consumption sociologist at Wageningen University." [...] "Tax on meat: please, bring it on! We can beat around the bush, but it has been proven over and over again: meat is not good for the climate."* ("Voor- en nadelen van de vleestaks: moet straks ook de salami op je pizza worden belast?" AD, 30 March 2022).

[19] "*The minister wants the ratio between the amount of animal and plant-based proteins that the Dutch consume to shift from 60/40 to 50/50 by 2030. Hoste cannot specify how high the tax should be to achieve that."* ("De vleestaks ligt weer op tafel: ministerie gaat gezondheidseffecten onderzoeken" Volkskrant, 30 March 2022).

[20] *"Let's first look at the facts. In 2020, research commissioned by the FAO revealed [...]."[...]"We hope that in the next round of negotiations in June in Nairobi, such texts, which are currently in parentheses, will be embraced by all countries... And thus, to make our piece of meat future-proof by setting a fair and realistic price."* ("Opinie: Belasting op vlees is hoognodig om biodiversiteit op aarde te redden" Volkskrant, 3 April 2022).

[21] "*The introduction of this sustainability contribution could reduce CO2 emissions by 4.2 megatons in 2030, or 2.6 percent of the total Dutch emissions in 2020, according to CE Delft."* ("De vleestaks ligt weer op tafel: ministerie gaat gezondheidseffecten onderzoeken" Volkskrant, 30 March 2022).

[22] *"Little research has been conducted on the effect of a meat tax, admits Liesbeth Velema, an expert on nutrition and behavior at the Nutrition Center. 'So we don't know how well it really helps if we want to reduce meat consumption. However, that's why we believe it's very good that a meat tax is being further investigated.'"[...] "Researchers from Wageningen concluded last year that a 'simple meat tax' - making consumers pay extra and putting that money in the government's treasury - is not very effective. Dutch livestock farmers would likely export the meat that is sold less in the Netherlands, so our environment would not benefit much from it."* ("Voor- en nadelen van de vleestaks: moet straks ook de salami op je pizza worden belast?" AD, 30 March 2022).

[23] *"Especially people with a low income buy the cheapest meat. And it is precisely that meat that is often produced less sustainably. When meat becomes more expensive, the group of people who opt for the cheapest product in the supermarket will only grow."* ("Vleestaks helpt het milieu amper maar dupeert wel de armsten" AD, 30 March 2022).

[24] *"'The idea of a meat tax is not new,' says LTO chairman Van der Tak, 'and the conclusion is well known: the consumer doesn't want it, the producer doesn't believe it, and the government can't do it.' D66 MP De Groot actually thinks it is a good idea to do research. 'Eating less meat saves the climate and nature.'He is supported by GreenLeft and the Party for the Animals."* ("Ruime Kamermeerderheid tegen vleestaks, coalitie verdeeld" NOS, 30 March, 2022).

[25] *"[...] the socioeconomic effects of a meat tax on people with low incomes."* ("Ruime Kamermeerderheid tegen vleestaks, coalitie verdeeld" NOS, 30 March, 2022).

[26] *"Meat tax barely helps the environment but harms the poorest."* ("Vleestaks helpt het milieu amper maar dupeert wel de armsten" AD, 30 March 2022).

[27] "*Staghouwer wants to help lower-income groups by abolishing VAT on vegetables and fruit."*("De vleestaks ligt weer op tafel: ministerie gaat gezondheidseffecten onderzoeken" De Volkskrant, 30 March 2022).

[28] *"The higher price, which does have support, is based on including all the real costs of meat production in the price the consumer pays. Because a fair farmer's wage, reducing animal suffering, and the impact of meat consumption on climate, the environment, and biodiversity are currently not included in the price but should be."* ("Opinie: Belasting op vlees is hoognodig om biodiversiteit op aarde te redden" Volkskrant, 3 April 2022).

[29] *"In addition to reducing meat consumption, the Schijf van Vijf remains important for the government. 'If more people eat according to the Schijf van Vijf, which includes a good balance between the consumption of animal and plant-based proteins, it contributes to both sustainability and health,' writes Minister Staghouwer to the Second Chamber."* ("Kabinet onderzoekt belasting op vlees, consumentmoet minder vlees gaan eten" NOS, 29 March 2022).

[30] *"A government that makes it (financially) more difficult for us to buy a piece of meat, that touches some of us in the heart. The word 'nannying' also quickly comes up. Who is the Minister of Agriculture, in this case, Henk Staghouwer of the Christian Union, to tell us what we should eat?"* ("Voor- en nadelen van de vleestaks: moet straks ook de salami op je pizza worden belast?" AD, 30 March 2022).

[31] *"According to MP Eppink of JA21, we are 'on the way to culinary dictatorship.' He believes that the government should not determine what someone can or cannot eat."* ("Ruime Kamermeerderheid tegen vleestaks, coalitie verdeeld" NOS, 30 March 2022).

[32] *"According to the airline, this will not solve the nitrogen issue in the Netherlands, as aviation is responsible for only 1 percent of nitrogen."* ("Krimp Schiphol: 'Historisch maar nog niet genoeg'." NOS, 24 June 2022).

[33] *"Schiphol is, of course, just a facilitating company for airlines. So you shouldn't look to Schiphol for a reduction in flight movements, but at KLM, Transavia, Ryanair, and all the other airlines."* ("Voor krimp moet je niet bij Schiphol zijn, maar bij KLM en al die andere luchtvaartmaatschappijen" Volkskrant, 17 June 2022).

[34] *"Rob Loekenbach has been fighting against airplane noise for about 15 years; the resident of Leimuiden was also part of the Schiphol Environmental Council. The news of many flights being canceled does not make him rejoice. 'It's too early. Consider just the revision of the airspace that is still coming. The main point is: how does Schiphol distribute flights across all runways? The Polder and Kaag runways have been burdened more for a while, and the residents of the municipality of Kaag and Braassem suffer a lot from that.'"* ("Voorlopig minder vluchten vanaf Schiphol: dit zijn de (positieve) gevolgen voor onze regio." AD, 18 June 2022).

[35] *"But people should still be able to go on vacation, right?"* ("Voorlopig minder vluchten vanaf Schiphol: dit zijn de (positieve) gevolgen voor onze regio." AD, 18 June 2022).

[36] *"Do we want to exclude certain groups of people who can no longer afford a vacation? Taking that away now is a weighty decision."* ("Vluchten schrappen? Sommige bestemmingen zullen verdwijnen en tickets worden duurder" AD, 17 June 2022).

[37] *"That is fundamentally unfair, and moreover, ineffective. One percent of the world is responsible for over half of aviation emissions. We should limit these frequent flyers instead of facilitating them."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[38] *"As the best option, she [Barbara Baarsma] also sees: making companies pay for the damage they cause (instead of subsidizing the fossil industry) [...]."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[39] *"To further limit the most frequent flyers, you could introduce a tax on airline tickets that increases as you fly more often – an idea from Milieudefensie. At the same time, the government, as often promised, could finally tax wealth more heavily. With the proceeds, the tax on labor could be reduced (immediately an incentive to work more – I'm looking at you, labor shortage), thereby slightly mitigating the higher prices, which primarily affect lower incomes."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[40] *"But besides a voice in my head, no one confronts me when I let the delivery person from Bol.com, Wehkamp, or Jumbo come for the eightieth time this year with things I could easily do without. [...] our footprint is still ridiculously large. In that sense, I am in favor of Barbara Baarsma's idea, the chief economist of Rabobank."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[41] *"[...] it seems undesirable in any case for an app that records all consumption to fall into the hands of an institution. I can already imagine the data breach of the century, not to mention possible malicious intentions."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[42] *"It is a given that we have to make sacrifices."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[43] *"Sure, you can still do things, but a new outfit every month, multiple flights a year, and cheap meat every night won't work anymore."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[44] *"A clean, green conscience awaits you, lying on the Playa de la Barceloneta."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[45] *"[…] the climate from rapidly going down the drain."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[46] *"But from the parliamentary debate on Wednesday, it became clear that coalition parties VVD and CDA are not yet convinced by Staghouwer's plan. They do not doubt the effectiveness of the measure; they are mainly afraid of expensive groceries."* ("De vleestaks ligt weer op tafel: ministerie gaat gezondheidseffecten onderzoeken" Volkskrant, 30 March 2022).

[47] *"When meat becomes more expensive, the group of people opting for the cheapest product in the supermarket will only grow."* ("Vleestaks helpt het milieu amper maar dupeert wel de armsten" AD, 30 March 2022).

[48] *"Will salami on your pizza also be taxed?"* ("Voor- en nadelen van de vleestaks: moet straks ook de salami op je pizza worden belast?" AD, 30 March 2022).

[49] *"This undermines KLM and Schiphol's hub function significantly. [...] That is one of the few things that still make the Netherlands attractive for entrepreneurs to stay, to become more sustainable here, or to come here." [...] "Thijssen fears for the global network of direct flights from Schiphol. 'This is where you put the axe in. It's one of the few things that still make the Netherlands attractive for entrepreneurs to stay, to become more sustainable here, or to come here."* ("Krimp Schiphol: 'Historisch maar nog niet genoeg'." NOS, 24 June 2022).

[50] *"The loss of this hub function, according to the SEO research agency, results in an economic loss of over 600 million euros per year."* ("Vluchten schrappen? Sommige bestemmingen zullen verdwijnen en tickets worden duurder" AD, 17 June 2022).

[51] *"No politician in the Netherlands wants to introduce a social credit system, but it seems undesirable in any case for an app that records all consumption to fall into the hands of an institution. I can already imagine the data breach of the century, not to mention possible malicious intentions. No, it's going through blockchain, Baarsma said on Op1. [...] When the word 'blockchain' is mentioned, all alarm bells should go off. [...] We can't even reduce the VAT for fruits and vegetables within a year in the Netherlands, let alone develop an all-encompassing smart carbon wallet without ethical objections."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[52] *"Meanwhile, Earth Overshoot Day falls earlier every year, and the climate is changing at record speed."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[53] *"The government should focus on making healthy meat alternatives cheaper."* ("Vleestaks helpt het milieu amper maar dupeert wel de armsten" AD, 30 March 2022).

[54] *"Staghouwer wants to compensate lower incomes by abolishing VAT on vegetables and fruits."* ("De vleestaks ligt weer op tafel: ministerie gaat gezondheidseffecten onderzoeken" Volkskrant, 30 March 2022).

[55] *"Even if Schiphol remains at its current level or can grow a bit, as the previous government decided, the end is in sight. 'There will soon come a moment when it won't work anymore,' says Heerkens [aviation professor]."* ("Vluchten schrappen? Sommige bestemmingen zullen verdwijnen en tickets worden duurder" AD, 17 June 2022).

[56] *"After years in which governments aimed for growth, Rutte IV now concludes that the airport has become too large and causes too much nuisance in all respects."* ("Kabinet snijdt in Schiphol: luchthaven moet 10 procent krimpen, overlast voor omwonenden belangrijkste reden" Volkskrant, 16 June 2022).

[57] *"According to Chairman Fruitema, the plan was never discussed with the sector and is in conflict with the coalition agreement and the Aviation Memorandum 2020-2050. 'It seems that the government is consciously trying to strangle aviation and turn the Netherlands into Europe's ugly duckling. They are playing with fire.'"* ("Krimp Schiphol: 'Historisch maar nog niet genoeg'." NOS, 24 June 2022).

[58] *"[...] the best solution for this has already been proposed (in 1920 by the British economic Arthur Pigou) and is called taxing environmental damage."* ("De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten" Volkskrant, 5 August 2022).

[59] *"It's childish that it 'has to be' this way, but there is no other option."* ("Droevig dat het moet, maar een CO2-budget voor iedereen is een prima idee" AD, 2 August 2022).

[60] *"That the problem can now only be solved by pulling so many teeth should be attributed to the Prime Minister, and it would be commendable if he generously acknowledges that responsibility. It would immediately make many realize that the problem is not new but is increasingly getting out of hand. The leader of Farmers Defence Force will not be convinced by it. But for the rest of the Netherlands, it is not too late to finally take control and tell the bigger story."* ("Opinie: Wat nou als de maatregelen jegens boeren en Schiphol gezamenlijk waren gecommuniceerd in één overkoepelend plan?" Volkskrant, 21 June 2022).

[61] *"As a result, it is inherently ineffective and only impacts the poorest. That is unfair and undesirable, especially at a time when consumers are already facing price increases."* ("Vleestaks helpt het milieu amper maar dupeert wel de armsten" AD, 30 March 2022).

[62] *"Like many other opponents in the opposition, he believes that the meatball should remain affordable for the average man or woman."* ("Ruime Kamermeerderheid tegen vleestaks, coalitie verdeeld" NOS, 30 March 2022).

[63] *"Reducing the number of flights will also have consequences elsewhere. Studies on the economic importance of Schiphol show that, depending on the definitions, the airport generates 60,000 to 90,000 jobs and 4 to 8 billion euros in added economic value."* ("Vluchten schrappen? Sommige bestemmingen zullen verdwijnen en tickets worden duurder" AD, 17 June 2022).

[64] *"Thijssen [chairman of VNO-NCW] fears for the global network of direct flights from Schiphol. 'That's where you put the axe. It's one of the few things that still make the Netherlands attractive for entrepreneurs, to stay here, to make it sustainable, or to come here.'"*("Krimp Schiphol: 'Historisch maar nog niet genoeg'." NOS, 24 June 2022).

[65] *"Should a relatively sustainable and healthy meat option like chicken be lightly taxed, while a climate-damaging hamburger is heavily taxed? What do we do with slices of salami on pizza? And what about cheese, which is also not exactly produced in a climate-neutral manner?"* ("Voor- en nadelen van de vleestaks: moet straks ook de salami op je pizza worden belast?" AD, 30 March 2022).

[66] *"Harbers does not want to comment publicly on the leaked figures yet. He says he is gathering information and will then come up with a plan."* ("Ook op langere termijn fors minder vluchten vanaf Schiphol, vanwege milieueisen" NOS, 16 June 2022).

[67] *"A contentious issue would now mainly be the noise pollution caused by the airport for local residents. This is recorded in the so-called Airport Traffic Decision. This includes decisions on the noise nuisance that the airport may cause. [...] Residents suffer a lot from the noise." It should be noted that this concerns the well-being of a specific group of people (the residents) rather than the well-being of citizens in general. The times when "well-being in general" was described mainly included (delaying) statements like: "It is certain that we have to make concessions."* ("Schiphol moet fors krimpen van kabinet: 50.000 vluchten minder" AD, 16 June 2022).

[68] *"The government already knew then that 'aviation too must contribute to reducing CO2 emissions.'"*
("Schiphol moet fors krimpen van kabinet: 50.000 vluchten minder" AD, 16 June 2022).

[69] *“Companies should pay for the damage they cause (instead of subsidizing the fossil industry) and pass the cost on to consumers.”* (“De rechtvaardigste klimaatmaatregel is al bedacht in 1920: milieuschade belasten” Volkskrant, 5 August 2022).

EXPLORING ORGANIZATIONAL MODELS AND FINANCIAL STRUCTURES FOR THE ESTABLISHMENT OF HEAT COOPERATIVES: RECOMMENDATIONS AND INSIGHTS FROM GERMANY.

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Abstract

In Germany, residential areas are seeking sustainable alternatives to traditional energy generation to meet climate targets. Energy cooperatives have gained prominence, especially in urban areas where expanding district heating networks offer eco-friendly and cost-effective solutions. Heat cooperatives, while smaller in number, are becoming more appealing due to recent changes in legal frameworks like the Renewable Energy Sources Act (EEG) and the Building Energy Act (GEG). These cooperatives generate heat through methods like block heat and power plants, biomass facilities, solar thermal systems, or external providers. Regional focus in bioenergy villages enhances local autonomy and fosters long-term fossil-free energy in rural regions. This study conducts a system goods analysis of German heat cooperatives, starting with the legal and operational context. It explores existing models and actors, emphasizing organizational and financial structures through expert interviews. Key findings reveal that social and cultural engagement, especially during inception, is vital for success. Financially, subsidies, local bank support, and incentives to replace outdated heating systems have eased cooperative establishment. Challenges include navigating bureaucratic financing hurdles and addressing geographical constraints impacting construction and costs. Demographic changes and finding successors may also affect cooperative sustainability. Despite commonalities, individual circumstances significantly influence cooperative success. Future research should focus on sustained political incentives.

1. INTRODUCTION

The decarbonization of the heating sector has become a central topic in German energy policy, especially since the draft revision of the Building Energy Act from 2024 and the obligation for municipal heat planning was published. In Germany, heating, cooling, and hot water supply for buildings are responsible for approximately 18 percent of emissions. This roughly corresponds to one-fifth of total emissions (BDEW, 2021). Accordingly, both centralized and decentralized thermal energy producers shall aim to convert and substitute their fossil energy sources with renewables.

In large cities and densely populated urban areas, the expansion of district heating networks presents an ecologically and economically sensible solution for the heating transition. While, the establishment of local heating networks and decentralized systems holds still significant potential in rural regions. Unlike electricity and gas grids, more energy is lost during the transportation of heat in form of water. Thus, heat networks with shorter transport distances are more efficient (BMWK, 2022). Especially in rural areas of Germany, more solutions must be found to replace conventional energy generation systems and thereby achieve climate protection goals and establish their municipal heat plans. Decentralized energy systems have a high potential here, as they can be more effectively implemented in municipalities and communities. One possible option is the formation of energy cooperatives which are already today carriers of the energy transition in rural areas and communities (Klemisch, 2014).

Heat cooperatives provide a financially participatory form that is communal and cost-effective at the same time. In recent years, the number of energy cooperatives has increased (Drewing, 2020). While there has been a comprehensive examination and evaluation on electricity cooperatives in the academic literature (Bauwens, 2016; Ruggiero et al., 2019; Yildiz et al., 2015), literature on heat cooperatives remains limited. Some studies adopt a descriptive approach and give a broad overview focusing on their potential and investigations (Drewing, 2020; Pfister et al., 2015). Others explore business models for district heating (Lygnerud, 2018; Moser & Jauschnik, 2023). However, there is a general scarcity of scientific literature on the more detailed development of their financing and organizational structures.

Therefore, this study examines the financial and organizational models of heat cooperatives within the context of the System Good analysis (Beckers, Gizzi, and Jäkel 2012; Wealer and von Hirschhausen, 2020). Initially, the research approach and the methodology are explained. Subsequently, a theoretical background is provided regarding a definition of cooperatives, their requirements and the current state in Germany. Based on the evaluation of interviews with the boards of directors of five heat cooperatives in Germany, an organizational model for the development of a local heating network is derived. It includes the technical prerequisites to the phases of development and financing. Then, this model is discussed and drivers and barriers for heat cooperatives of a local heating network are identified. Last but not least, we place special emphasis on understanding people's active roles in energy transition processes, exploring what motivates them to join energy cooperatives and how social learning plays a role in driving behavioral changes. The investigation concludes with a final summary and a prospective outlook.

2. RESEARCH APPROACH AND METHODOLOGY

2.1. Organizational Model Framework

The paper examines heat cooperatives as provider of local heating and heat networks in the context of achieving decarbonization of the heat sector and decentralized heat management. In general, the provision of infrastructure can be viewed and discussed from different angles, leading to fundamental institutional economic debates about effectiveness and implementation. The analysis of a ‘System Good’ by Beckers et al. is applied to evaluate the role of local heat networks provided by heat cooperatives as an infrastructure asset (Beckers et al., 2012). The theoretical basis of this analysis comes from infrastructure policy research by Beckers et al. (2012), who refers to such an infrastructure good as a System Good. Wealer (2020) has further developed this approach and defines a System Good as a complex good or service that requires coordination between different actors in the supply chain. Rooted in New Institutional Economics (NIE), the framework aims to emphasize the importance of institutions, their design, and their impact on economic progress, i.e., following North's Concept (North, 1990). The concept of NIE extends neoclassical economic theories by including factors such as time, individual or emotional behavior, and transaction costs. Economic and technological progress is determined by the development of institutions and their organic emergence (Hirschmann, 1958; North, 1991). A 'system good analysis' includes the following key elements: the technological system, roles, tasks, actors and institutions as the main elements, all (possible) components and their interconnections. The technological system defines the concrete properties of the goods associated with the roles that the actors must take. Actors with their individual goals, characteristics, and resources can take different as well as similar roles in a substitution relationship (Beckers et al., 2012). Each role has a defined set of tasks associated with specific decisions. Relationships between roles can be created to bridge different types of roles. This requires coordination between these actors and their decisions in so-called coordination areas. Identifying such coordination needs is a key objective of this framework, highlighting the contribution and impact of institutions.

