TECHNISCHE UNIVERSITÄT DARMSTADT

Shaping future housing policies: Behavioural trends and sustainability insights for a “sufficient” built environment

Dem Fachbereich Bau- und Umweltingenieurwissenschaften der
Technischen Universität Darmstadt

zur Erlangung des Grades eines
Doktors der Ingenieurwissenschaften (Dr.-Ing.)

Dissertation

von

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Darmstadt 2024

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Bagheri, Mahsa: Shaping future housing policies: Behavioural trends and sustainability insights for a “sufficient” built environment
Darmstadt, Technische Universität Darmstadt,
Jahr der Veröffentlichung der Dissertation auf TUprints: 2024
URN: urn:nbn:de:tuda-tuprints-288850
Tag der mündlichen Prüfung: 19.09.2024

تقدیم به پدر و مادرم،
برای عشق ومحبت بی دریغشان و حمایت و اعتماد بی چون و چرایشان.

To my parents,
for their endless love and unconditional support and trust.

Acknowledgements

This journey, like all others, has come to an end. Along the way, and in all the years before, I have encountered many people who have left their mark on the path that leads to where I am standing now. I am thankful to all of them.

Yet, it is my wonderful family that has truly shaped who I am now and what I have achieved so far. I am deeply grateful for all their love and support.

I am profoundly thankful to my parents, whose unconditional faith gave me the courage to dream big and overcome every obstacle along my way. With their generosity and dedication, they provided an oasis of harmony and warmth, a place I could always return to for energy, confidence and inspiration. Through their actions and peaceful manner, they taught me to care for others and for nature.

مامان و بابای مهربونم،
ممنون که همیشه، حتی با وجود فرسنگ ها فاصله، پشت و پناه ما بودید،
ممنون که با تمام وجود و بی چشمداشت زندگیتون رو وقف خوشبختی و موفقیت ما بچه ها کردید،
ممنون که با اعتماد بی چون و چراتون به ما شهامت و قدرت دادید تا به هدف های بزرگ فکر کنیم و برای رسیدن به اونها با تمام موانع سر راه مقابله کنیم،
و ممنون از عشق و محبت بی دریغتون که در تمام این سالها تسلی بخش دلتنگی ها بوده.

I want to express my gratitude to Heike Brugger for empowering me to start this journey and for finding me the best mentor for the way. I am very grateful to Clemens Rohde for giving me the necessary pieces of advice I needed to succeed, while still allowing me the freedom to find my own way and bringing me back on track whenever I felt lost. Clemens and Heike, I have been fortunate to have you by my side and to have benefited from your great leadership and your solution-oriented and innovative thinking. I would also like to extend my sincere thanks to Hans-Joachim Linke for welcoming me into his team, for his open and supportive supervision of my work, and for being easily and always reachable.

My gratitude goes also to my colleagues at Fraunhofer ISI and my friends from whom I have learned so much. Special thanks to Elisabeth Dütschke for the insightful exchanges and discussions, and to the “Dissselbsthilfegruppe”, all its weekly meetings and Pomodoro sessions. I also want to thank Nadine Steinhübel for her support in proofreading and final formatting of my thesis.

I am truly thankful for the patience of my family and friends over the past few months. Their understanding has allowed me to devote as much time as I needed to complete this work. I am extremely grateful to Antoine, without whom this journey would not have been possible. Thank you for your support and patience, both at work and at home. You have been there through all the ups and downs, always ready to cheer me up, listen to my intense thoughts, inspire me and comfort me when life's challenges seemed overwhelming. Thank you for believing in me.

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Abstract

The residential sector significantly contributes to final energy consumption in the EU. In 2021, it accounted for 27% of total EU total energy consumption, of which 65% was attributed to space heating. The reduction in specific heating consumption observed in the residential sector in recent years, thanks to the implementation of energy efficiency measures, stricter building regulations and building renovations, has been offset by a significant increase in the floor area of residential buildings, from 32.9 m^2 in 1991 to 46.3 m^2 in 2021. This substantial increase in floor area exerts considerable pressure on the housing sector, both during the construction phase (due to the use of energy-intensive building materials) and in the use phase. Numerous studies have investigated the reduction of energy consumption in the residential sector through behavioural changes and have proposed a range of strategies and policies to achieve this goal. However, the crucial role of the user perspective in energy reduction remains under-explored in the existing literature and under-represented in current housing policies. Furthermore, there is a notable lack of empirical data on user behaviour and its underlying motives, particularly concerning living space.

This dissertation aims to provide recommendations for enhancing the effectiveness of policies targeting the reduction of high energy and space consumption in the residential sector. The study concentrates on the first pillar of the "Avoid-Shift-Improve" framework, which has been identified as having the greatest potential for reduction. This dissertation emphasises the necessity of incorporating the user perspective and individual behavioural aspects into the policy development process. The thesis employs a multi-method research approach, utilising both qualitative and quantitative methods for data collection and analysis. It addresses the aforementioned research gap through literature review, paper questionnaire, online multi-country surveys, and interviews. To provide a more comprehensive view of the topic, the thesis captures different perspectives (users and providers) and covers different geographical scopes, from a neighbourhood to the whole of the EU.

In conclusion, to realise the full potential of the existing tools and policies that address the reduction in energy consumption, improvements in the technical and social infrastructure are required. Furthermore, various external factors shape individual behaviour and influence choices, which in turn are reflected directly and indirectly in household consumption patterns. In order to develop efficient and effective policies, it is essential to recognise and consider the diverse backgrounds and their influence on policy acceptance and compliance. The financial aspects play a crucial role in the decision-making of all stakeholders. Therefore, designing policies with a financial component seems to be an effective method of triggering positive changes towards lower consumption. Finally, communication is crucial for the success of policies, as a lack of communication can lead to mistrust and dissatisfaction. Identifying the most appropriate means of communication, implementing transparent communication and assigning responsibility to the most suitable stakeholders are key to involving households and building trust.