To create the organizational model for heat cooperatives, the following steps are needed. First, the system good is described in terms of its key characteristics and technical aspects. Then, the various tasks, roles, and relationships are described. From this, the coordination areas can be identified. As the analytical result, the organizational model is elaborated and the different actors in the different temporal phases are identified (Beckers et al., 2012). Additionally, a financing model is elaborated. The heat cooperative, as the system good, takes on a central role and is responsible for the entire process of infrastructure development and local heating provision.

2.2. Methodology

In our analysis, a combination of primary and secondary sources was employed. Chapters two and three primarily relied on literature to establish a theoretical and scientific underpinning definition of the research approach and cooperatives. Chapters four, five, and six mainly drew from primary sources. Additionally, the identification of heat cooperative stakeholders was influenced by both primary and secondary sources.

As primary sources, expert interviews were conducted with the board members of five heat cooperatives in Germany. These interviews were organized via online video calls. The structured interview guide, following a semi-standardized approach as defined by Gläser and Laudel (2010). The analysis was conducted qualitatively and categorically (Gläser & Laudel, 2010). The selection of heat cooperatives was based on their construction status and the availability of public information. The collection of data varies from cooperatives in the planning, existing and operational stages, as well as from failed projects. On this basis, an organizational model for heat cooperatives was constructed. In addition, obstacles and success factors in various areas of cooperative operation were identified and discussed on the basis of different characteristics.

3. THEORETICAL BACKGROUND

3.1. Concept and Definition of Heat Cooperative

Due to different regulatory levels and socioeconomic literature, different definitions of energy cooperatives exist: Yildiz et al. (2015) determines that cooperatives are a type of social and economic enterprise that enables citizens to collectively own and manage renewable energy projects by following a joint economic purpose (Yildiz et al., 2015). Furthermore, beyond the core objective of mutual assistance, cooperatives represent further attributes, which include "self-help, self-accountability, self-administration, democratic governance, and the confluence of proprietorship and utility among their stakeholders" (Drewing, 2020, p.1). Moreover, these entities create value within their geographic locale welfare contribution and their role in fostering improvement and optimization at the regional, communal, or local levels (Drewing, 2020). A cooperative works according to the identity principle. It is thus a customer and an operator at the same time, a prosumer. It distinguish itself from a traditional company or corporation and strive for deprivatization (Klemisch, 2014).Any cooperative whose purpose is to provide energy is referred to as an energy cooperative, which has existed since the 20th century (Drewing, 2020). Klemisch (2014) describes energy cooperatives as "decentralized, independent of corporations, and ecological" (Klemisch, 2014, p.22).

3.2. Requirements of a Heat Cooperative

Fundamental Requirements	**Characteristic**
Structure	Supervisory board, board of directors
Heat Source	Regional focus, local heat network, Sources: combined heat and power plants, biomass installations, biogas resources, or solar thermal systems, or it can be provided by an external entity (e.g., industrial waste heat
Community	Trust-building, encourage to join cooperative, correlation between higher level of education and engagement in community, democratic
Benefits	Environmental: long-term fossil free energy supply, new outdated heating sources; financial: low prices, long tariffs; strengthen the sense of self-determination; local value creation
Participation	Information, Discussion, Inclusion of citizens

Table 1: Fundamental Requirements

German Law	
German *Erneuerbare Energie Gesetz, EEG, 2023* *(*Renewable Energy Act)	Min. two individuals, a supervisory board, and an unspecified number of members, with an energy cooperative requiring "at least 50 natural persons as voting members or voting shareholders" 75 percent of voting rights held by natural persons and located within a radius of 50 km from the generation facility Max. 25 percent of the voting rights applies to small and medium-sized enterprises (SMEs)
Genossenschaftsgesetz, GenG, 2022 (cooperative law)	"societies comprising an indefinite number of members, with the primary objective of advancing the economic interests of their constituents or fostering their social and cultural concerns through collaborative commercial undertakings" Own bylaws are defined in the Cooperative Act
European Law	
Renewable Energy Directive (EU) 2018/2001/ Internal Electricity Market Directive (EU) 2019/944	cooperatives as a possibility for citizens to contribute jointly to energy systems. Moreover, they do not determine a specific legal foundation
(European Commission et al., 2020)	profit distribution is constrained, and any excess funds are reinvested to benefit the members and/or the community; based on democratic governance, meaning decisions are made according to the principle of "one member - one vote"

Table 2: Juristic Requirements

3.3. Status quo of Heat Cooperatives in Germany

The prevalence of heat cooperatives in Germany is on the rise. As of 2022, the Federal Office for Energy Cooperatives within the German Cooperative and Raiffeisen Confederation (DGRV) had documented the establishment of 202 energy cooperatives actively managing local heating networks. The majority of these cooperatives were established between the years 2009 and 2015 (Kajimura, 2023). Approximately 60 percent of these heat cooperatives in Germany rely on biogas plants as their primary heat source, while around 30 percent utilize woodchip plants, and eight percent utilize natural gas combined heat and power (CHP) systems. Some of the cooperatives supply their members with previously unused waste heat, for example from industrial companies or from combined heat and power plants that produce electricity from biogas. Others for example operate a woodchip heating system or a solar thermal system (Kajimura, 2023; Pfister et al., 2015).The findings of the DGRV's most recent annual survey offer a more comprehensive understanding of the composition of existing heat cooperatives. In this survey, 115 energy cooperatives were interviewed, of which 35 are engaged in the operation of heating networks. Among these, 28 cooperatives manage a single heat network, two manage two heat networks, and one manages three heat networks. In total, these 31 heating networks serve 2,636 users, with the number of connections per network ranging from a minimum of 3 to a maximum of 360. The 31 heat networks have a combined length of 138.534 km, although two of the 31 did not specify network length. The shortest network is 0.07 km, the longest 24 km (DGRV, 2023). Regarding the production 27 cooperatives maintain one or more heat production facilities, while 8 have no independent heat production capacity. Consequently, four cooperatives do not operate a heat network but solely manage a heat generation plant (DGRV, 2023).

3.4. Behavior Change Dynamics in Energy Transition

As mentioned previously, the potential membership of a cooperative needs to be collected first. In the sense of "self-help" heat cooperatives also demonstrate the willingness of citizens to participate in and take control of the energy transition within their community (Flieger, 2011). Some individuals see the benefits of a cooperation directly, others still need to be convinced that people's behavior can be effective. It is to be considered that the traditional idea of a 'rational consumer' does not fully explain how people make decisions. Instead, people often take shortcuts and are influenced by others, which can make it hard to adopt sustainable habits, even if they save money. There are a number of theories that connect people's involvement in cooperatives with their environmental actions, like practice theory and social learning. Practice theory says for example that what we do every day affects our choices. It also says that changes in how we do things come from many factors, not just one. Being part of a group, like a cooperative, can change how we think and act, making us eco-friendlier even outside of the group. Additionally, experiencing that your locals are participating in a well-working cooperative can make you leave your defensive position on self-determinative energy transition. Thus, especially your direct environment can make you rethink and change your behavior. (Kahneman 2011, Shove 2010).

4. RESULTS: AN ORGANIZATIONAL MODEL FOR A HEAT COOPERATIVE

An organizational model for setting up a heating network and providing local heating will be developed by evaluating the coordination areas and the actors in their phases. It is based on the case studies and expert interviews. An overview of the case studies can be found in the appendix.

4.1. Production

In order for the heat cooperative to be able to supply its members with local heating, it must build up the appropriate infrastructure. Based on the interviews conducted, it is evident that the same technical components were needed in all case studies. The types and capacities of the infrastructural components differ according to regional conditions and needs.The first factor to be determined is the heat source. In three of the five case studies, waste heat from a local biogas plant is used (Nahwärme Burggrumbach eG, Energiegenossenschaft Steinburg eG). In two cases, woodchip-fired boilers were acquired (Nahwärme Amerbach eG) or are planned to be purchased (Nahwärme Wettelsheim-Bubenheim eG). In another case, waste heat from a cogeneration plant (CHP) is used (Wärme-Strom-Gemeinschaft eG). This means that in three out of five cases an existing source could be used for heat generation.

The connection between the heat source and the consumers is designed by a pipeline system. Hot water runs as the transfer medium from the heat generator to the consumers and from the consumers the cold water runs back to the generator. The supply temperature is between 70 and 85 degrees Celsius. It is important to know that a larger heating network can lead to more heat loss during delivery and insulation plays an important role in this regard as well. Each consumer is connected to the heating network via its own heat transfer station. Usually, this heats the heating water of the building via a heating exchanger. Heat accumulators and buffer tanks store the generated heat for hours up to months, depending on the type. On the one hand, this allows excess heat to be stored when customers do not need it, and on the other, heat storage units can be used to cover possible peak demand and absorb daily fluctuations. In addition, peak load systems can serve as backup for outages and for peak loads in winter. These are often operated with fossil fuels, e.g. gas boilers (Nahwärme Burggrumbach eG).

4.2. Provision

As described in Beckers et al. (2012), certain phases must be passed through to provide a system good. This approach has been adapted to the construction of a local heating network by a heat cooperative. The heat cooperative must proceed through various project phases to build up the heating network and supply local heating. Five phases can be identified from the interviews. Figure 1 shows the different phases and the tasks in each phase. These phases can overlap and vary in duration depending on the requirements and procurement of the individual cooperative. In most cases, the tasks printed in bold can be performed by the cooperative itself; the other tasks should be handed over to external companies. However, some tasks in bold can be outsourced to lighten the cooperative's workload. It is essential to note that during the provision phase, the board of directors is the primary responsible body, although members may occasionally assume specific tasks. The board can enter into contracts and secure loans, but its actions must consistently align with the members' collective interests (see chapter 3.1).

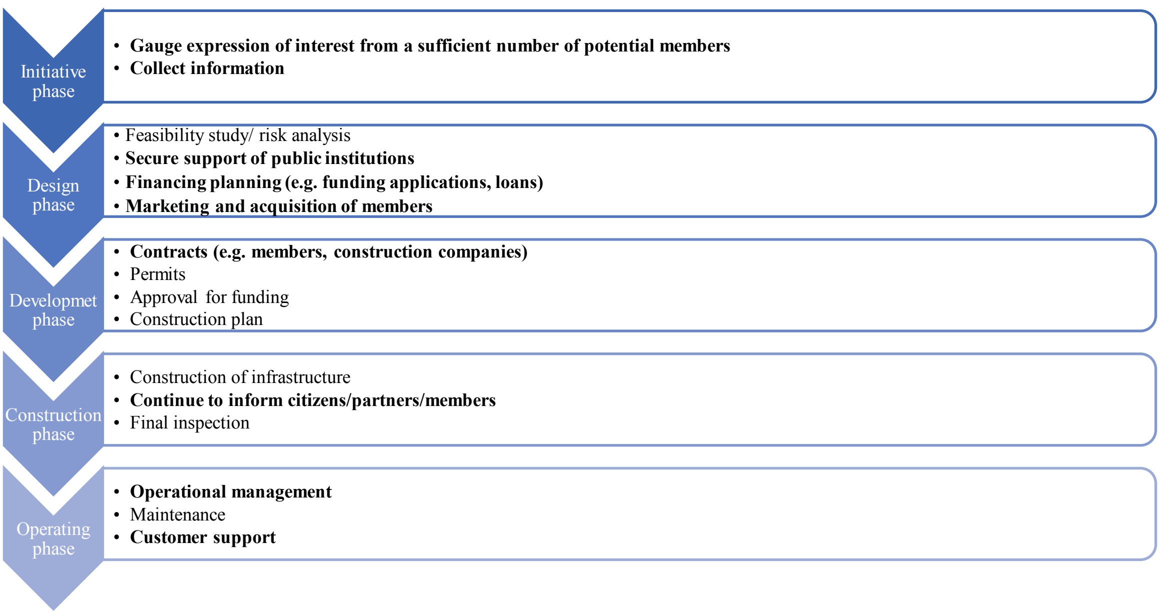

Figure 1: Project phases for heat cooperatives in the implementation of a heating network

Source: Own illustration.

First, citizens must join together and initiate the project. In this **initiative phase**, in all five cases it was residents of the municipality who brought along a high ideal value and wanted to reduce the CO_2 emissions of their community. Moreover, the citizens saw the potential of undercutting the heating price of local suppliers with a heat cooperative and thus achieving an economic advantage. For this, a cooperative must be founded (see chapter 3.1 and 3.2). In the initiative phase, it was crucial that the board of directors and the supervisory board of the cooperative meet very regularly; once a week can be a benchmark (Nahwärme Burggrumbach eG, Steinburg eG). In the interviews it was emphasized that it is necessary to collect a wide range of information, e.g. on the topics of costs, technical requirements/possibilities, experience reports. In this way, all responsible persons must be able to acquire knowledge on the subject in order to be able to make important decisions specifically for their location. Here, knowledge from cooperative members or citizens can also be beneficial, such as engineers, lawyers, project planners (Steinburg eG, Amerbach eG). In addition, there should be a high level of interest of the citizens right from the start, because the more citizens are behind the idea, the easier the next steps will be.

In the **design phase**, the structure of the cooperative is established (board of directors and supervisory board, see Chapter 3.1) and there is a general interest among the citizens. Now it is important to recruit additional members and customers for the planned heating network. To acquire customers, the heat cooperatives organize information evenings, send out newsletters, designs flyers and does door-to-door campaigning in person (Nahwärme Burggrumbach eG, Steinburg eG, Nahwärme Wettelsheim-Bubenheim eG, Steinburg eG). The personal approach and letters are particularly important, for example, to reach older citizens (Steinburg eG). In addition, the cooperative must commission a feasibility study to review its planning and draw up a financing plan (see also Chapter 4.3). Financing in this phase includes negotiations with banks for loans and applications for government funding. In the case of government funding, it is important that the application is submitted before construction begins (Steinburg eG). To estimate the costs, it is also important to determine how much equity capital can be used for calculation purposes and offers for the required components of the heating system (see chapter 4.1) should be obtained. In addition, it is important to talk to the city administration or the municipality and ask for their support, as they can be both customers (through the connection of municipal buildings) and owners of land or roads, which can be important during the construction phase. It is advisable not to accept any further customers at the end of the phase, so that the planning and cost calculation can be completed (Wettelsheim-Bubenheim eG).

In the **development phase**, the cooperative concludes all the preconditions for the construction. This means that the feedback for the financing applications has been received, the loans have been concluded with the banks, and the heat supply contracts have been concluded with the members as well as contracts with the external companies. In addition, permits should be given, for example, for construction. During this phase, it is also crucial to keep the members informed about decisions on an ongoing basis (Nahwärme Burggrumbach eG, Steinburg eG, Nahwärme Wettelsheim-Bubenheim eG, Steinburg eG). On the basis of the contracts concluded, the profitability calculation can then be reviewed and adjusted if necessary (Amerbach eG). In general, planning is completed by then and the transition to implementation follows.

In the **construction phase**, the heat cooperative has to hand over many tasks and acts mainly as a communicator between the parties involved: external companies, the city administration, members and citizens who are not members. In the case studies, it was particularly in this phase that citizen blocked or slowed down the process (see Chapter 5.1). Therefore, great importance should be attached to informing citizens and members in the first three phases.

In the **operating phase**, the cooperative acts mainly as an operator. This includes meetings, annual financial statements and customer management. In addition, the heating network must be maintained and repaired if necessary. There have been instances in the case studies of, for example, breakdowns in the heating network (Steinburg eG), damage caused by severe weather

(Burggrumbach eG). In Germany, there is also the mandatory cooperative audit, a legally required audit of annual financial statements. It includes an analysis and assessment of the operational organization and performance factors, the general finances and an in-depth analysis of the economic circumstances and membership relationships between the cooperative and its members (Genossenschaftsgesetz, GenG, 2022, §53). The audit is carried out at least every second financial year; every year if the balance sheet total exceeds 2 million euros (Genossenschaftsgesetz, GenG, 2022, §53). This can involve a lot of work and time in compiling documents and preparation for the cooperative and should be addressed at an early stage (Nahwärme Burggrumbach eG). The cooperative can use external companies for maintenance and repair as well as for the preparation of economic audits. However, it remains crucial to inform the members. For this purpose, the cooperatives in all five case studies rely primarily on websites and e-mail distribution lists.

The interviews focused on lessons from setting-up and planning cooperatives; therefore, our research attention was primarily on the first three phases of the process.It is important to keep in mind that the cooperative faces particular constraints, including regular meetings, information gathering, citizen communicating, offer soliciting, and financial planning. As the project progresses, tasks can be delegated. The duration of phases and the overall process, from initiative to network start-up, varies widely based on local conditions and network size. In the case of Nahwärme Burggrumbach eG and Nahwärme Amerbach eG, it took about a year from establishment to operation. Steinburg eG took about two and a half years, and Wärme-Strom-Gemeinschaft eG two to three years (although they also offer electricity). Nahwärme Wettelsheim-Bubenheim eG was founded in 2021 and is still in the construction phase.

In summary, Figure 2 illustrates the organization of local heat provision by a heat cooperative, defining key actors and their relationships according to the System Good framework.

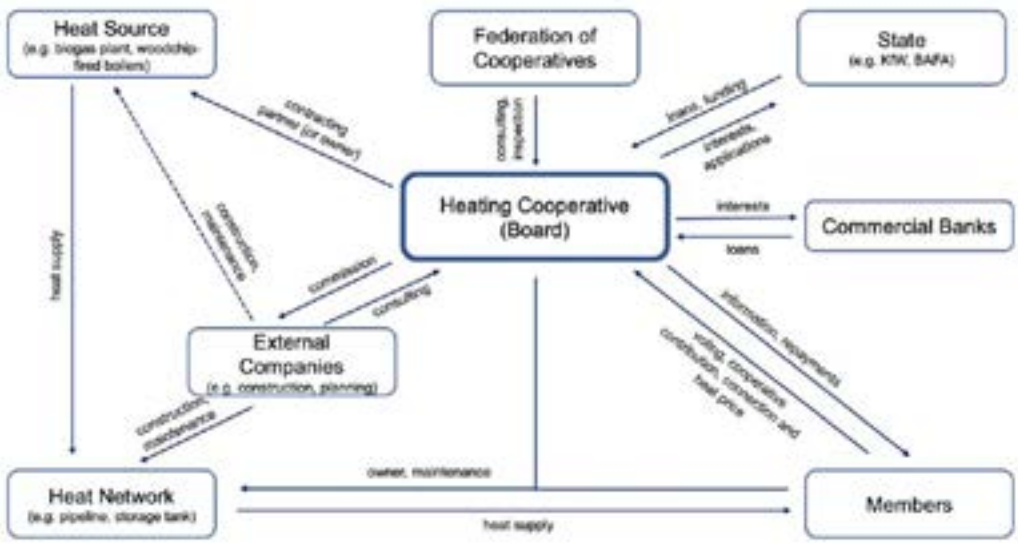

Figure 2: Actors and relationships in local heat provision by heat cooperatives

Source: Own Illustration.

4.3. Financing

For the provision of local heating and the construction of a heating network, the heat cooperative faces high investment costs. The investment costs for the heating network ranged from 200,000 euros (Wärme-Strom-Gemeinschaft) to six million euros (Wettelsheim-Bubenheim eG). It should be noted that Wärme-Strom-Gemeinschaft eG was able to use existing infrastructure, while Wettelsheim-Bubenheim eG is building a very large project with 302 subscribers and a route length of about 14 km. To finance this, the cooperative can draw on its equity capital and borrowed capital.

On the one hand, equity results from the cooperative shares. The members buy shares in the cooperative. The amount of the share can vary greatly from, for example, 1,000 euros (Wärme-Strom-Gemeinschaft G) to 6,000 euros (Wettelsheim-Bubenheim eG, Amerbach eG). Furthermore, a unique connection fee can come in addition. For example, with Steinburg eG subscribers pay in addition to 1,500 euros cooperative portion still 2,500 euros connection fee. At Wettelsheim-Bubenheim eG, Amerbach eG and Burggrumbach eG, this is included. In all five cases, the subscribers pay an annual or monthly base price, e.g. 300 euros per year (Wettelsheim-Bubenheim eG). In addition, they pay an energy price per kilowatt hour (kWh). The highest net operating price in the case studies was 12.5 cents per kWH (Steinburg eG) and the lowest was 3.5 cents per kWh (Burggrumbach eG). These four parameters (cooperative share, connection fee, basic price, operating price) form the equity and are mutually dependent and must be selected individually for each case. In three cases, the equity capital covered about 25 percent of the investment costs (Wettelsheim-Bubenheim eG, Amerbach eG, Wärme-Strom-Gemeinschaft eG). In Burggrumbach eG it was 15 percent and in Steinburg eG 10 percent. This means that 75 percent or more of the investment costs had to be covered by borrowed capital. The debt capital consists of subsidies from the state and loans from commercial banks. In the case studies, the cooperatives financed themselves between 40 and 50 percent through government subsidies. In this context, all five made use of a loan from the KfW. In three case, there was additional funding from BAFA (Burggrumbach eG, Amerbach eG, Wettelsheim-Bubenheim eG). In all cases, the biggest hurdle for state funding was the bureaucratic effort involved (see Chapter 5.3). Loans from commercial banks were used for interim financing. It is striking that in all five cases the local Raiffaisenbank, i.e. a cooperative bank, acted as business partner. From the interviews, it was clear that there were few hurdles in obtaining financing from Raiffaisen banks and that they provided the required amount of credit to the heat cooperatives (Burggrumbach eG, Amerbach eG, Wettelsheim-Bubenheim eG, Steinburg eG).