Zusammenfassung

Der Wohnsektor trägt erheblich zum Endenergieverbrauch in der EU bei. Im Jahr 2021 machte er 27 % des gesamten Energieverbrauchs in der EU aus, wovon 65 % auf die Raumheizung entfielen. Die in den letzten Jahren im Wohnsektor beobachtete Verringerung des spezifischen Heizenergieverbrauchs, die auf die Umsetzung von Energieeffizienzmaßnahmen, strengere Bauvorschriften und Gebäudesanierungen zurückzuführen ist, wurde durch eine deutliche Ausweitung der Wohnfläche ausgeglichen, die von 32,9 m² im Jahr 1991 auf 46,3 m² im Jahr 2021 gestiegen ist. Diese erhebliche Vergrößerung der Wohnfläche übt sowohl während der Bauphase (aufgrund der Verwendung energieintensiver Baumaterialien) als auch in der Nutzungsphase einen erheblichen Druck auf den Wohnungssektor aus. In zahlreichen Studien wurde die Reduzierung des Energieverbrauchs in Wohngebäuden durch Verhaltensänderungen untersucht und eine Reihe von Strategien und Maßnahmen zur Erreichung dieses Ziels vorgeschlagen. Die entscheidende Rolle der Nutzungsperspektive bei der Energieeinsparung wird in der vorhandenen Literatur jedoch noch nicht ausreichend untersucht und ist in der aktuellen Wohnungspolitik unterrepräsentiert. Darüber hinaus besteht ein erheblicher Mangel an empirischen Daten zum Nutzungsverhalten und den zugrunde liegenden Motiven, insbesondere in Bezug auf den Wohnraum.

Diese Dissertation zielt darauf ab, Empfehlungen zur Steigerung der Wirksamkeit von Maßnahmen zur Reduzierung des hohen Energie- und Flächenverbrauchs im Wohnungssektor zu geben. Die Studie konzentriert sich auf die erste Säule des „Vermeiden-Verlagern-Verbessern“-Ansatzes, der das größte Reduktionspotenzial zugeschrieben wird. Diese Dissertation betont die Notwendigkeit, die Nutzungsperspektive und individuelle Verhaltensaspekte in den Prozess der Politikentwicklung einzubeziehen. Die Dissertation verwendet einen multimethodischen Forschungsansatz, bei dem sowohl qualitative als auch quantitative Methoden zur Datenerhebung und -analyse eingesetzt werden. Sie befasst sich mit der oben genannten Forschungslücke durch Literaturrecherche, Fragebogen, Online-Umfragen in mehreren Ländern und Interviews. Um einen umfassenderen Überblick über das Thema zu geben, erfasst die Dissertation verschiedene Perspektiven (Nutzungs- und Angebotsseite) und deckt verschiedene geografische Bereiche ab, von einem Stadtviertel bis zur gesamten EU.

Zusammenfassend lässt sich sagen, dass Verbesserungen in der technischen und sozialen Infrastruktur notwendig sind, um das volle Potenzial der vorhandenen Instrumente und Politikmaßnahmen zur Senkung des Energieverbrauchs auszuschöpfen. Darüber hinaus prägen verschiedene externe Faktoren das individuelle Verhalten und beeinflussen die Entscheidungen, die sich wiederum direkt und indirekt in den Verbrauchsmustern der Haushalte widerspiegeln. Um effiziente und wirksame Politikmaßnahmen zu entwickeln, ist es unerlässlich, die unterschiedlichen Hintergründe und ihren Einfluss auf die Akzeptanz und Einhaltung der Politikmaßnahmen zu ermitteln und zu berücksichtigen. Die finanziellen Aspekte spielen bei der Entscheidungsfindung aller Beteiligten eine entscheidende Rolle. Daher scheint die Gestaltung von Maßnahmen mit einer finanziellen Komponente eine wirksame Methode zu sein, um positive Veränderungen in Richtung eines geringeren Verbrauchs herbeizuführen. Schließlich ist die Kommunikation für den Erfolg von Politikmaßnahmen von entscheidender Bedeutung, da ein Mangel an Kommunikation zu Misstrauen und Unzufriedenheit führen kann. Die Ermittlung der am besten geeigneten Kommunikationsmittel, die Umsetzung einer transparenten Kommunikation und die Zuweisung von Verantwortlichkeiten an die am besten geeigneten Beteiligten sind der Schlüssel zur Einbeziehung der Haushalte und zum Aufbau von Vertrauen.

Preamble to the cumulative dissertation

This cumulative dissertation consists of five scientific publications, constituting Chapters 2-6. Four of these publications (Papers 1, 2, 4 and 5) have been published in international peer-reviewed journals. The remaining one (Paper 3) has been submitted to an international peer-reviewed journal and is under review. These papers are listed below in the order in which they appear in the thesis.

1. **Bagheri, Mahsa** (2020): Traces of Social Sustainability in Garden Cities- Karlsruhe as a Case Study. In: European Journal of Sustainable Development 9(4):250. DOI: 10.14207/ejsd.2020.v9n4p250. The original published version of this paper can be found in Appendix A.

2. **Bagheri, Mahsa**; Tröger, Josephine; Freudenberg, Charlotte (2024): Investigating the influence of current trends and behaviours on household structures and housing consumption patterns. In: Consumption & Society. DOI: https://doi.org/10.1332/27528499Y2024D000000025. The original published version of this paper can be found in Appendix B.

3. **Bagheri, Mahsa**; Pröpper, Alexandra; Klein, Geneviève (2024): Exploring residential space use pattern: Findings from a multi-country survey. Submitted to an international peer-reviewed journal.

4. **Bagheri, Mahsa**; Kochański, Maksymilian; Kranzl, Lukas; Korczak, Katarzyna; Mayrhofer, Lukas; Müller, Andreas; Özer, Ece; Rao, Swaroop (2024): Reduction of gas demand through heating behaviour changes in households: Novel insights from modelling and empirical evidence. In: Energy and Buildings. DOI: 10.1016/j.enbuild.2024.114257. The original published version of this paper can be found in Appendix C.

5. **Bagheri, Mahsa**; Roth, Linda; Siebke, Leila; Rohde, Clemens; Linke, Hans-Joachim (2024): Implementing housing policies for a sufficient lifestyle. In: Buildings and Cities, 5(1), DOI: https://doi.org/10.5334/bc.435. The original published version of this paper can be found in Appendix D.

1. Introduction

1.1. Sustainable development

The year 1987 is certainly a landmark in the history of sustainability. The term "sustainable development", to which Mebratu (1998, p. 493) refers as "a basis for overcoming the environmental challenges", came into a widespread use by different communities following the publication of the Brundtland Commission's report, Our Common Future. The Brundtland report defined sustainable development as "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, p. 54).

Although sustainability is traditionally known as a three-pillar concept encompassing social, economic and environmental dimensions, the social aspect has often been overlooked and lacks substantial theoretical and empirical exploration (Littig et al. 2005; Dempsey et al. 2011). Colantonio (2007) notes that the environmental and economic dimensions were initially prioritised in sustainability discussions, with the social dimension only gaining recognition in the late 1990s within the sustainability development agenda.