Since the cooperative could not make a profit, there were two ways of dealing with surpluses. On the one hand they could be paid out to the members. This was done by retroactively reducing the heating price instead of paying out dividends (Burggrumbach eG). But it can be challenging to keep a heat cooperative profitable over the long term. For example, Steinburg eG operated at a deficit until 2022 when it achieved its first surplus. On the other hand, surpluses could also be used as reserves to cover running costs or interest if necessary.

Estimating running costs is very difficult and the cooperatives found it hard to evaluate this point. Running costs can include electricity costs, repair, maintenance, administration. They were estimated in the case studies between 4,000 and 10,000 Euro per year. Over time, the costs for maintenance and repair may increase, too (Amerbach eG).

5. ANALYSIS AND DISCUSSION

After we have broken down our results based on the System Good analysis and elaborated an organizational and financial framework in the section above, in the following section we will identify which concrete barriers and drivers for development are relevant for heat cooperatives. Based on the interviews we will distinguish between (i) Social and Cultural Engagement (ii) Project Setup and Economical Factors (iii) Political Environment and (iv) Geographical and Infrastructural Factors.

It should also be noted that there are indeed strong differences between individual cases. Geographical as well as social differences lead to different accelerators and hurdles, but we have identified the most important commonalities.

5.1. Social and Cultural Engagement

Especially in the field of energy cooperatives and accordingly also heat cooperatives, one of the main driving forces for founding a cooperative is inner conviction. Some of the interviewees had already been involved in nature conservation beforehand, or at least had been self-driven by idealism and had carried the idea of founding a cooperative within themselves (Energiegenossenschaft Steinburg eG, Wärme-Strom-Genossenschaft eG). Furthermore, within the community, the idea of a local heating network was often considered long before its establishment. Consequently, the social networking of the people who are responsible in the initial phase plays a major role. The broader the social background of the initiators is, the better a potential membership can be convinced quantitatively and qualitatively, and the better is the confidence in the project. For example, in the case of Nahwärme Wettelsheim-Bubenheim eG a good starting point was the activity in the village's soccer club. Especially in the initial phase, it seems important to be able to spread the individual idea through contacts within the community. Social contacts and personal communication count as a basis. In the case studies, the significance of having a network of friendships was highlighted, as it became evident that responsibilities and leadership roles could extend beyond simple volunteerism (Amerbach eG). Thus, people who initiate and drive the project and bring not only passion but also know-how are an essential factor in the foundation (Nahwärme Wettelsheim-Bubenheim eG).

It also becomes clear in the expert interviews that without the willingness to invest private time, it can be hard to come beyond the initiative phase. Getting involved in the community and actively taking on tasks and risks is the key for a successful implementation (Nahwärme Amerbach eG).

In addition to this social support, demographic changes and the high responsibilities and demands make it challenging to implement and maintain a heat cooperative after a generational shift. The Wärme-Strom-Gemeinschaft eG, for example, had to consider selling its assets despite having a functional model and an ongoing demand. Because the work within the heat cooperative is remunerated very low or rather nothing, having less salary would simply not be a sustainable option for younger successors. Thus, after four years of concept development and the search for successors, they decided to sell the heat cooperative’s assets. In addition, however, it may also happen that the village community already has doubts about the operation of a nearby heating network from the beginning. Concerns regarding cost-effectiveness and noise pollution are often the reasons for such doubts. Another social barrier is the fear of dependence, which, however, would be similar for other heat suppliers (Wärme-Strom-Gemeinschaft eG, Nahwärme Burggrumbach eG). Thus, the personal relationship between the stakeholders and the initiators seems to play a role in dispelling initial doubts. Especially personal conversations with older individuals are important for a personal connection. (Nahwärme Wettelsheim-Bubenheim eG).

There were also civic initiatives and protests at the Energiegenossenschaft Steinburg eG which have been actively organized against the construction. The main argument was that the plots would lose value if installations for the infrastructure were to be placed in the immediate vicinity of the houses, e.g. the use of high chimneys. It had also been claimed that the planning phase had not been agreed with those concerned, which created a mistrust of the project.

In conclusion, social cohesion is especially crucial in local projects that are deeply connected to the village community. However, this level of cohesion can differ from one case to another. Some villages displayed overwhelming support for the project, with demand surpassing the available supply of connections (Wärme-Strom-Gemeinschaft eG).

5.2. Project Setup and Economical Factors

In order for a heat cooperative to be successful in the long term, or for it to be founded, there are some facilitating preconditions. Thus, the foundation is not only a pure act of will but must also be supported by fundamental knowledge. The Wärme-Strom-Gemeinschaft eG, for example, approached the foundation with energy conceptual expertise as well as commercial and legal assistance. These three components enabled a promising transition from the initiative phase to the design phase. At the same time, the actual assets within the residential communities stood in contrast. The actual properties must therefore provide an incentive so that the owners think about changing the heat supply. The case studies revealed that old oil (and in some cases gas) heating systems were an economic driver on both the supply and demand sides. Likewise, replacement would have been necessary in many residential buildings. Thus, a local heating network offered a sensible alternative (Nahwärme Wettelsheim-Bubenheim eG, Nahwärme Amerbach eG, Wärme-Strom-Gemeinschaft). This describes mainly the benefit from the user side, but equally older oil heaters also mean that a higher subsidy rate is granted (Nahwärme Amerbach eG).

With regard to hurdles, the interviews clearly show that the lack of collateral always leads to problems in the case of debt financing. Often, a loan agreement is entered with the local Raiffeisen bank, whereby the pipelines and infrastructure assets are deposited as collateral together with the heat supply contracts (Nahwärme Wettelsheim-Bubenheim eG). The interview emphasized how important the support of the local bank is to advance the realization of the project. The greatest challenge in keeping a cooperative profitable in the long term lies in the difficulty of planning. On the one hand, the expiry of subsidies for biogas plants and, on the other hand, the unclear development of heat/electricity and wood ship prices make a long-term calculation difficult (Burggrumbach eG, Amerbach eG, Wettelsheim-Bubenheim eG, Steinburg eG).

5.3. Political Environment

Each heat cooperative has received some form of subsidy to cap either the working price for energy or the investment costs in the long term. Thereby, one is mainly dependent on three support mechanisms: the CHP subsidy (highly efficient combined heat and power plants receive temporary funding for the electricity the plants produce), BAFA grants and the KfW subsidy program. Similarly, all the interviews mentioned the problems they had with state subsidies. The main argument is twofold: firstly, the lack of clarity in the application process; one is dependent on experts who are already familiar with the details. Without external support, correct compliance is hardly possible. On the other hand, the receiving time for an approval or the actual payment of benefits is too long. Due to the high number of applications, there are always delays in the actual implementation, which in turn causes financing problems. The interviews cause a staff shortage for this (Nahwärme Amerbach eG). The bureaucratic effort required to obtain the corresponding benefits is extremely demanding and means that projects are repeatedly stalled, both structurally and financially. In addition, the planning horizon shrinks as the requirements for the applicants change, and thus the basis for economic operation collapses. Almost all of the interviewees would like to see a much more straightforward and plannable funding process. This seems to be a major problem on the part of state support.

5.4. Geographical and Infrastructural Factors

In addition to the attractiveness of the buildings for a heating network, the geographic environment for such a network is also an important factor for the successful establishment of a heat cooperative. It is necessary to distinguish between two conditions: the natural relief and the available infrastructure.

To begin, the flatter and smaller the area to be served, the easier it is to build the network. This is because laying pipes on mountains or slopes is much more difficult than in flat areas. The other decisive factor is the distance between producer and consumer. Since there is always a difference between gross and net heat power which arrives at the customer (efficiency losses in the network), a possible low distance between the houses to be connected and the generating plant is advantage (Wettelsheim-Bubenheim eG, Energiegenossenschaft Steinburg eG).

Infrastructural or cultural factors are also a hindrance. Federal roads, highways, level crossings and similar. This is due to the fact that the project is not only delayed because you need permission, but also has additional costs to relocate the actual network. Particularly, in the case of geography and external infrastructure, it is always an individual consideration, depending on local circumstances, whether a successful and long-term operation of a district heating network will succeed.

5.5. Behavior Change Factors

The interviews have shown that citizens who did not have specific touching point with the heat transition before, still could be convinced to change their heating system at home. Due to the demographic distribution of a high amount of older generations in rural areas of Germany, a high focus on public participation and information lay on this group. Thus, the initiators of the need personal contact to inform and explain a heat cooperative or organized discussion meetings for free participation for the regional citizens. This knowledge spread and persuasion work made the membership join this collective and change their behavior.
If one wants to transfer the experiences from Germany to an international level, the exchange of best practices is certainly beneficial. However, it should be noted that not all countries have uniform regulations and laws in this regard. Therefore, incentive regulations at the EU level would certainly be the basis for further progress.

6. CONCLUSION

In conclusion, the emergence and growth of heat cooperatives in Germany represent a promising approach to address the pressing challenges of decarbonizing the heating sector while fostering local community engagement. The central theme of these cooperatives revolves around not only the reduction of carbon emissions but also the empowerment of citizens to actively participate in the energy transition.
This paper has explored various aspects of heat cooperatives, from their theoretical underpinnings rooted in cooperative principles to the practical considerations of their establishment and operation. Through a System Good analysis based on five case studies, we have developed an overarching organizational model encompassing technical requirements, provision and financing. It facilitates local heating supply through the legal form of heat cooperatives.
Given the significance of local conditions in shaping heat cooperatives, it may not be feasible to create a one-size-fits-all organizational model. However, this flexibility allows for decentralized adaptation of heating supply to meet the needs of local citizens.
Based on this, we have identified both the drivers and barriers that shape the landscape of these cooperatives. Social and cultural engagement emerges as a driving force behind the founding of heat cooperatives. Idealism, and the willingness to invest personal time have been central in initiating and sustaining these projects. However, demographic shifts and the demand for generational continuity pose significant challenges. Furthermore, the project setup and economic factors play a critical role in the success of heat cooperatives. The condition of existing heating systems, the availability of technical expertise, and access to financing greatly influence the viability of these cooperatives. Furthermore, the bureaucratic complexities associated with state subsidies have highlighted the need for streamlined and efficient support mechanisms. Geographical and infrastructural factors also impact the feasibility of heat cooperatives. The topography of the area to be served and the proximity of consumers to heat sources significantly affect the efficiency and cost-effectiveness of local heating networks.
In conclusion, heat cooperatives represent a grassroots approach to addressing the critical issue of decarbonizing the heating sector. While challenges exist, the potential for these cooperatives to drive local economic development, foster social cohesion, and contribute to a sustainable energy future cannot be underestimated. It is through the collective efforts of citizens, policymakers, and local communities that heat cooperatives can continue to flourish and make a meaningful impact in the transition to a more sustainable heating sector.

REFERENCES

Bauwens, T. (2016). Explaining the diversity of motivations behind community renewable energy. *Energy Policy*, *93*, 278–290.

BDEW. (2021). *Zahl der Woche*. https://www.bdew.de/presse/presseinformationen/zahl-der-woche-fast-ein-fuenftel-aller-co2-emissionen-in-deutschland/#:~:text=Rund%2018%20Prozent%20aller%20CO2,Fernw%C3%A4rme%20und%20Strom%20f%C3%BCr%20Heizzwecke).

Beckers, T., Gizzi, F., & Jäkel, K. (2012). *Ein Untersuchungsansatz für Systemgüter: Einordnung, Darstellung, Vorgehen bei der Anwendung* (2012–01; WIP-Working Paper). Technische Universität Berlin.

BMWK. (2022). *Diskussionspapier des BMWK: Konzept für die Umsetzung einer flächendeckenden kommunalen Wärmeplanung als zentrales Koordinierungsinstrument für lokale,effiziente Wärmenutzung* [Diskussionspapier]. Bundesministerium für Wirtschaft und Klima.

DGRV. (2023). *Deutscher Genossenschafts- und Raiffeisenverband. Energiegenossenschaften. Ergebnisse der DGRV-Jahresumfrage (Durchführung Mai und Juni 2023)*.

Drewing, E. (2020). Energieinfrastrukturen umbauen: Potenziale und Grenzen genossenschaftlich organisierter Wärmenetze. *Handbuch Energieeffizienz im Quartier: Clever versorgen, umbauen, aktivieren*, 1–14.

Erneuerbare Energie Gesetz, EEG, 3, Bundesamt für Justiz, 15 (2023). https://www.gesetze-im-internet.de/eeg_2014/__3.html

European Commission, Joint Research Centre, Uihlein, A., & Caramizaru, A. (2020). *Energy communities: An overview of energy and social innovation.* Publications Office. https://data.europa.eu/doi/10.2760/180576

Flieger, B. E. (2011). Eine klimaverantwortliche, bürgernahe Energiewirtschaft ist möglich. *Ökosoziale Transformation–Solidarische Ökonomie und die Gestaltung des Gemeinwesens. Neu-Ulm: AG SPAK Bücher*, 315–338.

Genossenschaftsgesetz, GenG, Bundesministeriums der Justiz, 1 (2022).

Gläser, J., & Laudel, G. (2010). *Experteninterviews und qualitative Inhaltsanalyse als Instrumente rekonstruierender Untersuchungen* (4. Auflage). VS Verlag.

Hirschmann, A. O. (1958). *The Strategy of Economic Development* (Vol. 10. New Haven, USA: Yale University Press).

Kajimura, R. (2023). *Genossenschaftliche Biogas-Wärmenetze am Scheideweg: Wie geht es weiter nach dem EEG?* (Agentur für Erneuerbare Energien e.V., Hrsg.). https://www.unendlich-viel-energie.de/media/file/5151.AEE_RK_Biogas_Waermenetze_Mar23.pdf

Kahneman, D. (2011). Thinking, fast and slow, 1. ed. ed. Allen Lane, London. Kahneman, D., Slovic, P., Tversky, A. (Eds.), 1982. Judgement under uncertainty: Heuristics and biases. Cambridge University Press

Klemisch, H. (2014). Die Rolle von Genossenschaften in der Energiewende. *Ökologisches Wirtschaften-Fachzeitschrift*, *29*(1), 22–23.

Lygnerud, K. (2018). Challenges for business change in district heating. *Energy, Sustainability and Society*, *8*, 1–13.

Moser, S., & Jauschnik, G. (2023). Using Industrial Waste Heat in District Heating: Insights on Effective Project Initiation and Business Models. *Sustainability*, *15*(13), 10559.

North, D. C. (1990). *Institutions, Institutional Change and Economic Performance* (Cambridge: Cambridge University Press.).

North, D. C. (1991). *Institutions* [Journal of Economic Perspectives 5 (1): 97–112].

Pfister, T., Wallraf, C., Sieverding, U., & Verbraucherzentrale, N. (2015). Nahwärmegenossenschaften. *Chancen & Risiken aus Verbrauchersicht. Hg. v. Verbraucherzentrale NRW eV Düsseldorf.*

Ruggiero, S., Isakovic, A., Busch, H., Auvinen, K., & Faller, F. (2019). *Developing a Joint Perspective on Community Energy: Best Practices and Challenges in the Baltic Sea Region*.

Shove, E., (2010). Beyond the ABC: climate change policy and theories of social change. Environment and Planning A 42, 1273 – 1285. doi:10.1068/a42282 Shove, E., Pantzar, M., Watson, M., 2012. The dynamics of social practice: everyday life and how it changes. SAGE, Los Angeles

Wealer, B., & von Hirschhausen, C. R. von. (2020). *Nuclear power as a system good: Organizational models for production along the value-added chain* (DIW Discussion Papers 1883). Deutsches Institut für Wirtschaftsforschung (DIW). http://hdl.handle.net/10419/222865

Yildiz, Ö., Rommel, J., Debor, S., Holstenkamp, L., Mey, F., Müller, J. R., Radtke, J., & Rognli, J. (2015). Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. *Energy Research & Social Science*, *6*, 59–73.

APPENDIX

1 Case studies

This annex provides a review of five case studies of heat cooperatives from Germany.

Name	Nahwärme Amerbach eG
Region	Bavaria, Germany
Foundation	2020
Commissioning	Since 2021
Project phase	Operating
Heat source	Woodchip boiler
Route length	860 m
Number of connections	18 connections
Investment costs	400,000 Euro
Description	The initiator was a private person from the community. There is a local producer of wood chips, which come from stocks in the region. In addition, many households with old oil/ gas heating systems that should have been replaced in the near future. Already good community present in the settlement as a base. Cooperation with company for the production of heat networks and cooperative association Bavaria. Great support of the local cooperative bank.
Date of interview/ interview partner	31.07.2023/ Thomas Stenzenberger

Name	Nahwärme Burggrumbach eG
Region	Bavaria, Germany
Foundation	2012
Comissioning	Since 2013
Project phase	Operating
Heat source	2 biogas plants (with a total of 4 combined heat and power plants)
Route length	3.85 km

Number of connections	50 connections
Investment costs	1.02 Million Euro
Description	The biogas plants were already existing and wanted to offer heat themselves at a comparatively higher price. In the neighborhood there are many old buildings and accordingly a high heat demand. The cooperative was lucky and was able to finance itself through a double subsidy, which normally does not overlap. It has been able to reimburse its members a total of 90,000 euros over the last eight years.
Date of interview/ interview partner	23.07.2023/ Rudolf Lang

Name	Energiegenossenschaft Steinburg eG
Region	Schleswig-Holstein, Germany
Foundation	2015
Commissioning	Since 2017/2018
Project phase	Operating
Heat source	Waste heat from a biogas plant
Route length	6 km
Number of connections	70 connections
Investment costs	2.5 Million Euro
Description	The biogas plant already existed and there was no customer for waste heat. Initiator came from the village, in the beginning two times a week meeting. Many citizens were against it, much time in information and advertisement. Problems to find a location for the heating house and storage, because residents did not want it close to the village. Geographically challenging, as there is a river between the biogas plant and the village, and the streets are protected as historic monuments.
Date of interview/ interview partner	12.09.2023/ Roland Ortega

Name	Wärme-Strom-Genossenschaft eG
Region	Bavaria, Germany
Foundation	2009
Commissioning	Since 2016
Project phase	Operating and Phase Out
Heat source	Combined heat and power generation and cogeneration plant from biogas
Route length	-
Number of connections	43 connections
Investment costs	250.000 Euro
Description	There were organizational difficulties within the municipal utilities. So that the current board organized themselves to provide energy for the community. They built up combined heat and power generators offer heat and electricity and two cogeneration plant for heat. When they built their first combined generator, they could sell it to non-

	members. They need to phase out their plants because they cannot find a new board.
Date of interview/ interview partner	27.07.2023/ Ralf Hansen

Name	Wettelsheim-Bubenheim eG
Region	Bavaria, Germany
Foundation	2021
Commissioning	-
Project phase	In Construction
Heat source	Woodchip boiler, cogeneration plant from biogas
Route length	13,764 km
Number of connections	302 connections
Investment costs	10,1 Million Euro
Description	The initiators knew that the old heating systems with oil needed to be substituted. Moreover, they already were good connected in the community. They are going to build cogeneration plants and a woodship boiler. At the same time, they want to build up the glass fiber cable network. The heat cooperative had some difficulties with the municipality regarding the costs of the network. They provide heat mostly to private persons but also to five public buildings.
Date of interview/ interview partner	31.07.2023/ Martin Huber

2 Interview Layout

This appendix contains the questionnaire on the basis of which the interviews with the heating cooperatives from Germany were conducted.

Heat Cooperative:

Date:

Place:

Interviewee:

Interviewer:

General data of the cooperative:

City	
Characteristics	
Size/ Coverage area	
Status	
Route length of the heat network	
Heat quantity	
Connection rate	
Heat generators/heat sources	
Heat storage	
Network temperatures	

Special aspects of integration and operation	
Environment	
Installation of further infrastructure / pipelines	
commodity price / capacity charge	
Investment costs	
Heat price	

Section 1: Organizational model

1. Who and/or what was the initiator for the foundation of the heat cooperative? Is there any special potential for heat generation?