At the operational level, social sustainability emerges from various key thematic actions, ranging from "capacity building and skills development to environmental and spatial inequalities" (Colantonio et al. 2009, p. 18). Thus, social sustainability encompasses a mix of traditional social policy fields and principles such as participation, needs, social capital, economy and environments. Over the past decade, the Oxford Institute for Sustainable Development (OISD) has extended the concept of social sustainability to include happiness, well-being and quality of life as additional essential factors.

Given the interdisciplinary approach and the broad spectrum of themes covered by social sustainability research, many authors outline various aspects and dimensions of social sustainable development instead of offering a precise definition of the concept. A review of the themes shows that basic needs and equity are frequently recognised as fundamental pillars of social sustainability, as they are crucial for both the physiological and social well-being of individuals and communities (Colantonio 2010).

Vallance et al. (2011) described three classifications of social sustainability, namely development, bridge and maintenance, each addressing different sustainability targets. Development social sustainability focuses on basic needs, social capital and justice. Bridge social sustainability involves altering behaviours to enhance the relationship between individuals and their environment. Maintenance social sustainability concerns itself with preserving cultural traditions, personal preferences, and cherished locations that people would like to see maintained or improved, such as natural landscapes.

Colantonio (2007) outlines four aspects of social sustainability: (1) social, (2) socio-institutional, (3) socio-economic and (4) socio-environmental, which cover various thematic areas concerning the social realm of individuals and communities. Weingaertner et al. (2014) contend that social sustainability is generally perceived through three main themes: social capital, human capital and well-being. These themes can synthesise both individual and communal concerns, which are significant to social sustainability.

Recent studies show that social sustainability themes and indicators are moving away from traditional social measures, such as employment and income levels, toward multi-dimensional sustainability measures, such as quality of life and social cohesion (Landorf 2011; Larimian et al. 2021). The existing literature enumerates various physical factors of social sustainability, including decent housing, attractive public realm and local environmental quality (Eizenberg et al. 2017).

Since introducing the concept of sustainability, this topic has been set as a goal in various fields including urbanism. Making the cities and communities more sustainable is one of the 17 sustainable development goals (SDGs) set by the United Nations General Assembly in 2015 (Bagheri 2020). The Office of the Deputy Prime Minister (ODPM) defines Sustainable communities as 'places where people want to live and work, now and in the future. They meet the diverse needs of existing and future residents, are sensitive to their environment, and contribute to a high quality of life. They are safe and inclusive, well planned, built and run, and offer equality of opportunity and good services for all' (ODPM 2005, p. 56).

Hilgers (2013) provides a clear understanding of urban social sustainability by identifying three distinct interpretations: The first, 'Basic social sustainability', focuses on maintaining social balance within an urban setting, primarily through two main principles of equity and sustainability of the community (Bramley et al. 2009b). The second, 'Sustainable behaviour', deals with the social foundations necessary for sustainable development rather than its social goals. Rotmans et al. (2000) suggests that technology and behavioural management are key in fostering sustainable behaviour. The third, 'Cultural sustainability', draws influence from postcolonial studies and deals with encouraging and protecting social and cultural diversity. This approach also serves as a way to resist against a hegemonic interpretation and use of the concept of social sustainability which only refers to Western developed cities.

1.2. Human needs and wants and the link to consumption pattern

People and their needs, well-being and quality of life are at the centre of the above quotes and definitions in regard to (social) sustainability. Accepting the necessity of sustainable development and referring to Brundtland's definition of the concept, Redclift (2005) argues that the "need" and consequently the definition of sustainable development change, not only from one generation to another, but also from one culture to another. As the author says:

> "If in one society it is agreed that fresh air and open spaces are necessary before development can be sustainable, it will be increasingly difficult to marry this definition of 'needs' with those of other societies seeking more material wealth, even at the cost of increased pollution". (Redclift 2005, p. 213)

On the other hand, as noted in the Bruntdland report (WCED 1987, p. 14), "the 'environment' is where we all live; and 'development' is what we all do in attempting to improve our lot within that abode". Therefore, the environment is related to people, their needs and their activities.

However, there is an ongoing debate in the scientific community about the difference between "wants" and "needs", with some arguing that the distinction is clear, while others show that this categorisation is more subjective (Darby et al. 2018). Gough (2015) defines needs as a particular category of goals that are considered universal and whose failure to be met will result in serious harm (e.g. a sheltered place to sleep, a washroom), whereas wants are goals that

stem from an individual's particular preferences (e.g. an artist's studio, a garage) (Doyal et al. 1984). A different approach is proposed by Sen (1999), where the focus is not on a person's resources (food or shelter) but on their capabilities to perform these functions (mobility, literacy).

On the other hand, how and which needs and wants are to be satisfied defines the consumption patterns of individuals and households. Consumption patterns are the processes of finding and purchasing products to satisfy needs or desires (Coelho et al. 2020), reflect the values and preferences of individuals (Bosserman 1983) and are influenced by various factors such as income, culture and social norms (Bagheri et al. 2024d). As the boundary between basic needs and human wants is blurred, consumption patterns could be shaped by the human quest for comfort (e.g. living more comfortably in a larger house), or the effort to fit in the group. While increases in consumption have traditionally been assumed to be correlated with higher human well-being and quality of life, recent studies show no or even a negative correlation between them (Vita et al. 2019a; Jackson 2005).

Housing satisfies one of the basic human needs. However, in addition to meeting the basic need for shelter, housing also provides comfort and contributes to an individuals' identity, status and sense of belonging (Bagheri et al. 2024d). Studies show that housing needs and preferences are influenced by factors such as societal norms, working styles and income levels (SALAMA 2011; Benedikter 2012). The approach introduced by Sen (1999) in the need vs. want debate provides a broader approach to housing needs (Darby et al. 2018), as the need for a personal workspace can now be met with different solutions (additional living space, public library). Consumption patterns are therefore also shaped by the solutions available to meeting needs.

1.3. Energy consumption in residential sector

As a major energy consumer, the residential sector accounted for 27% of final energy consumption in the European Union (EU) in 2021 (Eurostat 2023i). Around 65% of this consumption stems from space heating and the rest is due to other operational needs (i.e. water heating, lighting and electrical appliances, cooking, space cooling and other uses) (Eurostat 2023i). In the same year, greenhouse gas (GHG) emissions from all household activities accounted for 25% of EU emissions, of which 43% were due to heating and cooling activities (Eurostat 2022a). The high energy consumption in the residential sector is mainly attributed to the amount of floor area in the residential sector.