2. Why is your municipality/place of residence particularly suitable for a heating cooperative? Which requirements do you see as binding?

    2.1 Technical:

    2.2 Social:

    2.3 Financial:

    2.4 Infrastructure/Logistics:

    2.5 Administration/Planning:

    2.6 Other:

    2.7 Necessary Requirement:

3. How did the first concept come up?

4. How did you convince/inform the citizens about a cooperative? What were the citizens' concerns?

5. Were there any major hurdles during planning that forced your concept to be restructured? How were you able to overcome these hurdles?

6. Where do you see political/governmental possibilities that the organization of a heat cooperative is simplified/supported?

Section 2: Financing model

1. Costs:

    1.1 What were your capital costs?

    1.2 What are the maintenance costs/long-term costs?

    1.3 Other costs (resources etc.)?

2. What is the equity ratio, what is the debt ratio?

    2.1 Equity:

    2.2 Debt:

3. If you received government assistance funds, how much were they? What were the basic options?

    3.1 Type of funding:

3.2 Amount:

3.3 Other options:

4. What hurdles did you face in getting government assistance?

5. What hurdles did you face in applying for the loan? Which person takes the loan and assumes the risk?

5.1 Hurdles:

5.2 Risk:

6. What hurdles did you face in obtaining private debt capital? (Contribution to join the cooperative or other?)

7. What customers do you have (anchor customers, residential customers)? What financial impact do they have?

8. How much does one kWh cost? How much additional collateral does this give you?

9. Where do you see difficulties/challenges to keep/finance a heat cooperative economically in the long run?

10. Do you see regulatory instruments that would minimize/lower the financial risk?

Roles, drivers, and barriers for local organizations as intermediaries in energy-related support: case-study Setúbal Municipality, Portugal

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Keywords: Energy efficiency, One-stop-shop, Hard-to-reach energy users, Vulnerable households, Stakeholder interviews, Middle actors

Abstract

Hard-to-reach groups (e.g., vulnerable households) are receiving increasing attention for just energy transitions. Local organizations, such as municipalities, community associations, sports and arts clubs, and social support institutions, have been suggested as potentially relevant partners in deploying tailored energy-related interventions. Nevertheless, scarce research has directly engaged them to critically assess their willingness, capabilities, and unmet needs. In this case-study research, we draw on the mapping of 200 local organizations and on 35 exploratory interviews conducted after deploying a pilot energy one-stop shop in Setúbal, Portugal. Interviews focused on the characterization of activities and target audiences, assessment of the knowledge baseline on energy topics, analysis of potential collaborative roles, and recognition of drivers, barriers, and solutions. Results show that most organizations are willing to disseminate activities, forward citizens to energy-related support, facilitate contacts with local partners, co-organise events, and participate in training. Half can identify vulnerable families for targeted support. Few seem able to provide energy-related support, redirect staff, or participate in coordination. Drivers include environmental concerns, community participation, and social support. However, this willingness is hindered by scarce human resources, lack of time and other priorities, and financing concerns. This case study finds potential for local organizations to act as intermediaries in energy-related support, building on their well-established communication channels and trusted relationships with hard-to-reach groups. However, they are often hard-to-reach themselves, already over-burdened with demanding activities. Thus, we suggest that building an effective network of local intermediaries demands dedicated financing, time, and resources.

1. INTRODUCTION

The involvement of citizens and businesses has been identified as a key success factor in the increasingly urgent energy transitions needed to mitigate the worst effects of climate change (IEA, 2021). In this context, the concept of hard-to-reach energy users is receiving growing attention, broadly defined as groups that are "either hard-to-reach physically, underserved, or hard to engage or motivate in behaviour change, energy efficiency, and demand response interventions" (Rotmann *et al.*, 2020). Hard-to-reach energy users include five major groups – vulnerable households, high-income households, tenants and landlords, small and medium enterprises, and commercial subsectors – representing a significant share of the population and enterprises whose engagement requires greater attention (Rotmann *et al.*, 2020).

Vulnerable households are more susceptible to suffering from energy poverty, defined as the inability to access an adequate level of energy services due to low incomes, inefficient buildings and equipment, and high energy prices, among other factors (Gouveia *et al.*, 2019). Research in global north countries suggests that demographic and socio-economic variables – such as age, income, gender, education, employment, household composition, health and disabilities, migratory status, ethnicity, and homeownership – can aggravate the risk of energy poverty and may signal a hard-to-reach profile (Rotmann *et* al., 2020; Simcock *et al*., 2021).

Recent studies have suggested that local-scale approaches coupled with the active enrolment of local organizations can successfully deploy energy-related support (Horta *et al.*, 2019; Sequeira & Melo, 2020; Sequeira *et al*., 2021). Besides fostering participation among the population, local organizations are strategically placed to facilitate the engagement of hard-to-reach groups, such as vulnerable households, benefiting from a relationship of trust that may be transposed to the energy field (Ramsden, 2020; Mundaca *et al.*, 2023).

However, scarce scientific research has directly engaged with these stakeholders to critically assess their willingness to enroll in energy-related interventions, the contributions they can realistically provide, and their needs to unlock deeper collaboration. Furthermore, most previous research has considered local stakeholders as homogeneous or has focused only on pre-established typologies of organizations (*e.g.* Ramsden, 2020). In this research, we aim to address this gap by drawing from a case study analysis, including a stakeholder mapping exercise and semi-structured exploratory interviews, conducted after deploying a physical energy efficiency one-stop-shop pilot project in the Setúbal Municipality in Portugal. The novelty of this work lies in the empiric exploration of potential collaborative roles of diverse local organizations in delivering energy-related support to vulnerable audiences, leveraging on existing networks and regional dynamics. Although the results are case-specific, the applied methodology and critical insights are relevant for local-scale interventions elsewhere.

2. METHODS

2.1. Case-study: Transition Point physical one-stop-shop in Setúbal, Portugal

The Setúbal Municipality is in the Lisbon Metropolitan Area, Portugal. For administrative purposes, the municipality is divided into five civil parishes. Data from the Portuguese

Census of 2021 paints a picture of the demographic, socioeconomic, and buildings factors that may affect energy poverty vulnerability at the local scale, especially considering the severe nationwide situation where 29% of the population is energy-poor (INE, 2023; Portuguese Government, 2023). Mainly urban, Setúbal hosts a population of 123 000, 53% women. Buildings are energy inefficient and need renovation, as 49% were built before 1980 when thermal regulations were non-existent (country average: 38%). 25% of households rent their dwelling (country average: 22%). 51% of the population has a high school diploma (country average: 46%), and the unemployment rate is 9% (country average: 8%). 7% have foreign citizenship (country average: 5%). 23% is over 65 years old (country average: 23%).

In this context, the Transition Point physical one-stop shop pilot project was launched at the beginning of 2022 in Setúbal to provide energy-related support at a local scale and mitigate energy poverty (CGF, 2023). One-stop shops are internationally seen as a promising solution to tackle the persistent barriers to household engagement in energy efficiency, building renovation, and integration of renewables by delivering tailored advice and financing solutions and supporting households throughout their energy-related projects (European Commission, 2020). Nevertheless, these models are still underdeveloped in most European countries. They are just kick-starting in Portugal, and scarce research has been conducted on this topic (Sequeira & Gouveia, 2022). The Transition Point physical one-stop shop was innovatively located in a mobile container, providing the following services: i) energy efficiency advice, ii) energy tariffs optimization, iii) support on application to national energy efficiency funding schemes, and iv) free home energy audits (Gouveia *et al*., forthcoming). A vital component of the project was the direct collaboration with local organizations to foster participation from the community, particularly vulnerable households.

2.2. Stakeholder mapping in the Setúbal Municipality

Following three systematic data collection approaches, a stakeholder mapping exercise focused on local organizations was performed for the Setúbal Municipality in Portugal. First, from the publicly available list of organizations participating in the Local Social Action Council of Setúbal, a network of around 80 local organizations managed by the Setúbal City Council. Second, from the publicly available lists of organizations that participate in the Civil Parish Social Committees, a mechanism like the social action council but operates at the civil parish scale (only available for two out of five civil parishes in Setúbal). Third, from the websites of local governments, namely from the pages listing local associations.

Data on the organization's name, e-mail, website, and social media were collected. Based on the publicly available information, mapped organizations were classified according to their primary type of activity: local government, energy agency, social support, arts, sports, community development, education, religion, health, and others. The full rough list of mapped stakeholders was refined by erasing duplicates and those without an active e-mail.

2.3. Semi-structured exploratory interviews with local stakeholders

All 199 mapped stakeholders were contacted by e-mail with a general presentation of the research activity and an invitation to participate in one-on-one interviews. It was possible to obtain an answer from 48 local stakeholders, of which 35 were available for semi-structured exploratory interviews. The interviewed sample does not intend to be representative of the study universe, nor do the results seek to have statistical meaning. Instead, it aims to explore the potential to integrate local organizations in energy-related support by testing a collaborative methodology and analysing results in a real-world case study. It should be noted that interviews were conducted with the organizations that agreed to participate, which may reveal a preexisting willingness to collaborate. Thus, the results are likely to be inherently biased towards positive answers when compared to the entire universe of local stakeholders.

The interviews were conducted online (27 out of 35) or by telephone (8 out of 35) when the interviewee lacked digital skills, following a script with four sections: i) characterisation of the current activities, geographical scope, and target audiences of the organization (16 open questions), ii) assessment of the knowledge base on energy topics (five open questions), iii) explore potential roles as intermediaries in energy-related support (one open question and one closed question with 19 options where interviewees answered yes/no/maybe to each option), and iv) recognize the drivers, barriers, and solutions to collaboration (three closed questions with six options each where interviewees chose two options in each question).

3. RESULTS AND DISCUSSION

3.1. Characterization of local stakeholders

The 199 mapped local organizations in the Setúbal Municipality are shown in Table 1 by their primary type of activity. The relatively low rate of responses from the mapped stakeholders shows the difficulty in engaging with local organizations that are not familiar with energy topics and may also be a lingering effect of the COVID-19 pandemic as a challenging time that tested the resilience of many local organizations. Virtually all interviewees mentioned relevant changes to their activities due to COVID-19 lockdowns, with around half (18 out of 35) stating that it caused long-term halts in their activities. Still, the other half carried on in some way to provide essential support to vulnerable populations.

Table 1 - Local stakeholders mapped and interviewed in Setúbal according to the primary type of activity.

Type of entity	No. mapped	No. answered	No. interviewed
Local government	6	3	2
Energy agency	1	1	1
Social support	44	16	11
Arts	28	6	4
Community	25	6	6
Sports	58	8	4
Education	16	3	3
Religion	7	1	0
Health	8	4	4
Other	7	0	0
Total	**199**	**48**	**35**

The self-reported goals of the interviewed organizations are shown in Table 2. Most are non-profit associations (17 out of 35) or private institutions for social solidarity (11 out of 35). Other types of legal entities, *e.g.,* cooperatives, mutualist associations, non-governmental humanitarian institutions, and public institutions for higher education, are less common in our sample.

Table 2 – Self-reported goals of the interviewed stakeholders.

Type	Code	Self-reported goals
Local government	Gov1	To define policies to in the interest of the population in all areas of life.
	Gov 2	To manage heritage, tradition, customs, school network, and associations.
Energy agency	Ene1	To promote energy efficiency, renewable energy, and sustainability.
Community development	Com1	To help the youth build their future and the elderly feel safe.
	Com2	To support local businesses, independent workers, and entrepreneurs.
	Com3	To promote the integrated development of rural, coastal, and urban areas.
	Com4	To help those in need, particularly the elderly and families with children.
	Com5	To foster communities as agents of change for sustainable behaviours.
	Com6	To support active citizenship, and associative and cooperative spirit.
Social support	Soc1	To contribute to a fairer society, dignified and participatory citizenship.
	Soc2	To support the vulnerable population of Setúbal.
	Soc3	To support persons with HIV/AIDS and prevent infections.
	Soc4	To provide humanitarian and social assistance to the most vulnerable.
	Soc5	To support those in need in coordination with the local churches.
	Soc6	To promote social justice, equality, inclusion, and opportunities for all.
	Soc7	To be a reference for people with autism and their families.
	Soc8	To educate children and young people and insert them into society.
	Soc9	To defend the rights of children, especially the most vulnerable.
	Soc10	To support to those infected by HIV/AIDS, provide training and informing.
	Soc11	To manage a social support facility for the residents and locally employed.
Health	Hea1	To raise awareness among the population about blood donation-
	Hea2	To reduce risks associated with the use of psychoactive substances.
	Hea3	To provide social protection and health through mutual assistance.
	Hea4	To de-dramatize the hospital context for hospitalized children.
Arts	Art1	To contribute to culture democratization and socio-cultural dynamization.
	Art2	To bring theatre to the local community and beyond.
	Art3	To promote active youth engagement through art and culture.
	Art4	To maintain and show the local traditions across the country and abroad.
Sports	Spo1	To bring together fans and support the local football club.
	Spo2	To provide young people with sports activities.
	Spo3	To promote water sports and especially canoeing in its various forms.
	Spo4	To encourage the population to practice sports outdoors.
Education	Edu1	To drive scientific, technological, economic, sociocultural development.
	Edu2	To prepare young people for the future in criminalized neighborhoods.
	Edu3	To encourage active retirement and establish bonds of friendship.

Only six stakeholders stated to be a local delegation of a larger organization, while the remaining (29 out of 35) are fully autonomous. The median year of foundation is 2003, but the range is wide, with the oldest dating back to 1860 and the newest from 2021. Regarding the geographical scope of these organizations, most report operating at the regional (14 out of 35) or municipal (14 out of 35) level, while fewer are focused on the civil parish (5 out of 35) or neighbourhood (2 out of 35) scale.

A significant share of the interviewed organizations (10 out of 35) entirely depends on volunteers, while an additional 15 have less than 10 persons employed full-time. Except for the municipality and higher education institutions, all the remaining organizations (8 out of 35) have between 10 and 85 employees. There is widespread performance of unpaid and part-time work, with most organizations (23 out of 35) relying on volunteers and precarious employees to perform at least some tasks; the number of volunteers varies from just a few to several hundreds of mobilized citizens.

The self-reported target audiences are shown in Figure 1, according to the primary type of activity of the organizations. The profiles of hard-to-reach energy users were coded based on the work of Rottman *et al.* (2020). While some types of organizations focus primarily on the general population, *e.g.,* those performing artistic activities, and others on their associates or members, *e.g.,* those performing sports activities, there is still overlap in many target audiences. Notably, there is significant coverage across most hard-to-reach groups by the local organizations, including social and health support to marginalized population segments such as homeless persons, persons with substance abuse problems, persons infected with HIV/AIDS, sex workers, and people living in poor housing conditions.

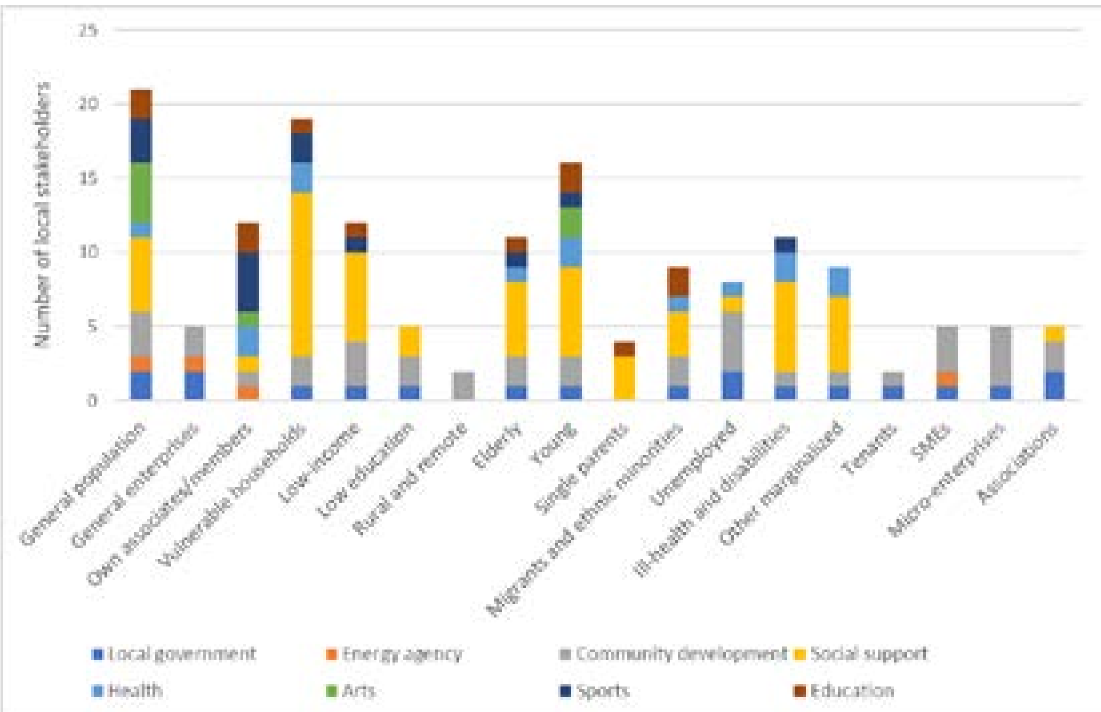

Figure 1 – Self-reported target audiences according to the type of stakeholder.

3.2. Knowledge base on energy topics

Only six out of 35 interviewed claimed to have a person specifically dedicated to environmental and/or energy issues, namely three community development organizations, one educational institution, the local energy agency, and the municipality. Nevertheless, most organizations expressed interest in becoming more involved in these topics as a component of their goals to improve the environmental, social, and economic sustainability of their communities. Furthermore, when asked if their members or beneficiaries suffer from energy poverty – framed as thermal discomfort and/or difficulty in paying energy bills – most interviewees emphatically acknowledged the problem by mentioning their lived experiences of interacting with vulnerable households.

3.3. Potential roles as intermediaries in energy-related support

Results from the interviews show areas where collaboration between local organizations and energy-related projects seems particularly encouraging. These are shown for the total sample and specific types of local organizations in Figure 2. At this stage, some of the defined typologies were merged due to the similarities of their answers. At the same time "local government" and "energy agency" are analysed separately due to the low number of data points.

A large share of the organizations provided positive answers for the roles of physical and online project dissemination (86% and 71%, respectively), forwarding citizens to energy-related support (77%), facilitating contacts with other local partners (77%), organise community events (77%), and participating in short training sessions (74%). Organizations focused on community development and education seem particularly well-placed for communication tasks and community mobilization through local events, as also found by Sequeira & Melo (2020). All types of organizations are willing to act as an intermediary with other local organizations, exploring their existing network of local partners. Social support and health institutions seem especially able to forward their beneficiaries to energy-related support, for instance, by communicating face-to-face the existence and advantages of these services while conducting their usual activities. Arts and sports clubs may collaborate in dissemination activities but seem to struggle in other areas.

Around half of the interviewees can identify vulnerable families and pass on that information to the coordinators of the energy-related support for their proactive contact, with an emphasis on community development associations and social support and health institutions, where this percentage rises almost to 70%. These results suggest that collaboration with social support institutions can provide synergies in addressing intersecting vulnerabilities and enable better access to vulnerable families, as Ramsden (2020) suggested. Nevertheless, in highly vulnerable or marginalized population segments (*e.g.,* persons with HIV/AIDS, homeless, unstable families, and persons living in inappropriate housing conditions), the urgency of basic health, social, or housing support may be so dire that energy is not a primary concern. Furthermore, the confidentiality of beneficiaries was mentioned as a potential barrier, primarily because the organizations have worked hard to build long-term trust.

Notably, few local organizations seem able to provide direct support to citizens, redirect existing staff or hire new personnel, contribute with technical knowledge, or coordinate energy-related support (*i.e.*, less than 20% of positive answers from the total sample). However, collaboration in these areas may be possible with a few community development associations whose goals are aligned with the engagement of citizens in environmental and social support issues. Finally, the interviews suggest that energy agencies and local governments may be well-placed to take up leadership roles and fill this void in human resources, technical knowledge, coordination, and financing. However, they may not be able to do this alone: technical and institutional capability is not necessarily coupled with the intimate acquaintance of the community and the trust required to engage vulnerable families.