Thanks to energy efficiency measures, stricter building regulations and building renovations, specific heating consumption in the residential sector (i.e. heating consumption per m^2) has been decreasing in recent years, with an average annual decrease of 1.4% between 2000 and 2021 (Odyssee-Mure 2023b). However, this reduction has been offset by the significant increase in residential floor area in recent years. The EU average residential floor area per person has increased from 32.9 m^2 in 1991 to 46.3 m^2 in 2021. However, the situation varies across the EU. The per capita floor area ranged from 24.2 m^2 to 86.4 m^2 in 2021, with Romania having the lowest and Malta the highest values (own calculation based on available data in Odyssee-Mure 2023a).

This increase in floor area is reflected not only in the rising number of dwellings, but also in the growing size of the dwellings – which, according to Ellsworth-Krebs (2020), is the main driver of household energy consumption. The increase in dwelling size is observed in almost all EU countries (with some exceptions e.g. Sweden and France) for both single and multi-family

houses (Odyssee-Mure 2023a). This large increase in required floor area puts a strain on the housing sector in the construction phase, as buildings are mostly constructed with energy- and carbon-intensive materials such as cement and steel (Bagheri et al. 2024b). Since buildings also require energy to be used and operated, there is a double burden on the energy consumption of the buildings sector.

The increase in living space per capita has been observed despite a decrease in the EU population (Bierwirth 2015). This means that fewer people are currently using more living space compared to decades ago, leading to a decrease in household size, which is expected to have an impact on final heating energy consumption (Guerra-Santin et al. 2010; Wei et al. 2014; Williams 2009). For example, according to Destatis (2022c), the per capita consumption of space heating energy in one-person households in Germany is about 38% higher than the average for all households.

Germany shows similar trends to the EU. In 2021, the residential sector contributed to 29% of total final energy consumption, of which 80% was used for space heating (AGEB 2023). Between 1991 and 2021, the floor area per person increased by 36%, reaching 47.7 m^2, compared to 35.2 m^2 in 1991. In this period, the average floor area of dwellings also increased steadily from 82.1 m^2 to 92.1 m^2 (118 m^2 for single-family houses and 70.5 m^2 for multi-family houses) (Destatis 2022a). Despite the low population growth of 4% and the 41% increase in available housing space over this period (Odyssee-Mure 2023a), the country is facing a housing shortage in its major cities, leading to a government decision to build 400 000 dwellings per year from 2024, putting even more pressure on the German buildings sector, which has already failed to meet its climate targets (Bagheri et al. 2024c).

1.4. Strategies to reduce consumption in residential sector

In his book on sustainable development, Huber (1995) addresses the topic of consumption and introduces consistency, efficiency and sufficiency as strategies for achieving sustainability. These concepts are widely used in energy research (see e.g. Samadi et al. 2017) and could be explained using the term “energy service” (i.e. the benefits provided by energy such as lighting, heating, cooling). Consistency refers to the use of sustainable energy inputs to deliver the energy service. Efficiency refers to reducing the energy input required for the energy service output and sufficiency refers to reducing the energy service (Zell-Ziegler et al. 2021a).

This categorisation is consistent with the Avoid-Shift-Improve (ASI) framework (Zell-Ziegler et al. 2021a) which originated in the transport sector and introduces an approach for categorisation of policies aimed at reducing energy consumption (Dalkmann et al. 2007). The three pillars of this framework are “Avoid” (i.e. reducing the need for services, e.g. the need for motorised travel), “Shift” (i.e. switching to more environmentally friendly means, e.g. shifting from private to public transport) and “Improve” (i.e. increasing the efficiency of the service provider, e.g. using more efficient fuels) (Bagheri et al. 2024d).

For the buildings sector, these pillars can be translated as follows:

- **Avoid/Sufficiency:** Changing consumption patterns towards low-consumption behaviour, e.g. reducing the per capita floor area of the dwellings or lowering the heating temperature
- **Shift/Consistency:** Using less energy-intensive building materials, e.g. timber construction

- **Improve/Efficiency:** Reducing the energy demand of the building by improving the efficiency of the building, e.g. insulating the walls or switching to a more efficient heating system to reduce the energy required for space heating

As excessive floor area is the main driver of high energy consumption (both in the construction and operation phases of buildings), the first approach appears to have the greatest potential for savings in the residential sector, as it has a dual effect: reducing the need for new construction and energy-intensive building materials, and also reducing the energy needs to operate the building (heating and cooling), as the larger the space, the higher the energy demand for heating and cooling (Bagheri et al. 2024d). In line with this, Fuhrhop (2015) considers the construction of new buildings to be antisocial (Fuhrhop 2015, p. 43). In his opinion, instead of constructing new buildings, we should make a better use of the existing ones with the help of the "tools" (Fuhrhop 2015, p. 163) that he introduces in his book.

From a different perspective, some studies, such as Pérez-Sánchez et al. (2022) and (Cherubini 2010), highlight the need for social and societal changes (concerning households and users) in addition to technical and technological innovations to reduce energy consumption in the residential sector. Reductions in consumption and emissions could be tackled from both the demand and supply sides (using renewable energy sources on the supply side and lowering heating temperatures on the demand side) (Bagheri et al. 2024b). In recent years, there has been a focus on the role of individual choices and behavioural changes in reducing the energy consumption on the demand side. The International Panel on Climate Change (IPCC) and European Commission provide two important examples of the integration of behavioural changes as a necessary strategy to reduce energy. IPCC (2022a) has considered lifestyle and behavioural changes as one of the socio-cultural factors, whose change contributes to mitigation in the buildings sector. The European Commission, in its REPowerEU and "Playing my part", proposes behavioural changes as short-term measures to rapidly save energy and reduce gas and oil demand (Bagheri et al. 2024a).

Resistance to change and the influence of external factors on individual behaviour makes inducing behaviour change a challenging task (Bagheri et al. 2024b). However, this challenging task can be addressed through a variety of strategies, ranging from soft nudging (e.g. providing tips on how to reduce heating demand and starting a competition between some households on the amount of heat demand reduction) to policies that mandate a reduction (e.g. setting a cap on the amount of space per person in a dwelling) or incentives it (e.g. facilitating the move to smaller dwellings for the elderly). Energy consumption in the residential sector could benefit from these behavioural changes both in the construction phase (e.g. through strategies to reduce the floor area and thus the need for new construction, such as changes in space use behaviour) and in the operation phase (e.g. through strategies to reduce the need to heat and cool the building, such as changes in heating behaviour) of the building life cycle.

1.4.1. State of research

Many studies, particularly in the recent decade, have focused on the high energy consumption in the residential sector, examined the causes of this high consumption and explored ways to reduce it. The main approaches observed in these studies are elaborated below.