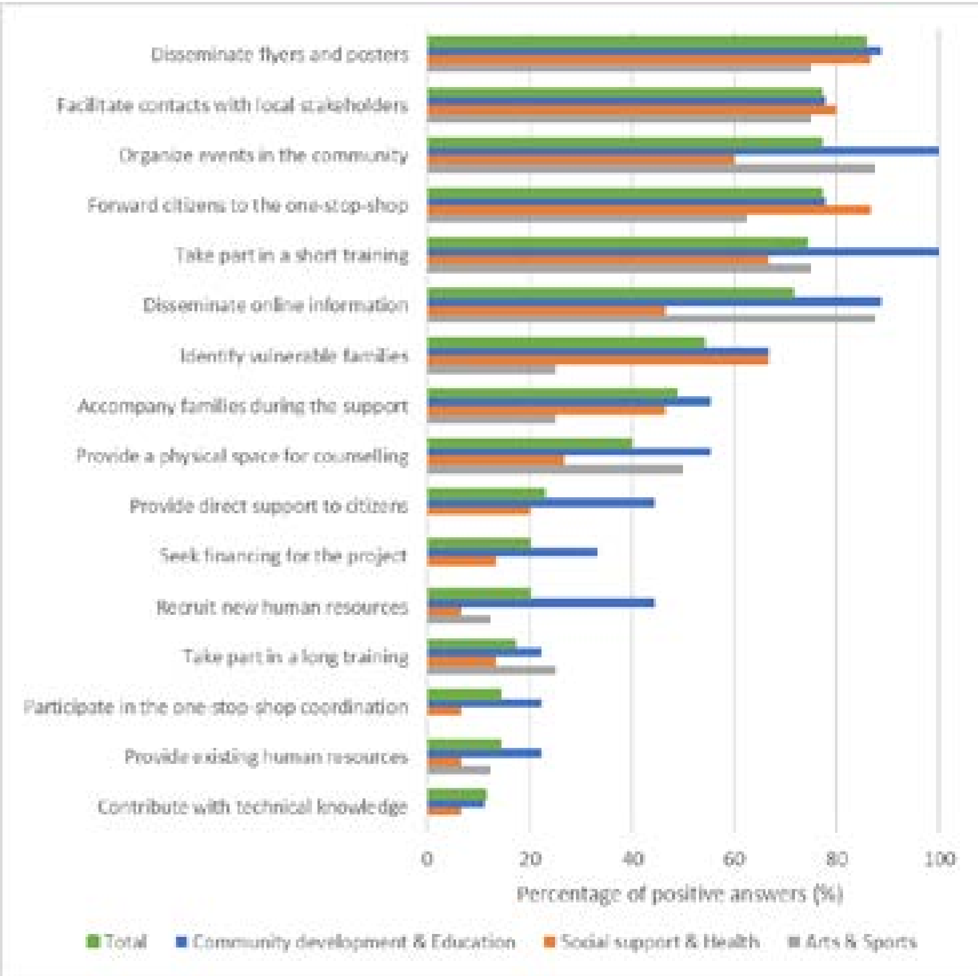

Figure 2 – Positive answers to potential collaborative roles for interviewed organizations.

3.4. Drivers, barriers, and solutions to foster collaboration

In the final section of the interview, the organizations were asked their motivations and obstacles to collaborate in providing local-scale energy-related support and to propose solutions to foster their involvement. Figure 3 and Figure 4 show the drivers and barriers,

respectively, while Figure 5 presents the solutions for deeper collaboration.
When asked about the critical drivers of collaboration, interviewed stakeholders most frequently mentioned environmental concerns (63%), participation in the community (46%, and social support to vulnerable populations (40%). Factors such as the possibility of obtaining financing (14%), improvement of local economic conditions (14%), involvement of other local partners (11%), and employment or training opportunities (9%) generally seem less important to the interviewees. A few differences between types of local organizations are noteworthy. Environmental concerns are the predominant driver in community development associations and education institutions but less relevant for social support and health institutions. On the other hand, social support to vulnerable populations is a major driver for social support and health institutions, but less relevant for community development associations, education institutions, and arts and sports clubs.

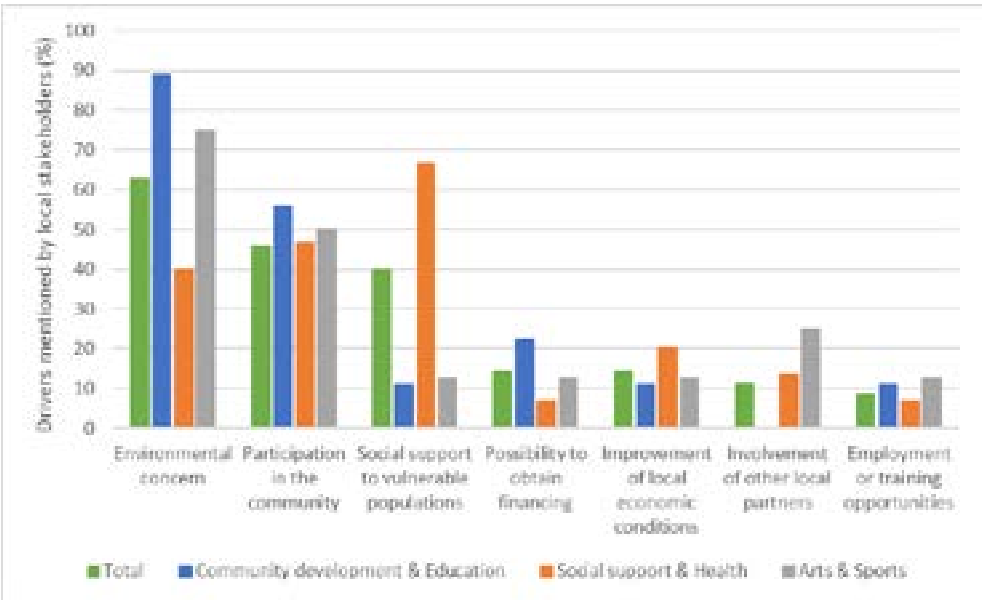

Figure 3 – Drivers for local stakeholders' collaboration in energy projects.

However, this willingness to participate in a topic that is seen as relevant is hindered by barriers, most notably scarce human resources (69%), lack of time and other priorities (40%), concerns related to financing and infrastructures (40%), and low receptivity to energy-related issues in their target audiences (20%). Most local organizations interviewed do not identify lack of institutional alignment, lack of knowledge on energy topics, and doubts about impacts as significant barriers (9% each). Community development associations and educational institutions seem to be the ones most struggling with human resources, with a dependence on volunteer work, and with financing and infrastructure concerns, often relying on ad-hoc funding and rented infrastructure. Social support and health institutions perform better on these dimensions, likely due to long-term partnerships with public authorities who are dependent on them to guarantee basic social services for the local population. However, social support institutions argue that lack of time and other priorities and low receptivity in their target audience to energy issues can be significant barriers. Arts and sports clubs also mainly mention the same obstacles of scarce human resources, financing and infrastructure concerns, and lack of time and other priorities; notably, doubts about the practical impacts of this type of energy-related support also emerge for one-quarter of the interviewed.

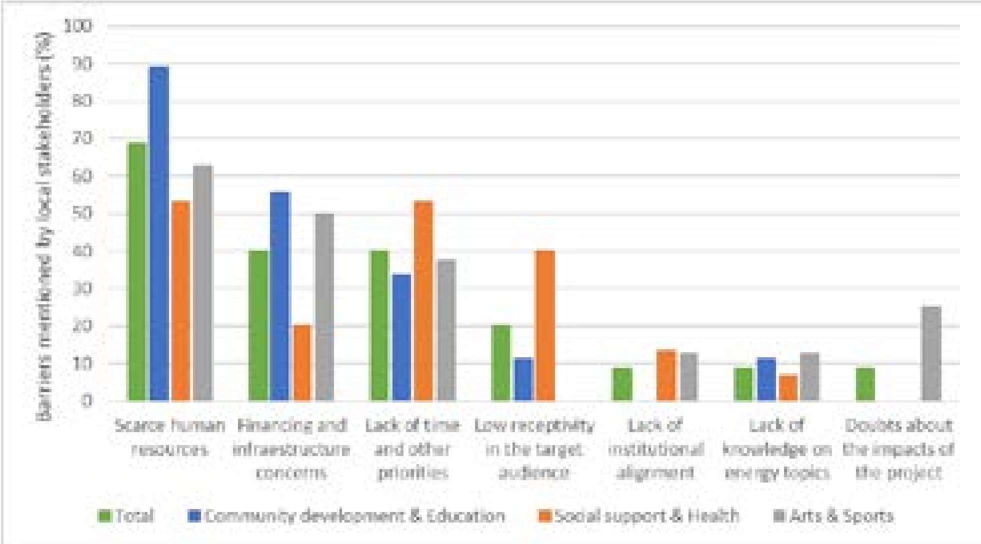

Figure 4 – Barriers to local stakeholders' collaboration in energy projects.

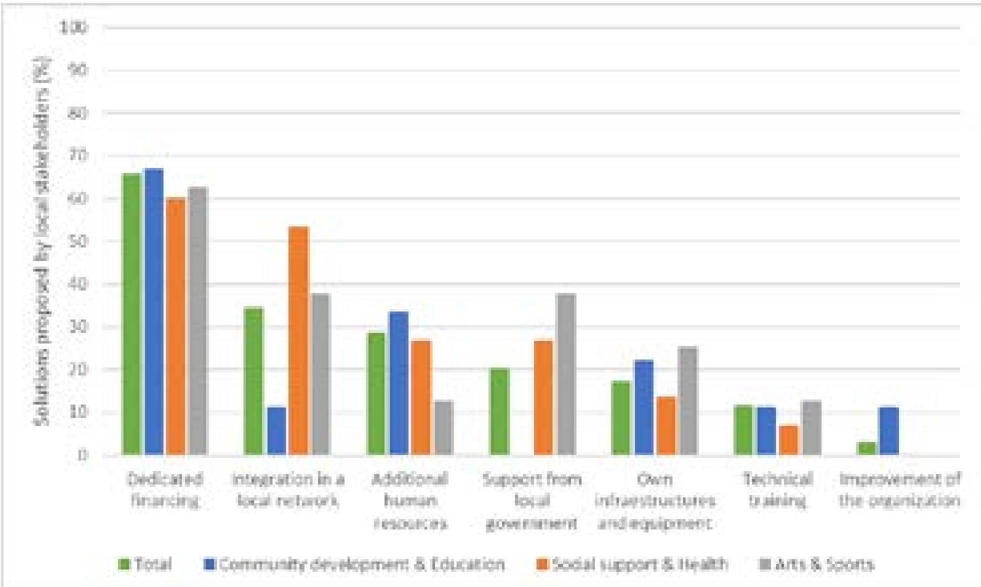

Figure 5 – Proposed solutions for local stakeholders' collaboration in energy projects.

The most frequently proposed solution to overcome the mentioned barriers is dedicated financing (66%) as the basis to solve most of the other barriers, followed by integration into a wider local network (34%), additional human resources (29%), and support from local governments (20%). Social support and health institutions and arts and sports clubs seem particularly keen on working on this topic by being integrated into a local network with support from the local government; this may reflect their acknowledgment that they can only contribute to a few specific tasks of providing energy-related support. Community development associations and education institutions may be more confident in their potential collaborative roles, particularly if better equipped with financing, human resources, and own infrastructure and equipment. While most stakeholders showed interest in participating in a small training to raise energy literacy and better understand the support services offered, only around 10% see it as one of the most important solutions to foster collaboration.

4. CONCLUSIONS

This case-study research contributes to an emerging literature that showcases the untapped potential of local organizations as intermediaries in energy-related support. These can build on well-established communication channels, existing local dynamics, and trusted relationships to foster community engagement and better identify and target hard-to-reach groups. However, the stakeholder mapping exercise and the exploratory interviews demonstrate an inherent diversity in the universe of local organizations regarding goals, activities, legal nature, number of employees and volunteers, geographical scope, and target audiences. By combining the target audiences of the 35 interviewed local organizations, it seems possible to reach most of the vulnerable households' hard-to-reach profiles identified in the literature. Furthermore, in the context of providing energy-related support through a one-stop-shop approach, different organizations can provide additional and complementary contributions that are symbiotic with their ongoing work.

However, these local stakeholders are often hard-to-reach themselves, being burdened with demanding activities performed under a generalized lack of financing and human resources and having scarce technical knowledge on energy topics. Thus, this research suggests that building a solid network of local partners (or, better yet, operationalizing an already existing network) requires dedicated funding, time, and resources to ensure meaningful and effective collaboration and to empower and capacitate local organizations. Furthermore, local stakeholders should be involved throughout the design, development, and implementation process to leverage their extensive expertise in the target audiences and territory. The applied methods of mapping and surveying local organizations and exploring opportunities for collaboration can be replicated elsewhere. Future work will continue to analyse interviews' results, looking to pinpoint the characteristics of "over-achievers" as specific local stakeholders that are willing and capable of significantly contributing to the provision of energy-related support to the general population and to hard-to-reach audiences.

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REFERENCES

CGF (2023). *Ponto de Transição: Projeto piloto de combate à pobreza energética em Portugal [“Transition Point: Pilot projet to combat energy poverty in Portugal”]*. Calouste Gulbenkian Foundation. September 2023: https://gulbenkian.pt/programas/programa-desenvolvimento-sustentavel/acao-climatica/ponto-de-transicao/

European Commission (2020). *A Renovation Wave for Europe - Greening our Buildings, Creating Jobs, Improving Lives*. COM(2020) 662 Final. Brussels, Belgium, 2020.

Gouveia, J. P., Palma, P., & Simões, S. G. (2019). Energy poverty vulnerability index: A multidimensional tool to identify hotspots for local action. *Energy Reports, 5, 187-201*. https://doi.org/10.1016/j.egyr.2018.12.004

Gouveia, J. P., Palma, P., Sequeira, M. M., and Mendes, M. (forthcoming). *Impact Report: Transition Point – A mobile one-stop shop for energy poverty mitigation*. In press by CGF.

Horta, A., Gouveia, J. P., Schmidt, L., Sousa, J. C., Palma, P., & Simões, S. (2019). Energy poverty in Portugal: Combining vulnerability mapping with household interviews. *Energy and Buildings, 203, 109423*. https://doi.org/10.1016/j.enbuild.2019.109423

IEA (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*.

INE (2023). *Census 2021 data*. Portugal Statistics. Retrieved June 2023 from: www.ine.pt

Mundaca, L., Rotmann, S., Ashby, K., Karlin, B., Butler, D., Sequeira, M. M., Gouveia, J. P., Palma, P., Realini, A., Maggiore, S., & Feenstra, M. (2023). Hard-to-Reach Energy Users: An ex-post cross-country assessment of behavioural-oriented interventions. *Energy Research & Social Science, 104, 103205*. https://doi.org/10.1016/j.erss.2023.103205

Portuguese Government (2023). *Estratégia de Longo Prazo para o Combate à Pobreza Energética 2022-2050 ["Long-term Strategy for Energy Poverty Mitigation 2022-2050"]*. Document for public consultation. Ministry of Environment and Climate Action.

Sequeira, M., & Melo, J.J. (2020). Energy saving potential in the small business service sector: Case study Telheiras neighborhood, Portugal. *Energy Efficiency, 13, 551-569*. https://doi.org/10.1007/s12053-020-09842-y

Sequeira, M.M., Gouveia, J.P., & Palma, P. (2021). *Case Study Analysis – Portugal*. User-Centred Energy Systems TCP - HTR Task. https://doi.org/10.47568/3XR115

Sequeira, M.M., & Gouveia, J.P. (2022). A Sequential Multi-Staged Approach for Developing Digital One-Stop Shops to Support Energy Renovations of Residential Buildings. *Energies 2022, 15, 5389*. https://doi.org/10.3390/en15155389

Simcock, N., E.H.K., Jenkins, Lacey-Barnacle, M., Martiskainen, M., Mattioli, G., & Hopkins, D. (2021). Identifying double energy vulnerability: A systematic and narrative review of groups at-risk of energy and transport poverty in the global north. *Energy Research & Social Science, 82, 102351*. https://doi.org/10.1016/j.erss.2021.102351

Ramsden, S. (2020). Tackling fuel poverty through household advice and support: Exploring the impacts of a charity-led project in a disadvantaged city in the United Kingdom. *Energy Research & Social Science, 70, 101786*. https://doi.org/10.1016/j.erss.2020.101786

Rotmann, S., Mundaca, L., Castaño-Rosa, R., O’Sullivan, K., Ambrose, A., Marchand, R., Chester, M., Karlin, B., Ashby, K., Butler, D., & Chambers, J. (2020). *Hard-to-Reach Energy Users: A Literature Review*. UsersTCP - HTR Task. ISBN: 978-0-473-64983-8.

Diffusion of energy technologies: the role and dynamics of supply-side information networks

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Keywords: energy transition, information networks, energy technologies adoption, supply-side actors, socio-spatial networks, innovation

Abstract

The diffusion of energy technologies is key for supporting the energy transition. While social influence and peer effects have been extensively studied on the demand side and found to impact adoption, less focus has been given to the role of information networks and collaboration among supply-side actors. This study analyses information networks in the photovoltaics, electromobility, and energy management systems sector in Switzerland to determine levers to improve communication among actors.

We identified and characterized 926 relevant supply-side actors in the field, iteratively through desktop research, interviews, surveys, and workshops. We conducted a geo-survey, collecting data from 157 actors regarding their information exchanges, events and associations used to exchange information, and geographic data associated with these interactions. By constructing socio-spatial information networks, we measured centrality, relatedness, and distance, comparing the social and spatial proximity perspectives.

The findings show that spatial distance does not play a significant role in determining connections among supply actors. Besides, the results highlight the potential of events and associations in rapidly disseminating information and bridging different types of actors (i.e. public entities, energy utilities, energy technology providers…), and of academic actors to act as intermediaries. Lastly, although there is a majority of energy technology providers and they are in direct contact with the demand, they are rarely information sources for public entities, indicating a top-down information flow. Strategies to enhance collaborations among supply-side actors should focus on leveraging these potentials and promoting bi-directional information flows, to tap into the experiences and insights of energy technology providers.

1. INTRODUCTION

Innovation's central role in the ongoing energy transition towards zero-carbon solutions has been highlighted from demand and supply-side perspectives (Kuzemko et al., 2017; Verbong & Geels, 2007). In the energy sector, many innovative solutions for decentralized, CO2-free electricity production and innovative mobility solutions exist. However, a broad uptake of these innovations is missing, especially in the case of integrated energy management systems (EMS) (Tagliapietra et al., 2019).

In the context of the Swiss energy strategy 2050 (SFOE. Swiss Federal Office of Energy, 2020), and the push towards a net-zero emission energy sector, integrated energy management systems based on innovative, new technological solutions are central. A key aspect to support the transition is the uptake of decentralized renewable energy production in households, such as photovoltaic panels (PV). In addition, the purchase of electric vehicles (EVs) has also been gaining ground in Switzerland. Thus, an increase in PV grid-connected prosumers combined with EV-related higher electricity consumption brings forward the need to focus on efficiently managing grid performance.

Based on the ideas of knowledge diffusion in networks and the uptake of novel ideas by co-located actors, the role of knowledge dissemination in adaptation to changing external conditions has been highlighted by many authors in different geographical, governmental, and contextual settings (Binder et al., 2017; Wyss et al., 2015, 2018). Concerning the diffusion of technological and social energy innovations, studies have pointed to the importance of localized communities of knowledge (Forrest & Wiek, 2014; Scotti & Minervini, 2017; Süsser et al., 2017), and the role of spatial and social distance in determining the uptake of novel technologies, which supports the energy transition (Bridge et al., 2013; Mattes et al., 2015).

The interaction between supply-side actors has been identified as a central aspect in the geographical diffusion of innovative technological solutions in the PV domain (Carattini et al., 2018). It also calls for the identification of central information carriers as well as innovation dissemination patterns to move towards more targeted and focused support and information campaigns in the context of the ongoing transition to renewable energy and mobility systems.

In this study, we specifically focus on information networks in the field of integrated EMS linking photovoltaics and electro-mobility. Thus, we are interested in identifying the central information carriers and channels in supply-side innovation-diffusion networks in Switzerland's EMS, PV, and EV sectors. These sectors have been identified to be of central importance for achieving the energy strategy 2050, and the shift to a zero-carbon society (Breyer et al., 2017; Haarstad, 2016). Innovative solutions to couple PV and EV exist, however, the systemic and spatial dynamic of the diffusion of information about these solutions remain unclear (Cohen et al., 2019).

Thereby, we aim to understand the role and dynamics of information flows among supply-side actors in the EMS, PV, and EV sectors. Supply-side actors considered include energy technology providers, energy or e-mobility service companies, including consulting, energy utility companies, the construction sector, public and non-profit organisations, associations, and academic organisations. We are interested in finding out who the main information catalysers within the region and domain of interest are, which types of organisations have a privileged position in the network, and how that network translates into the geographic space.

2. METHODS

This research was conducted with a mixed-methods approach that included (i) interviews with 26 demand and supply-side actors from the EMS sector (ii) workshops with supply-side actors (iii) a demand-side survey of 5,000 adopters of EMS, PV, and EV, (iv) desktop research to identify key actors in the EMS supply side landscape in Switzerland, and (v) a survey with 157 supply-side actors. This paper focuses on parts iv and v, with the goal of analysing the information networks of supply-side actors in the sector. However, other parts are mentioned in the data-collection section and the discussion frames the findings using the interview results. This work is centred on four regions of Switzerland, bounded by their respective cantons boundaries and representative of the three official languages of the country: Solothurn and St. Gallen (German), Vaud (French), and Ticino (Italian).

2.1. Data collection: supply-side actors survey

To select the supply target sample of key actors relevant to the diffusion of EMS integrating PV and EV, we used an iterative process that included workshops with regional supply actors (6% of the sample), interviews with supply and demand actors (3%), a survey of 5,000 demand-side actors (21%), and desktop research i.e. mentions of partners in websites (54%), organisers of events (7%) and members of relevant associations (9%). We validated the sample considering their field of activity (according to the Swiss general classification of economic activities, NOGA codes), their connection with technology users, and their location. The final target sample for the supply actors survey contained 926 organizations key for the diffusion of EMS in Switzerland. Of those, 60% are energy technology providers, mainly providing installation and engineering services. Associations, energy and e-mobility service companies and energy utility companies rank second (9%), followed by public and non-profit organizations (7%). Regarding the location, 56% of the organizations are concentrated in four cantons, Zürich (18%), Bern (14%), St. Gallen (13%), and Vaud (11%), while the rest is spread over the remaining Swiss cantons.

We contacted these organisations in January 2023 via post and invited them to fill in a map-based online survey hosted on the platform Maptionnaire and available in four languages (English, German, French and Italian). The first part of the survey contained questions about the general characteristics of the organization (sector, number of employees, location etc.) and the respondent's role within the organisation. The second part focused on information exchanges of organizations related to the technology. We filtered the survey respondents into three main groups, depending on which technology they worked the most with among EMS, PV or EV. The respondents answered the survey regarding this specific technology.

From the target sample, 157 organizations responded to the survey, a response rate of 17%. Of those, 37% of the respondents stated they were working with EMS, 49% have the most professional experience in PV and 14% with EV. The majority of the respondents are energy technology providers (36%), followed by energy or e-mobility service companies (18%), energy utility entities (15%), construction sector (12%), public and non-profit organizations (9%) and associations (6%). Compared to the target sample, we have a significantly lower share of energy technology providers, more energy and e-mobility service companies as well as energy utility companies in the sample. Also, a higher share of organizations from the construction sector answered the survey (12%).

The organizations in the sample are mostly located in the German-speaking cantons of Switzerland (56%), 33% are located in the French-speaking part and 11% in Ticino. 20% of the organizations are small-sized (1-9 employees), 40% are medium-sized (10-49), while the remaining ones are rather large, with 50-250 (20%) and >250 employees (20%).

Across the sample, 71% of the organizations state that they work with EMS. The majority work with PV (93%), battery storage (73%), and EV charging stations (81%), while only 29% work with EV. Related to EMS, the majority of the organizations state that they work with the residential sector (89%) as well as the industrial and production sectors (71%). They are less active in the office sector (55%) as well as the retail and service sectors (41%). For PV, the ranking of the sectors is the same as for the EMS technology, although they are less active in the industrial and production sectors. For EV, 100% of the organizations are active in the residential sector. They are also mostly active in the office sector (82%), as well as the retail and service sector (82%) and least active in the industrial and production sector (68%).

2.2. Network analysis

To analyse the information network between supply-side actors, we applied a reference-based and affiliations-based network approach.

Within the *reference-based* approach, the network was created based on the actors mentioned by the respondents in the survey when asked about the professional from another organization with whom they collaborate or exchange information the most.

First, we examined the relationships between categories of actors. We constructed an aggregated network of categories and looked at (ii) the strength of the links between each category and (ii) the centralities of the nodes. To measure centrality, we used *degree centrality* i.e. the number of direct connections a node has, in this case, the number of times a node is mentioned by other supply-side users, and *betweenness centrality* i.e. how often a node lies on the shortest path between other pairs of nodes. We used the software Tulip and the centrality algorithms included.

Second, we examined the geographic distribution of the specific supply-side actors in the reference network. To do that, we geocoded the addresses available on the supply-side actors' websites using the plugging MMQGIS available in QGIS. We used the SNoMaN social network mapping and analysis nexus web-based platform to visualize the network and measure the distances between actors. We also calculated the network community algorithm and observed their distribution in the geographic space. The objective was to evaluate if supply-side actors clustered in the network also clustered in space.

For the *affiliations approach*, supply-side actors were asked which events and associations

they used to exchange information on EMS, PV and EV. The data collected with these questions allowed us to create a bi-partite and a projected network.
A *bi-partite network* connects the actors directly to the events and associations they mention they use to exchange information. In this way, we can evaluate which events/associations are the ones used more often to exchange information (degree centrality), which ones have a brokerage role, i.e. are in a strategic position to diffuse information among actors (betweenness centrality) and if they connect diverse or similar actors in terms of category (academia, association....) or technology that the supply-side respondent mostly works with (EMS, PV or EV).
The *projected network* directly connects those actors that mention the same event and /or association. In this case, we created a combined affiliation network that included both events and associations. The links due to events were weighted double, as it was considered that potential face-to-face interactions in an event implied a stronger connection. We also looked at the geographic distribution of this network and the network clustering using the Louvain algorithm provided by Tulip.

3. RESULTS

3.1. Energy technology providers are central, the construction sector and academia show higher relative importance

In absolute terms, energy technology providers are the ones referred to the most as sources of information. When weighing the results by the target sample, the construction sector and academia gain relative importance (Table 1). This shows that these two groups may be underrepresented in the target sample when compared to their importance in the sector. When weighing these results by the number of survey respondents in each category, academia and associations are the ones gaining relative importance, implying that these two categories are often mentioned by others even if their presence is small.

Table 1: Categories mentioned by supply-side respondents when asked about with whom they exchanged information or collaborated regarding the technology, i.e. EMS, PV or EV.

Categories	# times mentioned	Total in the target sample	# times mentioned / target sample	Total in the survey sample	# times mentioned / survey sample
Construction sector	7	18	28%	19	37%
Academia	5	21	24%	3	167%
Public and non-profit entity	10	63	8%	14	71%
Association	13	82	6%	10	130%
Energy or e-mobility service companies	9	83	6%	29	31%
Energy utility entity (energy production, distribution and supply)	9	84	6%	24	37%
Energy technology provider	41	555	1%	56	73%
Grand Total	**94**	**928**	**1%**	**155**	**60%**

3.2. Strong information network between technology providers and service companies and asymmetric circulation of information flows

The network visualization of the references between categories (Figure 1) shows that energy technology providers are mostly mentioned by energy or e-mobility service companies, followed by the construction sector. They are mentioned far less often by energy utility entities, barely mentioned by associations and not mentioned at all by academia and public and non-profit entities. Energy technology providers, yet, mention very often not only energy or e-mobility service companies but also associations and public and non-profit entities.

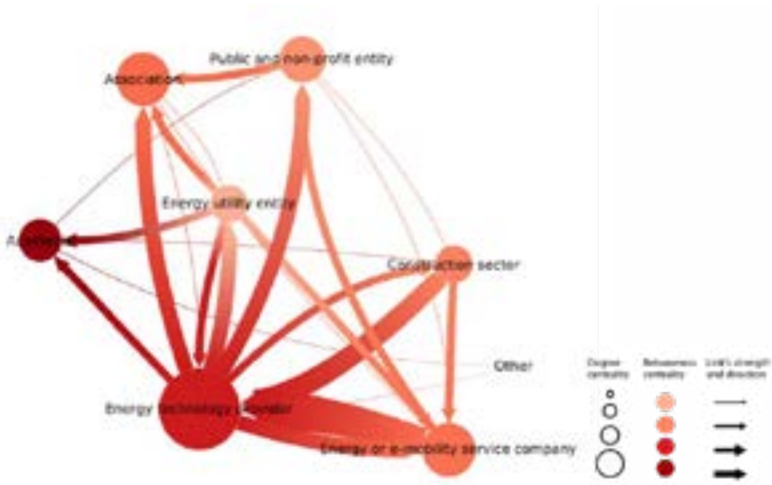

Figure 1. Reference network aggregated by supply-side categories. The arrows point to which the category was referenced by the respondent.

These results suggest (i) a great synergy between energy technology providers and energy or e-mobility service companies and (ii) an asymmetric "top-down" circulation of information flows, where energy technology providers obtain information from public entities while these do not see energy technology providers as sources of information or valuable collaborators. Additionally, the network allows us to see that, although energy technology providers may have a higher degree centrality, i.e. the overall number of respondents that mentioned them, academic actors seem to have higher betweenness centrality, that is, they are in more strategic positions to rapidly connect actors.

3.4. Events and associations have a brokerage role and connect diverse actors

A few events seem to be key for the exchange of information within the supply-side EMS, PV and EV sectors: Powertage (mentioned 19 times), the AEE congress (13 times), Innovationsforum Energie (11) and Smart Energy Party (10) in that order. They show both higher in-degree, meaning they are mentioned by more supply-side respondents, and betweenness centrality (100, 326, 240, 218), meaning they are in strategic positions to spread information in the network. The events also link different categories of actors (Figure 2, left). For instance, the AEE Congress is a reference for energy utility entities, energy technology providers, one association and one public and non-profit entity. Powertage connects, not only energy technology providers and energy utility entities but also energy or e-mobility service companies and associations. In terms of technologies, (Figure 2, right), professionals primarily working with different technologies seem to attend the same events.

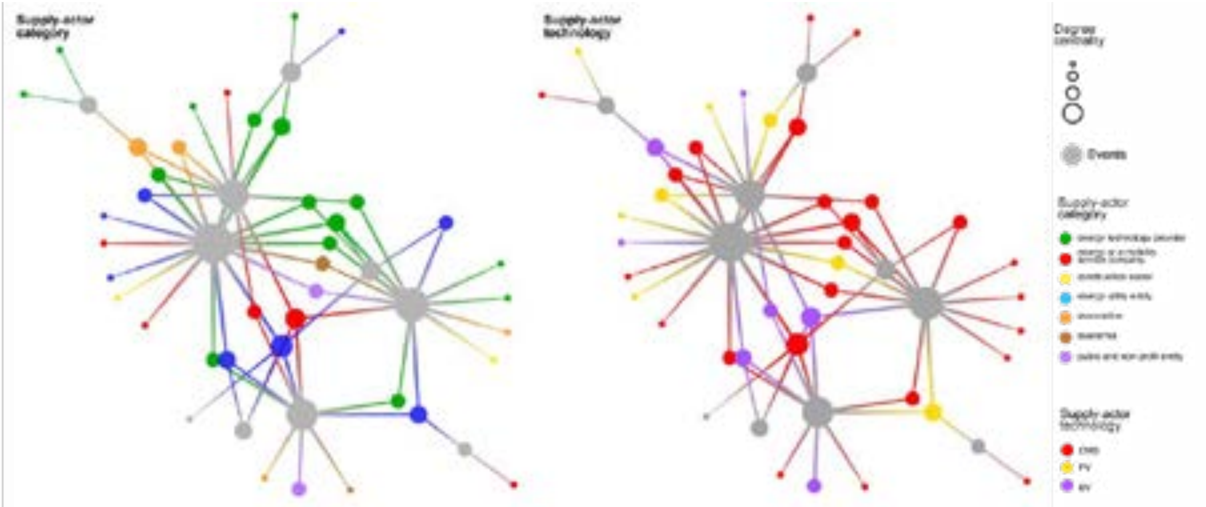

Figure 2. Network of events mentioned by supply-side respondents generated with the software Tulip and represented with the force-directed FM^3 (OGDF) algorithm layout.

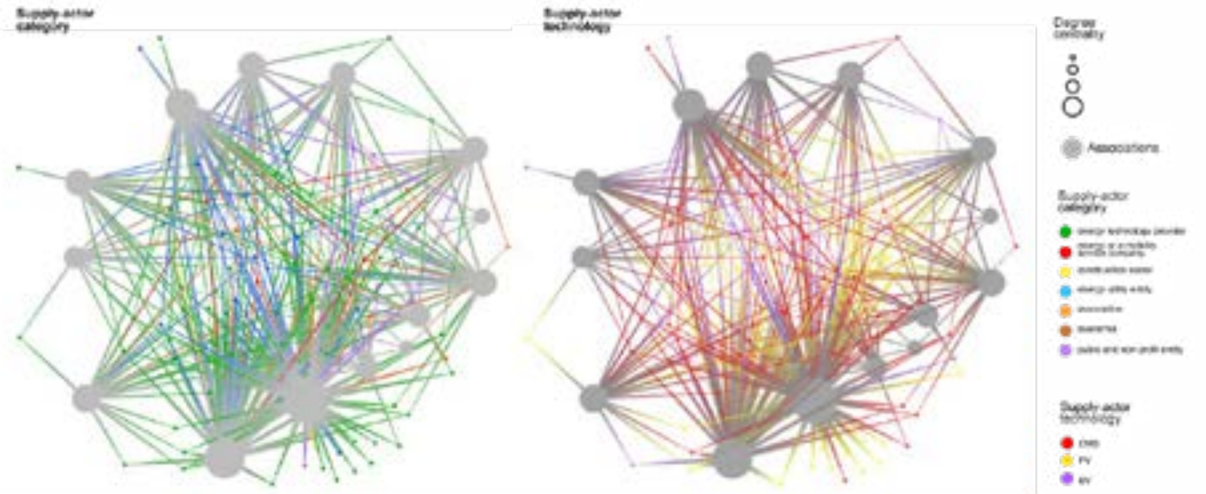

Figure 3. Network of associations mentioned by supply-side respondents generated with the software Tulip and represented with the fast multipole embedder (OGDF) algorithm layout.

Most associations seem to be important for the exchange of information within the supply-side EMS, PV and EV sector. Swissolar is mentioned 70 times and Electro is mentioned more than 50. They are followed by VSEAES (35), Mobility and EIT (24), VESE (23), eMobile, SIA and Energie-cluster (21), Swisscleantech (20) and others below 20. These all show high betweenness centralities (2179-140), being able to rapidly connect actors in the network. As with the events, they also show a high diversity of categories of actors connected and technologies these actors primarily work with (Figure 3).

3.3. No spatial patterns on reference network and spatial concentration of technologies on affiliations network

When looking at the geographic distribution of the reference network, connected actors are not particularly geographically close (Figure 4, left). Additionally, the communities automatically generated based on the structure of the network are not reflected in the location of these actors in space (Figure 4, right).

Figure 4. Distribution of reference network in the geographic space using the software SnoMaN. On the left, the size and colour of the nodes represent their degree centrality. On the right, the colour of the nodes represents the results of the link community algorithm while the polygons represent the convex hull by community.

The projected affiliations network (Figure 5) shows a higher concentration of connections between PV actors in the French-speaking region of Switzerland and of EMS in the German-speaking region. These patterns are also visible when considering the percentage of actors working with each technology in each linguistic region and the language preferred by the respondents when responding to the survey. Although with fairly balanced numbers, the EV network is the one showing the highest percentages in the Italian-speaking region and of Italian-speaking respondents.
When looking at the Louvain network-based clustering, no geographic pattern seems to be detected, with all the clusters being present in all linguistic regions of Switzerland. The network clusters also do not seem to be aligned with the technologies. All network clusters seem to have respondents of the three technologies and all technologies seem to be part of all network clusters.

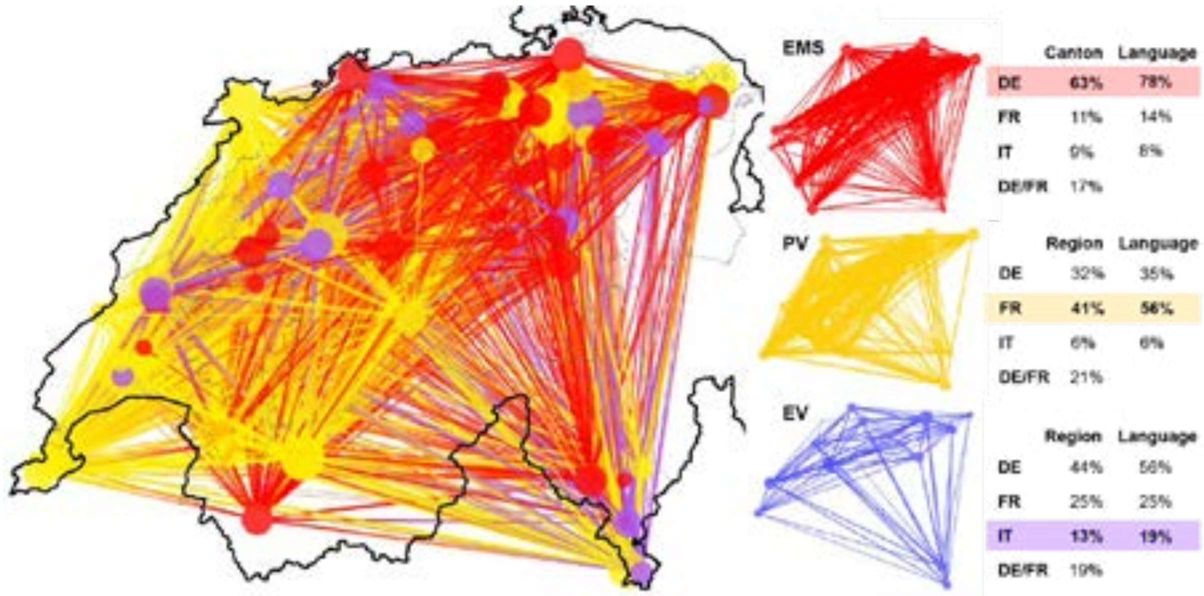

Figure 5. Projected affiliation network generated with the software Tulip. The colours of supply-side respondents show the technology the respondent works with. The layout is based on the geographic coordinates.

4. DISCUSSION

In general, the supply-side network is characterized by (i) diverse connected actors, (ii) "top-down" reference information flows, (iii) high diffusion and brokerage potential of events and associations, and (iv) limited relevance of spatial proximity.

The results suggest that actors from different categories exchange information, collaborate, attend the same events and are members of the same associations. Diffusion of innovations theory (Rogers, 2003) states that for innovations to flow through interpersonal networks, there should be a balance of homophily, the similarity of individuals interacting, and heterophily, the dissimilarity of those individuals. Based on the theory of "the-strength-of-weak-ties" (Grannovetter, 1973), new information flows into the group through heterophilic individuals, the weak ties, to rapidly diffuse through among the homophilic individuals, or strong ties. Therefore, to maximize innovation, we need heterophily to bring new ideas into a group while having enough homophily to ensure these diffuse. The supply-side network in Switzerland shows a high heterophilic potential that can be leveraged for the diffusion of information. Moreover, the tight and diverse network connections suggest that, by concentrating on some key actors, such as Solar Manager, Swiss eMobility or the SFOE, it may be possible to rapidly spread the information and practices.

An asymmetrical top-down circulation of information flows suggests that, although public or non-profit entities are active in sharing useful information for providers, such as regulations, subsidies or aid, they do not consider energy technology providers as sources of information. If public entities actively collect experiences and challenges from providers and are more involved with the implementation process, the direction of information flows could be balanced and the coordination between actors improved. With energy technology providers representing a great majority of the actors involved in the sector, one of the priorities for the diffusion of integrated EMS is to understand their needs and challenges when selling and implementing these technologies.

The results suggest that events and associations can become key channels to efficiently inform diverse actors. Some events have a central role in diffusing information, being a reference for several supply-side respondents, connecting actors of different categories, and having brokerage potential (Powertage, AEE Congress, Innovationsforum Energie, Smart Energy Party). Associations show a very extensive reach, with a more homogenous and higher diffusion potential. This suggests that, although they lack the personal face-to-face interaction component of events, they may be more effective at diffusing unidirectional information. Swissolar, ElectroSuisse and VSEAES are the most relevant, being a reference for information and with brokerage potential. A caveat of the survey is its timing, shortly after the COVID-19 epidemic, which could potentially have reduced the perceived relative importance of events.

Lack of coordination between actors and integration of the system is one of the barriers to the diffusion of EMS mentioned by supply-side actors during the interviews. One actor mentions the lack of compatibility of different systems and integration while another one talks about the lack of a consistent ecosystem. Some mention the need for a coordinating actor that accompanies the demand on the process of decision and implementation.