The first group of studies concerns the drivers of consumption. Numerous scholars, such as Huebner et al. (2017), Ellsworth-Krebs (2020) and Bierwirth (2015) emphasise the growing average floor area per person in recent decades and acknowledge the significant impact of living

space and house size on residential energy consumption. Many researchers highlight the crucial role of occupant behaviour on the energy consumption in the building and study its impact at different dimensions. At the macro level, Chen et al. (2021) provide a comprehensive review of the occupant's impact on building energy consumption, classified into different categories. Some researchers take a more focused approach, looking at specific domains in housing. For example, focusing on space heating, Guerra-Santin et al. (2010) analyse the impact of occupant behaviour on heating energy consumption, and Wei et al. (2014) investigate how various drivers of space heating behaviour are considered in models for simulating the building energy consumption. Guo et al. (2018) focus on residential electricity consumption behaviour, and Lindén et al. (2006) study user behaviour mainly in terms of the use of appliances.

The second group of studies deals with the quantitative impact of behavioural changes. An example of this is IPCC (2022a), which quantifies the demand-side mitigation potential achieved by behavioural changes. A common approach in the literature to quantify the potential savings of behavioural change strategies is scenario modelling. This approach is also used by Kost et al. (2021) where behavioural patterns are used for developing scenarios, and the energy consumption is calculated for each scenario. Pauliuk et al. (2013) use a similar approach to estimate the potential for reducing the consumption of the building stock. These studies typically calculate savings based on various assumptions, such as changes in floor area, heating habits including heating hours, thermostat settings and the renovation rates of buildings. These assumptions are based on the data found in the literature or expert opinion.

Finally, the last group of studies has its focus on actions, strategies and policies aimed at reducing energy consumption in the residential sector. Examples of this can be seen in a study on the sustainability of the residential sector, in which the authors present a list of actions at both the household (social innovation) and dwelling (technical) dimensions and their possible effects on energy and emissions (Pérez-Sánchez et al. 2022). Similarly, Creutzig et al. (2018) provide a set of options that contribute to mitigations in the demand side. In another study, Fischer et al. (2019) highlight the savings potential of downsizing and investigate the strategies for downsizing among seniors.

The impact of such strategies and policies on reducing energy consumption is further analysed in studies such as those by Khanna et al. (2021), who investigate the impact of different types of policies on emission mitigations in the residential sector, and Huebner et al. (2017), who specifically examine the potential of downsizing in reducing residential energy consumption. A large part of the literature in this group concerns sufficiency policies, such as those collected in a database by Best et al. (2022) or proposed by Schneidewind et al. (2013) to enable sufficiency in the buildings sector. In a more specific study, Bierwirth (2015) targets housing companies and presents a range of possible options that they can implement to develop a sustainable building stock.

1.4.2. Research gap

The discussion of sustainability outlined in Chapter 1.1 underscores the fulfilments of people's needs as the heart of this discussion. Housing, a fundamental human need, contributes to a high share of energy consumption, largely due to behaviours and habits aimed at fulfilling human needs. Additionally, the social pillar of sustainability emphasises the importance of resident involvement and community engagement for fostering sustainable communities. These

elements are crucial when designing strategies to reduce high residential energy consumption and achieve sustainability in this sector.

Integrating the user's perspective into policy making offers dual benefits: firstly, existing policies and infrastructures can shape behaviour and the manner in which needs are met; secondly, including user perspective in policy development leads to greater acceptance and compliance, thereby improving the effectiveness and success of these policies. Numerous studies, including those presented in Chapter 1.4.1, have explored the reduction of residential energy consumption through behavioural changes and have proposed strategies and policies to lower the energy consumption. However, the crucial role of user perspective in energy reduction remains under-investigated in existing literature and under-represented in current housing policies. Moreover, there is a notable lack of empirical data on user behaviour and its underlying motives, particularly in relation to living space. This gap highlights a significant opportunity for further investigating the strategies that could lead to more effective energy use strategies in the residential sector.

1.5. Research questions and thesis outline

This thesis aims to provide recommendations for enhancing the effectiveness of policies targeting the reduction of high energy and space consumption in the residential sector. It focuses in particular on the first pillar of the ASI framework, which has been identified as having the greatest potential for reduction (see Chapter 1.4). The thesis explores strategies to change consumption patterns towards lower use. It focuses on the need to integrate the user perspective and individual behavioural aspects into policy development. Consequently, the thesis revolves around three core components - users, housing consumption and policies - which are reflected in the main question of the thesis outlined below:

What strategies can be implemented to incorporate user behaviour and perceptions into policies, thereby optimising their impact on reducing energy consumption in the housing sector?

Accordingly, this main question is divided into three sub-questions (hereafter referred to as RQ), each of which reflects one of the three components and is addressed in one or more of the papers included in this thesis.

- **RQ1:** What defines housing needs and user behaviour around housing, and how will needs evolve in the future? (**Users**)
- **RQ2:** What factors influence consumption patterns in the housing sector? (**Housing consumption**)
- **RQ3:** How effective are existing policies targeting residential energy consumption, and how are they perceived? (**Policies**)

Applying qualitative and quantitative methods in data collection and analysis, this thesis is a multi-method research (Bryman 2006). It aims to provide answers to these research questions through literature review, paper questionnaire and online multi-country surveys and interviews. In order to provide a more comprehensive view of the topic, the thesis captures different perspectives (users and providers) and covers different geographical scopes, from a neighbourhood to the whole of the EU. An overview of the applied methods and the scope of each paper is provided in Figure 1.1.