The results how events and associations could be used as a platform to improve coordination and to discuss better forms of integration among systems. These spaces could also be used to introduce co-adoption dynamics and leverage them through business strategies, for instance, in the form of bundles. Co-adoption has been identified in the literature as an important lever to increase the adoption of related technologies (Bollinger & Gillingham, 2012; Rai et al., 2016; Rogers, 2003). Bundles have been identified in the supply-side interviews as a potential lever for diffusion. "*In general, discussions stop at the moment we make offers, so those who manage to get by, in my opinion, at the beginning, are those offering a bundle. They'll tell you: "I'm offering you everything, I'm equipping you entirely key in hand (...) everything is included." (...) Thus, we need to do the packaging. Basically, that's the future*", says one actor. From the demand-side perspective, interview partners also explain how the presence of coordinating actors helped them: "*The advantage for me was that everything was implemented as an overall/entire system with the coordination of the energy advisor.*"

Events and associations display an interface potential to increase coordination of actors and integration of systems. The strong connection between public and non-profit entities and associations could be used to set coordinated agendas, launch information campaigns and organise events. Public entities could also utilise associations' membership to start a matching program, i.e. e. connecting supply-side actors' pairs that could gain by collaborating.

Connections between supply-side respondents do not seem to be dictated by spatial proximity. This could also be a result of only considering the main location of the organisation for the analysis and of not distinguishing those organisations that have only one site from the multi-located ones. Further research should work on exploring these aspects in more detail and developing more refined measures of distance.

5. CONCLUSION

This research aimed at developing a better understanding of supply-side networks in the sector of EMS integrated with PV and EV in Switzerland. For this, we performed a mixed-method study to collect relevant actors in the energy innovations landscape in the region and we conducted a survey to understand the relationships between those actors and the structure of the information networks.

The findings show that actors of different types exchange and collaborate. However, although there is a majority of energy technology providers and they are in direct contact with the demand, they are rarely information sources for public entities, indicating a top-down information flow. The results also highlight the potential of events and associations in rapidly disseminating information and bridging different types of actors (i.e. public entities, energy utilities, energy technology providers…), and of academic actors to act as intermediaries. Lastly, spatial distance does not play a significant role in determining connections among supply actors. Strategies to enhance collaborations among supply-side actors should focus on leveraging events and associations potential and promoting bi-directional information flows, to tap into the experiences and insights of energy technology providers. Improved communication among supply-side actors is key to offer coordinated services to potential adopters and, with that, support the diffusion of energy technologies, as well as to increase compatibility of solutions and technology integration, opening the door to co-adoption dynamics.

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REFERENCES

Binder, C., Mühlemeier, S., & Wyss, R. (2017). An Indicator-Based Approach for Analyzing the Resilience of Transitions for Energy Regions. Part I: Theoretical and Conceptual Considerations. Energies, 10(1), 36. https://doi.org/10.3390/en10010036

Bollinger, B., & Gillingham, K. (2012). Peer Effects in the Diffusion of Solar Photovoltaic Panels. Marketing Science, 31(6), 900–912. https://doi.org/10.1287/mksc.1120.0727

Breyer, C., Bogdanov, D., Gulagi, A., Aghahosseini, A., Barbosa, L. S. N. S., Koskinen, O., Barasa, M., Caldera, U., Afanasyeva, S., Child, M., Farfan, J., & Vainikka, P. (2017). On the role of solar photovoltaics in global energy transition scenarios: On the role of solar photovoltaics in global energy transition scenarios. Progress in Photovoltaics: Research and Applications, 25(8), 727–745. https://doi.org/10.1002/pip.2885

Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2013). Geographies of energy transition: Space, place and the low-carbon economy. Energy Policy, 53, 331–340. https://doi.org/10.1016/j.enpol.2012.10.066

Carattini, S., Péclat, M., & Baranzini, A. (2018). Social interactions and the adoption of solar PV: Evidence from cultural borders. Centre for Climate Change Economics and Policy Working Paper. Grantham Research Institute on Climate Change and the Environment.

Cohen, J., Azarova, V., Kollmann, A., & Reichl, J. (2019). Q-complementarity in household adoption of photovoltaics and electricity-intensive goods: The case of electric vehicles. Energy Economics, 83, 567–577. https://doi.org/10.1016/j.eneco.2019.08.004

Forrest, N., & Wiek, A. (2014). Learning from success—Toward evidence-informed sustainability transitions in communities. Environmental Innovation and Societal Transitions, 12, 66–88. https://doi.org/10.1016/j.eist.2014.01.003

Grannovetter, M. (1973). Granovetter_1973_weakties.pdf. American Journal of Sociology, 78(6), 1360–1380.

Haarstad, H. (2016). Where are urban energy transitions governed? Conceptualizing the complex governance arrangements for low-carbon mobility in Europe. Cities, 54, 4–10. https://doi.org/10.1016/j.cities.2015.10.013

Kuzemko, C., Mitchell, C., Lockwood, M., & Hoggett, R. (2017). Policies, politics and demand side innovations: The untold story of Germany's energy transition. Energy Research & Social Science, 28, 58–67. https://doi.org/10.1016/j.erss.2017.03.013

Mattes, J., Huber, A., & Koehrsen, J. (2015). Energy transitions in small-scale regions – What we can learn from a regional innovation systems perspective. Energy Policy, 78, 255–264. https://doi.org/10.1016/j.enpol.2014.12.011

Rai, V., Reeves, D. C., & Margolis, R. (2016). Overcoming barriers and uncertainties in the adoption of residential solar PV. Renewable Energy, 89, 498–505. https://doi.org/10.1016/j.renene.2015.11.080

Rogers, E. M. (2003). Diffusion of Innovations (5th ed.). Simon and Schuster.

Scotti, I., & Minervini, D. (2017). Performative connections: Translating sustainable energy transition by local communities. Innovation: The European Journal of Social Science Research, 30(3), 350–364. https://doi.org/10.1080/13511610.2016.1237282

SFOE. Swiss Federal Office of Energy. (2020). Energy Strategy 2050. https://www.bfe.admin.ch/bfe/en/home/policy/energy-strategy-2050/what-is-the-energy-strategy-2050.html

Süsser, D., Döring, M., & Ratter, B. M. W. (2017). Harvesting energy: Place and local entrepreneurship in community-based renewable energy transition. Energy Policy, 101, 332–341. https://doi.org/10.1016/j.enpol.2016.10.018

Tagliapietra, S., Zachmann, G., Edenhofer, O., Glachant, J.-M., Linares, P., & Loeschel, A. (2019). The European Union energy transition: Key priorities for the next five years. Energy Policy, 132, 950–954. https://doi.org/10.1016/j.enpol.2019.06.060

Verbong, G., & Geels, F. (2007). The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). Energy Policy, 35(2), 1025–1037. https://doi.org/10.1016/j.enpol.2006.02.010

Wyss, R., Luthe, T., & Abegg, B. (2015). Building resilience to climate change – the role of cooperation in alpine tourism networks. Local Environment, 20(8), 908–922. https://doi.org/10.1080/13549839.2013.879289

Wyss, R., Mühlemeier, S., & Binder, C. (2018). An Indicator-Based Approach for Analysing the Resilience of Transitions for Energy Regions. Part II: Empirical Application to the Case of Weiz-Gleisdorf, Austria. Energies, 11(9), 2263. https://doi.org/10.3390/en11092263

Promoting Household Energy Conservation through Goal Setting and Signposting in a Rasch-Based Recommender System

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Abstract

Energy recommender systems comprise algorithms and interfaces that provide tailored energy-saving advice to consumers, helping them to save energy at home. Such systems have successfully used the psychometric Rasch model as their recommendation algorithm, matching energy-saving measures to consumers based on their respective difficulty and ability levels. While previous studies with such recommenders indicated positive user experiences, tailored advice did not lead to higher savings overall; not even when also using persuasive nudges, such as displaying social norm percentages in the system. One cause of these results could be that the system did not tap into goal setting or value-based motivational frames (e.g., signposts), as the system was perhaps used for exploration only.

In this study, we asked crowdsourcing and panel users (N=202) to use and evaluate our 'Saving Aid' Rasch recommender system, choosing any number of energy-saving measures they would like to perform at home. Through a 3x2-between subject design, we examined whether guided goal setting and signposts (kWh/Euro/CO2) affected user experience and energy savings. Following the signpost literature, we examined the moderation of these effects by user values, such as environmental concern (New Environmental Paradigm (NEP) score). A structural equation model analysis revealed that goal setting did not affect any outcome variables, while signpost framing had varying effects. Most importantly, contrary to our expectations, a CO2 signpost was not more effective with increasing NEP scores, but a kWh signpost did seem to result in less choice difficulty and higher self-efficacy for users with a lower NEP score, though without an increase in the amount of savings.

1. INTRODUCTION

To reach a greenhouse gas emission reduction towards net zero, both industry and household energy usage need to be reduced. As individuals can face many options to limit their energy usage (Gardner & Stern, 2008), choosing and taking efficient measures can be challenging. Energy recommender systems are digital technologies that can help consumers to overcome choice overload issues (Knijnenburg et al., 2015). They use tailoring algorithms to find suitable energy-saving measures for their users, presenting content that fits a consumer's needs.

An example is the 'Saving Aid' recommender system developed by Starke et al. (2020). It uses the psychometric Rasch model to provide tailored household energy-saving advice to its users, assessing the behavioural difficulty of energy-saving measures and matching these to individuals based on their energy-saving attitude (later, we refer to 'ability' instead). The use of Rasch is embedded in an attitude paradigm called 'Campbell's Paradigm' (Kaiser et al., 2010), which aims to mitigate the attitude-behaviour gap. It assumes attitude and behaviour are two sides of the same coin (Kaiser et al., 2010), proposing a stochastic, 'logit' relation between individuals' attitude and measures' difficulty when predicting whether a measure will be performed. An attitude becomes apparent by the increasingly behavioural steps that individual takes towards attaining an attitudinal goal, such as energy conservation. This is all modelled on a one-dimensional scale that captures both persons and measures on their ability and difficulty (Kaiser et al., 2010; Starke et al., 2020; 2021). The scale assumes measures are more difficult if they are performed by fewer people, while a person who performs more measures is considered more able, having a stronger ability or attitude.

For tailored advice, the Rasch model helps to explore the trade-off between a recommended measure's novelty and feasibility for a particular user (Starke et al., 2020). While the recommender system was effective in tailoring advice and increasing satisfaction (Starke et al., 2020), it did not necessarily make users choose the measures with higher energy savings. Additional studies that aimed to support higher energy savings through nudges, e.g., by presenting fit scores, social norms, and smart saving scores (Bams, 2018, Starke et al., 2017, Starke et al., 2021), affected *which* measures were chosen, but did not lead to higher savings.

One hypothesized problem is that kWh savings and their magnitude (e.g., how much is 100 kWh) are unclear. Moreover, users in the earlier studies might not have been committed or have had a specific goal in mind and thus opted for only few measures. To encourage higher savings, we implemented goal-setting functionality and investigated other value-based motivational frames, through signposting. Signposting refers to attribute translations (e.g., kWh, Euro) in line with user values, with the aim of activating certain user objectives (Ungemach et al., 2018). We summarize our research questions as follows: "*What are the effects of signposting and goal setting on the user experience and energy savings in a Rasch-based energy recommender system?*"

1.1. Goal setting

Goal setting is a commonly used method in environmental psychology and behavioural change studies (Abrahamse et al., 2005). According to Locke and Latham (2002), the mere presence of goals increases performance, and an adequate balance between goal difficulty and feasibility leads to higher satisfaction. A goal that is assigned by an authority figure will furthermore strengthen the belief that this goal is reachable (Locke and Latham, 1990). At the same time, feeling personally responsible for reaching a goal, leads to higher feelings of competence (Eccles and Wigfield, 2002). Goals that are autonomously set furthermore lead to higher achievement (Koestner et al., 2008). Following this, we presented users with three saving goals (an easy, moderate, and difficult goal), such that users had adequate guidance yet still had a degree of autonomy. We expected that this would lead to higher savings than having no goals.

1.2. Signposting

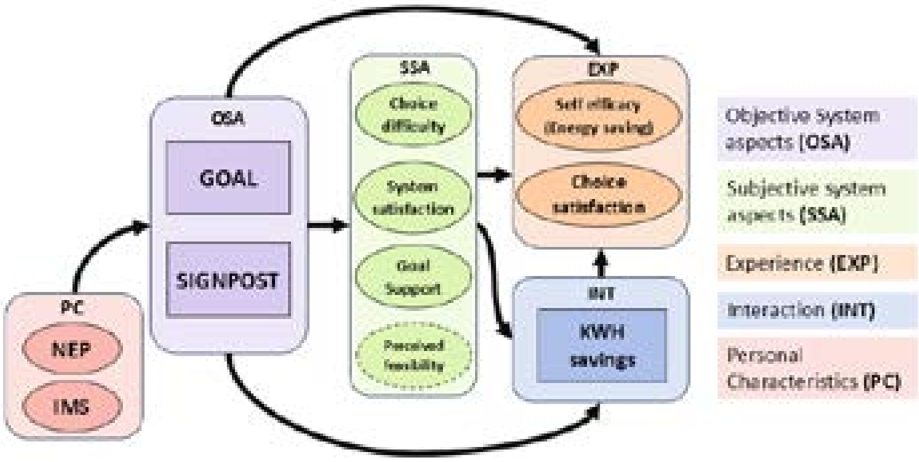
Energy-saving metrics are not restricted to kWh. They can be presented with different units, such as CO2 emission reductions and monetary savings. The understanding and expected consequences of measures can depend how the presented information is framed. According to Ungemach et al. (2018), such different translations of the same attributes can activate different user objectives, depending on the personal values of a user. For example, CO2 emissions might resonate with users who have stronger environmental values (Ungemach et al., 2018). This mechanism is referred to as 'signposting'. We expect that a CO2 signpost will motivate users with a high level of environmental concern to save more energy, based on the findings of Ungemach et al (2018), who observed that people with higher NEP scores were more likely to pick an energy-efficient car. We also expect that the monetary (Euro) signpost will increase savings for users who place more importance on money, and that the kWh signpost will work equally well for everyone, regardless of personal values.

1.3. User satisfaction

Previous recommender studies show that system manipulations on user behaviour (i.e., amount of energy saved) and user experiences (e.g., satisfaction) are mediated by user perceptions (Knijnenburg et al., 2014). We expect that presenting information in a way that is relevant to the user (i.e., signposting in line with user values), will aid the decision-making process, thus reduce choice difficulty and improve goal support (i.e. the extent to which the system helps users save energy), and that goal setting will improve user experience by providing a clear behavioural target. We furthermore expect that these subjective perceptions of the system would, in turn, lead to higher savings and improved user experiences as seen in earlier studies (Knijnenburg et al., 2014; Starke et al., 2021). Thus, an increase in choice satisfaction and improved energy-saving self-efficacy (i.e., belief in one's ability to save energy). Lastly, we expect that increased savings lead to an increased choice satisfaction, following (Knijnenburg et al., 2014). Figure 1 depicts these hypotheses, in a model that broadly follows the user-centric recommender evaluation framework of Knijnenburg and Willemsen (2015).

2. METHODS

Our experiment was subject to a 2x3 between-subject design. First, participants were either asked to set a goal or not. Second, there were three signpost conditions, presenting attributes and goals in terms of either kWh savings, monetary (€) savings, or annual kg CO2 reductions.



***NEP**= New environmental Paradigm (environmental concern), **IMS**= Importance of money score*

Figure 1: Hypothetical model, based on the evaluation framework of Knijnenburg and Willemsen (2015).

In total, 212 people participated in the initial study (202 after outlier removal), consisting of 86 males, 112 females, and 4 other/undefined, with a mean age of 25. 82% obtained at least some college education, while only 23% were homeowners. All participants lived in the Netherlands, following our selection criterium. After four weeks, we conducted a follow-up study to inquire about performed saving measures, which was completed by 170 returning participants (160 after outlier removal), with a comparable demographic distribution. Studies were run between May and June 2023 with participants from the Prolific and JFS Schouten participant databases, who were paid ~€4,- for their efforts. Participants were at least 18 years old and lived in the Netherlands, but home-ownership was not required. The study used a newly-developed online recommender system, based on earlier work (Starke et al., 2021), backed by a database of 135 energy-saving measures, obtained from Bams (2018).

To be able to provide ability-tailored advice, users indicated for 19 measures whether they performed them or not. Measures that did not apply to a user's housing situation were not used in the ability (i.e., attitude) calculation. This led to an ability rating between -2.7 and 3.6 logits. Afterwards, 'goal-condition participants' could select an accessible (600 kWh), moderate (1200 kWh) or challenging (1800 kWh) saving goal, based on the mean savings (1200 kWh) and median savings (660 kWh, for those who selected at least some amount) in the study by Bams (2018). Afterwards, all participants were presented 20 energy-saving recommendations closest to their ability level (sorted by absolute distance) to choose from. The total selected savings were shown at the top of the screen, as a proportion of the saving goal if applicable (as depicted in Figure 2). Gas-based measures were converted as 9.8 kWh / m^3. The recommender interface can be tested at: www.besparingshulp.nl/demo.

Following the choice task, participants were surveyed about their perceptions and experiences with the system, with the questions shown in Table 1. For the full overview of questions (before factor analyses), refer to Oonk (2023). Additionally, we used the revised New Environmental Paradigm (NEP) (α: 0.81 for both samples) by Dunlap et al. (2000) to measure environmental concern, the Money Importance Scale (IMS) by Franzen and Mader (2022) (α:

.77 for both samples) and the environmental self-efficacy scale by Lee and Tanusia (2016) (α: .87 & .85, AVE: .60 & .57). Participants could save their selected measures, and received an email with an overview one week after the study. After four weeks, participants were asked to join the follow-up study to indicate which measures they ended up performing.

We compared the differences in savings between goal conditions with rank-sum tests, the interaction effect between values and signposts with several (robust) multiple regressions, and the effect of subjective system aspects with a structural equation model (SEM).

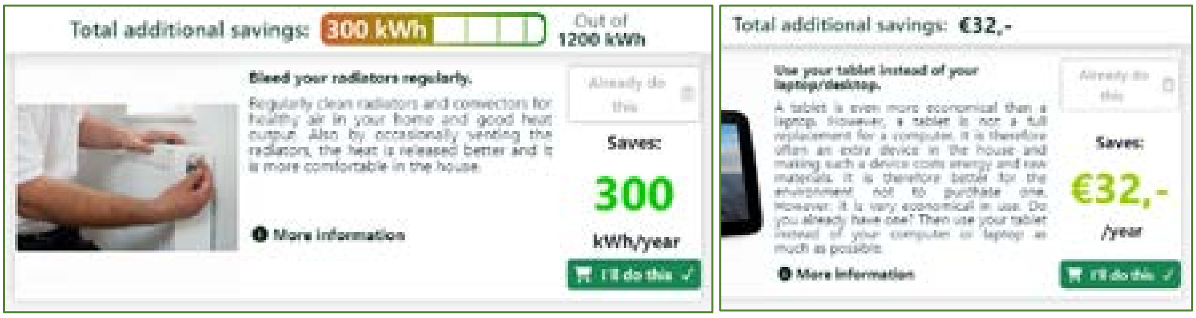


Figure 2: (Partial) screen captures of our recommender system interface. Depicted on the left is our Goal (kWh) condition, on the right the no-goal (euro) condition.

Construct	Name	Proposition	Study 1		Study 2	
			λ	R^2	λ	R^2
Choice difficulty	Cdif1	It was easy to choose between energy saving measures	-.73	.56	-.83	.71
Alpha:. 66(1)/.67(2)	Cdif3	The task of choosing energy saving measures was overwhelming	.53	.30	.50	.28
AVE:. 45(1)/.47(2)	Cdif4	Comparing the energy saving measures took a lot of effort	.73	.50	.63	.43
Choice satisfaction	Chsat1	I am satisfied with the measures I chose	.49	.66	.51	.78
Alpha: .73(1)/.76(2)	Chsat2	I think I would enjoy performing the chosen energy saving measures	.41	.47	.39	.46
AVE:. 66(1)/.65(2)	Chsat3	I would recommend the chosen measures to others	.47	.59	.49	.72
Goal support	Syssat 2	The Saving Aid (SA) is helpful to find appropriate measures.	.74	.62	.70	.51
Alpha: .86(1)/.82(2)	Gsup4	The SA gives me more insight into the energy consumption of devices and systems in my home	.77	.68	.78	.63
	Gsup5	The SA makes me more energy-conscious	.77	.69	.78	.63
AVE: .68(1)/.62(2)	Gsup6	The SA makes me more aware of my options for saving energy	.78	.71	.83	.72

Table 1: Questionnaire items and factor loadings (λ) for both the initial (1) and follow-up (2) samples. Alpha denotes Cronbach's Alpha, AVE the Average Variance Explained.