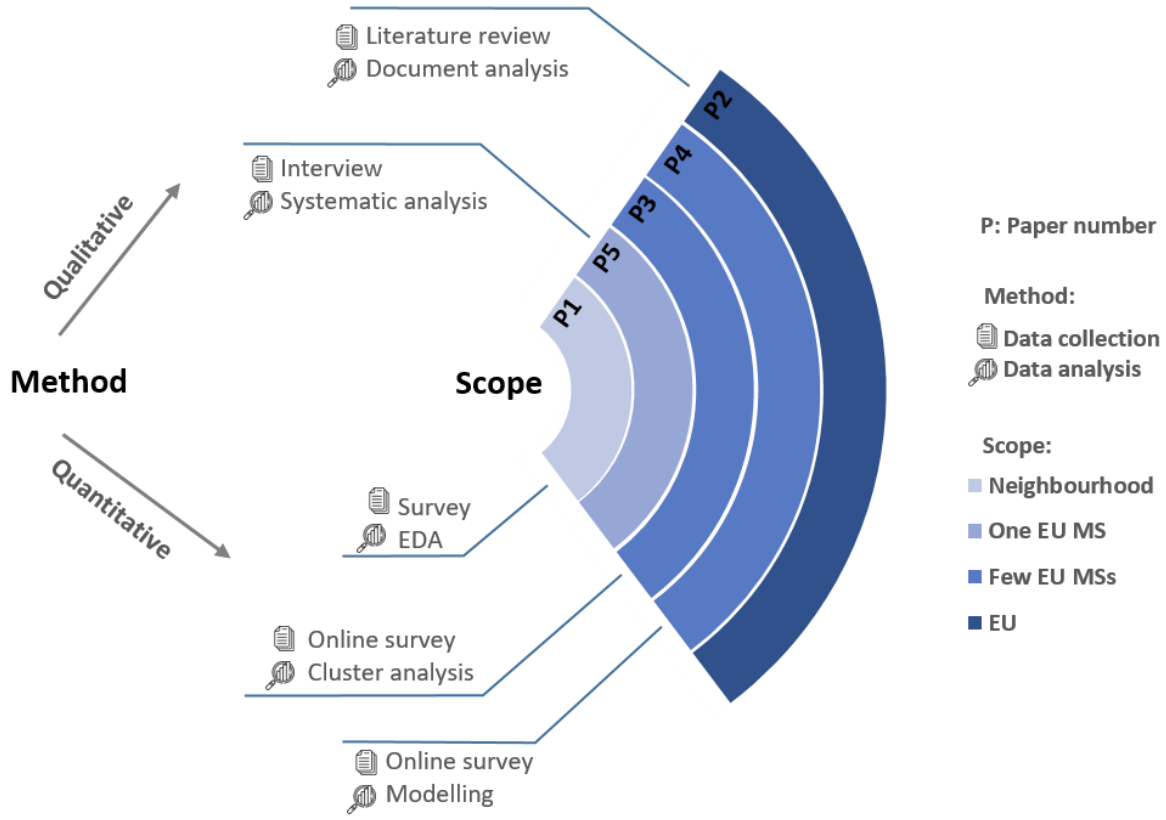

Figure 1.1: Applied method and scope of each paper

Figure 1.2 provides a visual representation of the thesis structure. Chapters 2-6 are each grounded in a scientific publication. These chapters are further organised into two main blocks: Chapters 2 and 3, which contribute to the contextual understanding of the study, and Chapters 4-6, which delve into user behaviour and policy acceptance.

Chapter 2 examines sustainable communities through the lens of the Garden City of Karlsruhe as an exemplary urban settlement from which some lessons can be learned. The ideas of the Garden City - a model established over a century ago to address issues of excessive rural-urban migration by offering a higher quality of life - are still considered relevant to today's society. However, residents' needs have changed over time. This chapter discusses survey results that indicate high satisfaction levels among Garden City residents. Nevertheless, it also highlights the factors that lead to dissatisfaction and mistrust. The chapter emphasises the importance of adapting to the changing needs of residents and improving the communication between the users and the Garden City Cooperative.

Chapter 3 examines the underlying factors that determine the behaviour of individuals and investigates the influence of current and emerging trends on energy and space use in the residential sector. This chapter provides an understanding of what shapes the lifestyle and behaviour of individuals, which is also reflected in the patterns of space use in dwellings. It also presents how household structure is affected by these trends and how this, in turn, affects space and energy consumption. The chapter also explores how certain behaviours and daily habits (e.g. working and leisure behaviour) affect space use. Using the ASI framework, the chapter presents social and technical potentials that could facilitate and trigger changes towards lower consumption in the housing sector.

Chapter 4 builds on the theoretical background provided in Chapter 3 and explores patterns of space use in the household sector in four European countries: Germany, Sweden, Poland and Portugal. Using empirical data collected in these countries through an online survey, the chapter examines the redistribution of floor space through strategies such as moving, sharing, and rearranging in order to reduce the need for new construction in the housing sector. A cluster analysis of the collected survey data identifies groups with high potential to change their space use behaviour. The chapter presents their willingness to change their space use behaviour and their level of support for selected policies. The chapter concludes by making recommendations for improving the efficiency of residential space use.

Chapter 5 presents a similar approach to Chapter 4 but focuses on the heating behaviour of households in four EU Member States: Germany, the Netherlands, Greece, and Poland. The chapter presents the results of an online survey conducted in these countries and explores how users have changed their heating behaviour in response to the energy crises. It also uses a building stock model to estimate the impact of these changes on the reduction of residential heating demand. This chapter recognises the inadequacy of the (short-term) measures proposed by the European Commission to reduce gas demand and concludes by proposing a policy package to transform short-term responses to unexpected circumstances - such as energy crises - into long-term behavioural changes.

Chapter 6 delves into the practical implication of selected measures - flat exchanges, moving bonus and moving advice - in reducing residential space use. These measures are parts of the redistribution strategies also mentioned in Chapter 4. The data for this chapter was collected through interviews with housing companies in Germany, as they have the technical capacity to implement such measures due to the available properties in their housing stock. The chapter presents the success and failure factors of these measures and gives recommendations for enhancing their implementation. By capturing the perspective of the housing companies as stakeholders in the provision of housing, this chapter complements findings of previous chapters, which mainly focus on the user perspective.

Chapter 7 builds on the previous chapters and includes the thesis discussion and conclusion, as well as recommendations and an outlook for future research.

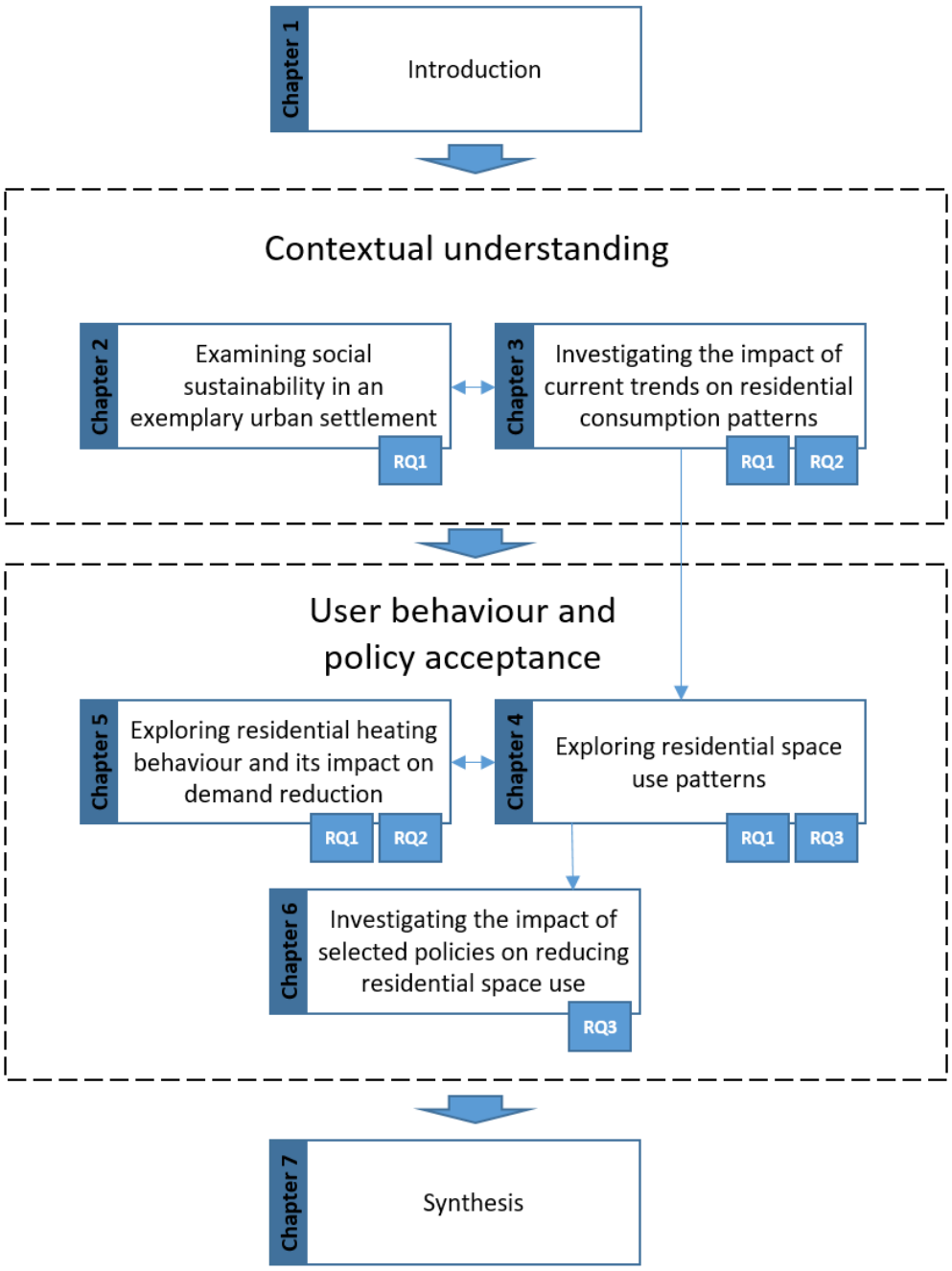

Figure 1.2: Outline of thesis: Chapters 2-6 are based on scientific publications and the boxes next to each chapter show the research questions that are addressed in each publication

2. Traces of Social Sustainability in Garden Cities - Karlsruhe as a Case Study[1]

Abstract: Discussions about sustainable communities as a significant measure in social sustainability began in the 2000s. Sustainable communities are defined as places in which existing and future generations would like to work and live. They contribute to the well-being and quality of life and offer equal opportunities to their residents. The definitions are similar to the objectives of one of the most influential movements in the history of urban planning: the Garden City. The principles of the Garden City are applicable to new and existing towns and its concept has been adopted in different contexts until today. Therefore, many lessons can be learnt regarding sustainable urbanism by studying social sustainability in this type of urban settlement. As a first step towards this aim, this paper studies the experience of living in the Garden City of Karlsruhe today. A survey was conducted among the current inhabitants. The study shows a high level of satisfaction and the tendency for a long residency in the Garden City because of the reasons like ample greenery, central location, and quietness of the settlement. The results will be used as the first dataset for developing a framework for urban social sustainability in the Garden Cities.

[1] This chapter has been published as Bagheri, Mahsa (2020): Traces of Social Sustainability in Garden Cities- Karlsruhe as a Case Study. In: European Journal of Sustainable Development 9(4):250. DOI: 10.14207/ejsd.2020.v9n4p250.

2.1. Introduction

Since introducing the concept of sustainability in the 80s, several scholars have tried to define and interpret it. The concept of sustainable development was soon spread all around the world, covering the discussions at different levels, ranging from local to global. Its flexibility resulted in several attempts in redefining and reinterpreting the concept, in order to make it compatible with the discussed issues. The topic has been addressed by scholars from different disciplines including urban studies. Making the cities and communities more sustainable is one of the 17 sustainable development goals (SDG 11) set by the United Nations General Assembly (United Nations 2015). Among the three pillars of sustainability, the social dimension, especially in relation to the built environment (Dempsey et al. 2011) has received the least attention compared to the environmental and economic dimensions. However, the recent discussions in sustainability are not limited to the environmental dimension only, instead they include economic and social aspects. Including the social dimension in sustainability discussion increased around the beginning of the 21st century (Colantonio 2007). As a context related concept (Dempsey et al. 2011) social sustainability has been discussed at different urban levels: from small-scale urban units (e.g. Ghahramanpouri et al. 2015) and neighbourhoods (e.g. Bramley et al. 2009a) to large-scale cities (e.g. Panda et al. 2016) and regions (Spangenberg et al. 2006). Having considered community as one of the three key components of the urban social sustainability by scholars like (Yiftachel et al. 1993) shows the importance of sustainable communities in enhancing social sustainability. Bristol Accord (ODPM 2005) defines sustainable communities as "places where people want to live and work, now and in the future. They meet the diverse needs of existing and future residents, are sensitive to their environment, and contribute to a high quality of life. They are safe and inclusive, well planned, built and run, and offer equality of opportunity and good services for all" (ODPM 2005). Dempsey et al. (2011) describe the community stability as one of the measures in community sustainability and Silburn (1999) indicates that a sustainable community requires long term residents.

In today's societies career paths have become more mobile and consequently people relocate more often compared to the past (Sennett 1999). This frequent spatial mobility and its effects on social attachment and stability of the society has been previously addressed by some scholars (see Toffler 1970; Packard 1972; Long et al. 1976 and Long et al. 1981). According to the world pictured by these authors, one would assume that the concepts like place attachment and sense of belonging, which are among the measuring factors of social sustainability, have no meaning in contemporary societies. However, most of the debates about the increased rate of mobility and its consequences in the society concern the United States. According to Schneider et al. (2013), the residential mobility in West Germany is much lower than in the US, nevertheless German residents still have a higher mobility rate compared to the average in the EU (European Union 2015).