3. RESULTS

We found that participants evaluated the system very positively. 89% agreed at least to some extent with the proposition that *"the saving aid was helpful to find appropriate measures"*. Participants chose on average 7.5 new measures in the initial study (*M*=3057 kWh, *SD*=4406), of which they reported to complete on average 2.1 measures four weeks later (*M*=315 kWh, *SD*=538). We found no correlation between NEP score and ability level, suggesting that those with stronger environmental concern, did not report to already perform more actions. We also did not find a correlation between the chosen goal amount and either NEP or IMS scores.

3.1. Goal conditions

We first compared the savings between the goal and no-goal condition. The energy savings for the initial (main) study and the follow-up survey across these conditions are depicted in Figure 3. On average, surprisingly, participants selected less energy savings in the goal condition (*M*=2166 kWh; SD=2624) than in the no-goal condition (*M*=3880 kWh; *SD*=5452). A rank-sum test indicated that this difference was, however, not significant. Four weeks later, in the follow-up survey, the difference was reversed, with goal-condition savings being higher on average (*M*=340 kWh; *SD*=565) compared to the no-goal condition (*M*=294 kWh; *SD*=516). However, once again, this difference was not significant (p = .46). In contrast, we did observe that a higher chosen goal led to higher savings, in both the initial study and the follow-up study. For a full overview per goal condition, refer to Oonk (2023).

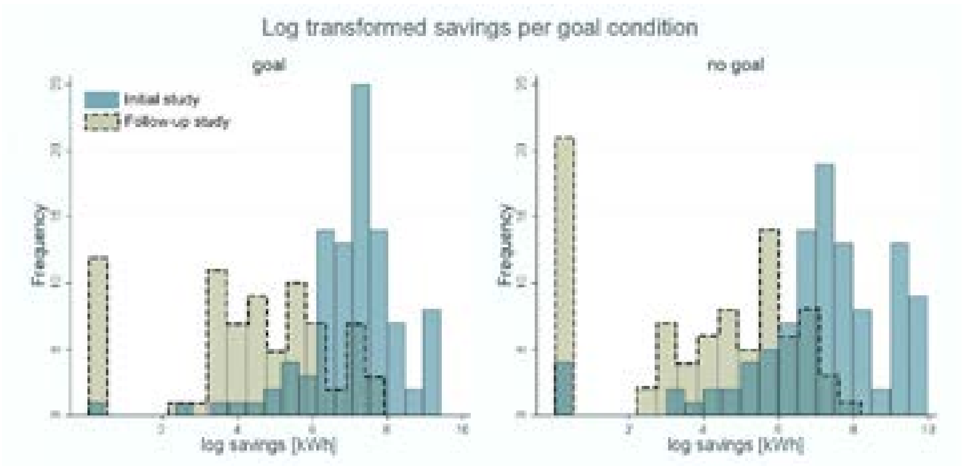


Figure 3: Chosen (initial study) and performed (follow-up study) Savings in the goal and no goal condition.

3.2. Signpost conditions

Figure 4 compares the chosen savings per signpost condition. We found that people saved significantly less in the CO2 condition (*M*=1782 kWh; *SD*=2554), compared to the kWh (*M*=3652 kWh, *SD*=4843) and Euro (*M*=3620 kWh, SD=5049) conditions (χ^2 = 10.11, p<0.001). After four weeks, participants saved on average 347 kWh (*SD*=507), 334 kWh

(*SD*=573) 268 kWh (*SD*=538) in the CO2, kWh, and Euro conditions, respectively. An Analysis of Variance (ANOVA) showed no significant difference between these three signpost conditions in the follow-up study, nor when a quadratic transformation was performed.

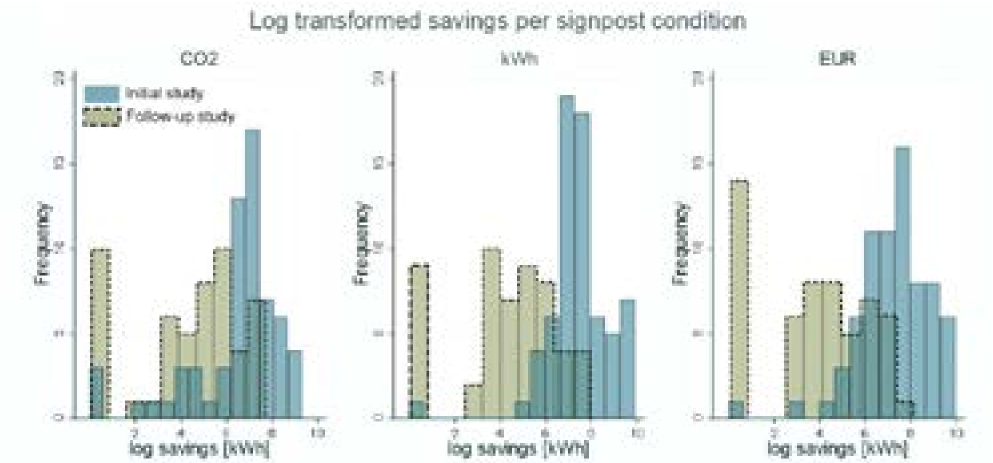


Figure 4: Savings per signpost condition, for both the initial (main) study and the follow-up study.

3.3. Signposts and values

To test for signposting effects, we inspected how a user's values (NEP) affected behavioural and user experience outcomes, using moderated regression. See Figure 5.

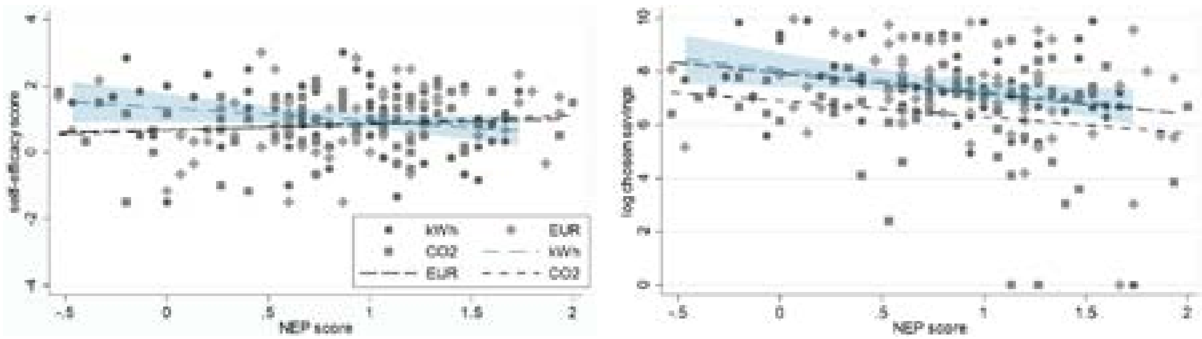


Figure 5: Effect of the NEP score on self-efficacy (left) and chosen savings (right) for different signposts. The blue shaded area depicts the 95% confidence interval of the kWh signpost.

We found an interaction effect between the NEP score and a CO2 signpost, where a higher NEP led to higher choice satisfaction (β=.30, p<0.01) and self-efficacy (β=.35, p<.05), compared to the effect of a kWh signpost. However, this was mostly due to a downward slope of the kWh signpost, as seen on the left in Figure 5 (similar results for choice satisfaction and choice difficulty). Additionally, the main effects of the CO2 signpost on choice satisfaction (β=-.59, p<.01) and self-efficacy (β=-.45, p<.05) were negative. Therefore, the beneficial effects of a CO2 signpost only applied to a minority with very high NEP scores, while the kWh signpost seems beneficial for a larger group of people lower on the NEP scale. We did not find such interaction effects on actual energy savings in the initial and follow-up studies (Figure 5 on the right depicts the savings in the initial study). We neither found any interaction effects between signposts and the Importance of Money (IMS) score on any of these outcome variables.

3.4. Subjective system aspects and SEM model

Finally, to examine mediated effects between changes in the interface, user perceptions and choice, and system evaluation, we constructed a structural equation model (SEM) in Mplus (Muthén & Muthén, 2023). The SEM model had a good fit: $\chi^2(202)=255.00$, $p<.01$, $RMSE=.040$, 90%-CI=[.025,.052], $CFI=.981$, $TLI=.979$. The fit for the follow-up SEM model was also good, and their results are merged in Figure 6, depicting only significant paths.

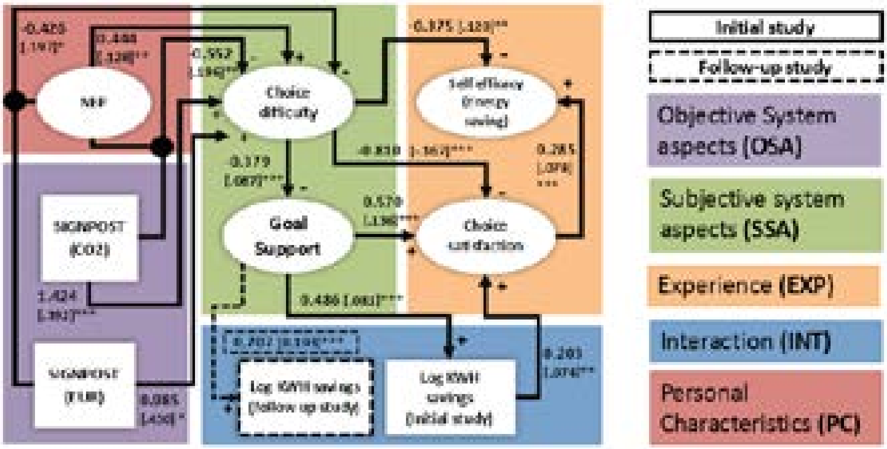


Figure 6: Structural Equation Model (SEM). Numbers on the arrows represent the β-coefficients; standard errors are between brackets. Effects between subjective constructs are standardized and resemble correlations. ∗∗∗, p < 0.001; ∗∗, p < 0.01; ∗, p < 0.05**.**

We found that the (interaction) effects between signposts and NEP scores on savings and experience outcomes were entirely explained by changes in choice difficulty and goal support. While the main effect of CO2 signposts (compared to kWh) *increased* choice difficulty (β=1.42, p<.001), CO2 signposts moderated by higher NEP scores *decreased* choice difficulty (β=-.55*, p*<.01). In turn, as shown in Figure 6, lower levels of choice difficulty led to an increase in goal support (β=-.38, p<.001), while increased goal support led to an increase in the selected savings, for both the initial study (β=.49, p<.001), as well as in the follow-up study (β=.71, p<.001). Lastly, an increased in the selected savings led to an increase in choice satisfaction (β=.20*, p*<.01*)*, which in turn led to a higher energy-saving self-efficacy (β=.29*, p*<.001).

4. DISCUSSION

We have evaluated the effectiveness of goal setting and signposting on energy-saving choices and user experience in the context of a tailored, Rasch-based recommender system. Our Rasch scale of energy-saving measures, rooted in Campbell's Paradigm, helps to effectively assess the ability of users, allowing our recommender system to present tailored advice. Our study has examined short-term user preferences for these tailored measures, that can be taken in one's household, examining user choices, perceptions, and evaluations, as well as their self-reported saving behaviour four weeks later. We have found that the system is rather effective for household energy conservation, with users reporting an average 316 kWh saved per person after four weeks. However, while users report to appreciate the system, we have found mixed results regarding our goal-setting and signposting manipulations. We did observe that all effects from signposting on outcomes were explained by changes in perceived choice difficulty and goal support, in line with our expectations and earlier work of Knijnenburg et al. (2014).

4.1. Goal conditions

We have not observed significant differences in kWh savings or user experiences between the goal and no-goal conditions, in contrast to previous non-recommender studies in an energy-saving context (Ungemach et al., 2018). We argue that the selection of energy-saving measures by users could have been experienced as a goal-setting task in itself (i.e., the total selected measures constitute a saving goal), diminishing the effect of overarching goal setting. Furthermore, the personalized Rasch system already aids users in finding ability-matched saving measures, which could minimize the effects of goal setting in terms of decision support Additionally, goal setting in an energy-saving context is often more effective when paired with feedback (Abrahamse et al., 2005), which was lacking in our session-based system. Lastly, participants selected on average 3057 kWh in savings, as compared to 1200 kWh in a previous study (Bams, 2018), surpassing the levels of the goals we suggested. This might have been due to a misinterpretation of the task for some participants: Several participants asked why there was not a 'I do not want to do this' button, and at least 33 participants clicked on either 'I'm already doing this' or 'I will do this' for *all* items in the list. This misinterpretation might have had an even stronger effect in the no-goal condition, due to the lack of a realistic saving target.

4.2. Signposting

Furthermore, we have compared the effects of three different signposts (kWh, CO2, and Euro) on user energy-saving behaviour and user experience. We have found that the CO2 signpost has led to lower chosen savings irrespective of value orientation. However, there was no significant difference in savings after four weeks. It could be that the kWh and Euro signposts motivated people to choose more measures, but this did not lead to a higher propensity to perform these measures. We have observed that users facing a CO2 signpost reported better user experience outcomes at the upper end of the NEP scale, compared to users facing a kWh signpost. This was, however, caused by the kWh signpost being less compatible with increasing NEP score, rather than the CO2 signpost working better with increasing NEP scores.

This contrasts with the findings of Ungemach et al. (2018), where a CO2 signpost led to more efficient car choices with increasing NEP scores. However, both the NEP scale and their car comparison task were perhaps more 'hypothetical' measures; they do not call for real-world action. In fact, an energy recommender system calls for an actual change in behaviour and might therefore yield different results. Previous studies have shown that a higher level of environmental concern does not lead to an increase in energy savings (Urban & Scasny, 2012).

4.3. Limitations and future research

An important limitation is the age of our sample. It is relatively young, comprising few homeowners, which might have also led to ambiguous answers, due to self-reporting in our system. For instance, some participants might not have been able to implement all suggested measures, which could have restricted choice possibilities. Additional research that involves mostly home-owners or where certain items are filtered out for non-homeowners, might be more informative and could show clearer differences between conditions. The latter was not done because of time constraints. Furthermore, the list of measures had a large range of savings, from 0 to 8000 kWh. This might, to a certain extent, have also caused our data to have large standard deviations and insignificant findings. Participants furthermore had seemingly high levels of environmental concern, which might have influenced our results; 91% of participants agreed (to some extent) to the NEP scale proposition that *'Humans are severely abusing the environment'*. Thus, the observed range of NEP scores was perhaps too small to show large effects between groups. For future research, it is also interesting to look at user satisfaction after an extended period of recommender system use and measure implementation.

5. CONCLUSIONS AND IMPLICATIONS

The current study does not find support for the idea that goal setting would be effective to increase savings or improve user experience in a Rasch-based energy recommender system. However, we also did not find evidence for detrimental effects, which raises the question whether we would find different outcomes with an improved system design. Given the large body of previous research on goal setting, optimizing our goal levels, or providing users with direct feedback in a more interactive system, might lead to valuable additional insights. It should be considered, however, that no goal might be better than a goal not reached, in terms of system satisfaction, and that personalized recommendations might already provide sufficient support to the user to not require explicit goal setting.

We did find several effects of signposting on user experience. While the CO2 and EURO signposts seemed to work equally well for everyone, the kWh signpost seemed to work especially well for people lower on the NEP scale, in terms of improved energy-saving self-efficacy, reduced choice difficulty, and increased choice satisfaction. Therefore, it would be helpful to consider the target population of a system and adapt the system accordingly. A side note here is that the differences between signposts were most pronounced for the lower end of the NEP scale in our sample and that these effects were small. We can furthermore state that in general, participants evaluated the system positively, and that they achieved substantial savings (316 kWh) after just four weeks, encouraging the further exploration and usage of this system.

6. REFERENCES

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. Journal of environmental psychology, 25(3), 273-291. https://doi.org/10.1016/j.jenvp.2005.08.002

Bams, L. P. (2018) *Exploring the determinants of energy-saving behavior to nudge users of a Rasch-based energy-saving recommender to higher energy savings* [Master's thesis, Eindhoven University of Technology, Eindhoven, Netherlands]. Retrieved from https://pure.tue.nl/ws/portalfiles/portal/107655057/Master_s_Thesis_Luc_Bams_0804795.pdf

Dunlap, R. E., Van Liere, K. D., Mertig, A. G., & Jones, R. E. (2000). New Trends in Measuring Environmental Attitudes: Measuring Endorsement of the New Ecological Paradigm: *A Revised NEP Scale. Journal of Social Issues, 56(3),* 425–442. https://doi.org/10.1111/0022-4537.00176

Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. Annual *Review of Psychology, 53(1),* 109–132. https://doi.org/10.1146/annurev.psych.53.100901.135153

Franzen, A., & Mader, S. (2022). The Importance of Money Scale (IMS): A new instrument to measure the importance of material well-being. *Personality and Individual Differences, 184,* 111172. https://doi.org/10.1016/j.paid.2021.111172

Gardner, G. T., & Stern, P. C. (2008). The short list: The most effective actions US households can take to curb climate change. Environment: science and policy for sustainable development, 50(5), 12-25. https://www.doi.org/10.3200/ENVT.50.5.12-25

Kaiser, F. G., Byrka, K., & Hartig, T. (2010). Reviving Campbell's paradigm for attitude research. Personality and Social Psychology Review, 14(4), 351-367. https://doi.org/10.1177/1088868310366452

Knijnenburg, B. P., Willemsen, M. C., & Broeders, R. (2014). Smart Sustainability through System Satisfaction: Tailored Preference Elicitation for Energy-saving Recommenders. Human Computer Interaction.

Knijnenburg, B. P., & Willemsen, M. C. (2015). Evaluating Recommender Systems with User Experiments. In F. Ricci, L. Rokach, & B. Shapira (Eds.), *Recommender Systems Handbook (pp. 309–352).* Springer US. https://doi.org/10.1007/978-1-4899-7637-6_9

Koestner, R., Otis, N., Powers, T. A., Pelletier, L., & Gagnon, H. (2008). Autonomous Motivation, Controlled Motivation, and Goal Progress. *Journal of Personality, 76(5),* 1201–1230. https://doi.org/10.1111/j.1467-6494.2008.00519.x

Lee, J. W. C., & Tanusia, A. (2016, August). Energy conservation behavioural intention: Attitudes, subjective norm and self-efficacy. *In IOP conference series: Earth and environmental science (Vol. 40, No. 1, p. 012087).* IOP Publishing. https://doi.org/10.1088/1755-1315/40/1/012087

Locke, E. A., & Latham, G. P. (1990). A theory of goal setting & task performance. *Prentice-Hall, Inc.* https://doi.org/10.2307/258875

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist*, *57(9),* 705–717. https://doi.org/10.1037/0003-066X.57.9.705

Muthén, L. K., & Muthén, B. O. (2023). Mplus: Statistical Analysis with Latent Variables: User's Guide (Version 8.5). Los Angeles, CA: Authors.

Oonk, A.S. (2023) *Sustainable Goals: Energy-Saving Goals and Signposting in a Rasch-Based Recommender System* [Master's thesis, Eindhoven University of Technology, Eindhoven, Netherlands]. Retrieved from https://pure.tue.nl/ws/portalfiles/portal/306950304/Master_Thesis_Report_Aleid_Oonk.pdf

Starke, A. D., Willemsen, M. C., & Snijders, C. C. P. (2017). Effective User Interface Designs to Increase Energy-efficient Behavior in a Rasch-based Energy Recommender System. Proceedings of the Eleventh ACM Conference on Recommender Systems, 65–73. https://doi.org/10.1145/3109859.3109902

Starke, A. D., Willemsen, M. C., & Snijders, C. C. P. (2020). Beyond "one-size-fits-all" platforms: Applying Campbell's paradigm to test personalized energy advice in the Netherlands. *Energy Research & Social Science, 59*, 101311. https://doi.org/10.1016/j.erss.2019.101311

Starke, A. D., Willemsen, M. C., & Snijders, C. C. P. (2021). Promoting Energy-Efficient Behavior by Depicting Social Norms in a Recommender Interface. *ACM Transactions on Interactive Intelligent Systems, 11(3–4),* 1–32. https://doi.org/10.1145/3460005

Ungemach, C., Camilleri, A. R., Johnson, E. J., Larrick, R. P., & Weber, E. U. (2018). Translated Attributes as Choice Architecture: Aligning Objectives and Choices Through Decision Signposts. *Management Science*, *64(5)*, 2445–2459. https://doi.org/10.1287/mnsc.2016.2703

Urban, J., & Ščasný, M. (2012). Exploring domestic energy-saving: The role of environmental concern and background variables. *Energy policy*, *47*, 69-80. https://doi.org/10.1016/j.enpol.2012.04.018

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