2.2. Notion of social sustainability in the Garden City

The *Garden City* movement, one of the most influential movements in the history of urban planning, targets the uncontrolled growth of the cities and its consequences. In 1898, Ebenezer Howard introduced the Garden City concept as a response to overcrowded and deteriorated cities like London and as a solution to improve the quality of life of the residents. Howard provided some ground rules for the concept but left the room open for the Garden City to be designed based on the site characteristics and the social and cultural backgrounds of the society. The aim of the Garden City was to improve the quality of life, to provide each family with a

house and a piece of garden, to accommodate people of different social classes and to provide working opportunities at different levels all through building a well-planned city. Some of the concerned are to be found also in the definition of sustainable communities: high quality of life, opportunity and services for all and well-planned communities.

The Garden City movement originated in the UK but was soon translated and interpreted in other countries. Germany was one of the pioneers to adopt the idea of the Garden City and to initiate realising the concept by planning and building Garden Cities. Among the German Garden Cities Karlsruhe was the first one to be founded and is considered as an important example in Germany. The flexibility in designing the Garden City makes the concept adoptable and transferable to different contexts and its principles applicable to new settlements as well as the existing ones (Unwin 2014). Considering that the characteristics of the neighbourhood play an essential role in residents' decisions to leave (or stay in) the neighbourhood (Feijten et al. 2009), it is necessary to analyse how the characteristics of a settlement, like the Garden City, influence the residents' behaviour, including residential mobility. Therefore, the current paper takes one of the most important German Garden Cities as the case study and analyses the perception of the residents, of living today in the Garden City.

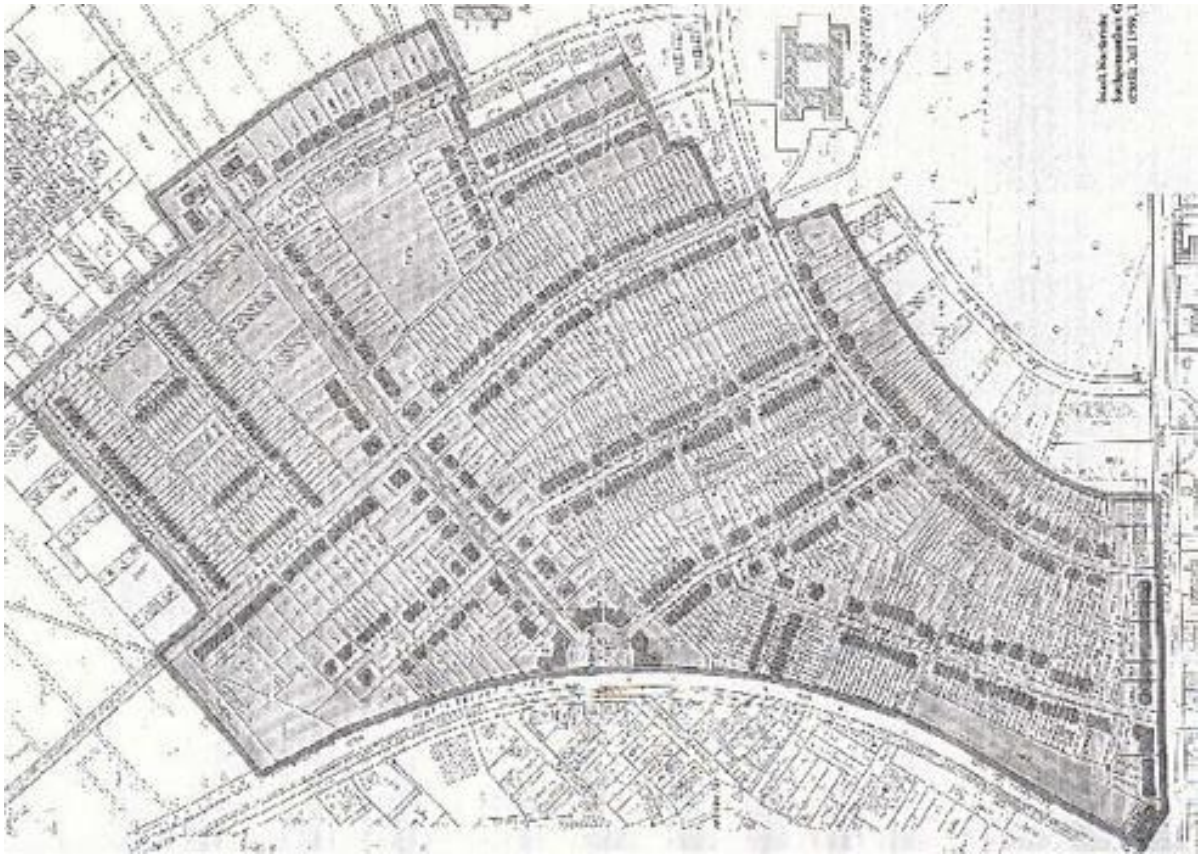

Figure 2.1: Houses considered as historical monuments in the Garden City of Karlsruhe (source: City of Karlsruhe)

2.3. Case study

The Garden City Cooperative in Karlsruhe was founded in 1907 with the aim of building the first German Garden City. However, the construction started first in 1911 and Karlsruhe Garden City was built, as the second German example, in an area called Rüppurr, located in the south part of Karlsruhe in southwestern Germany. According to an agreement between the Garden City Cooperative and the city of Karlsruhe, a large part of the Garden City was registered as

historical monument and therefore under conservation (Figure 2.1). Its architectural and socio-historical significance, the artistic elements and exemplary values were the reasons for this decision (DSchG BW 1983).

The area under conservation includes 641 single family houses (single buildings, row houses and double houses) and 70 apartment buildings; out of which 646 are classified as historical monument and considered in this paper. All single-family houses in the Garden City are provided with a garden and have a similar spatial division which follows the clear zoning; the kitchen and the living room on the ground floor; bedrooms on the upper floor and service area in the basement. They are categorised into different types according to their characteristics including the entrance (side or central), position of the staircase, number of the rooms as well as their arrangement and position (street side vs. garden side). The Garden City is run by community ownership and the inhabitants are the members of the cooperative. The Garden City Cooperative is in charge of the administrations and renting out the houses, meaning that the inhabitants of the Garden City do now own the properties.

2.4. Methodology and data collection

Data for this research was gathered through a survey carried out by the author. The survey was meant not to be anonymous as the end goal was to merge the data from the survey with the database of the Garden City Cooperative. To this aim the participants were requested to provide the address of their house. The survey covered questions regarding the building (architectural design, material, elements), inhabitants (demographic data, motivation for living in the Garden City, satisfaction with the neighbourhood) and neighbourhood (activities and facilities). These questions were in different forms; rating scale (5-point) questions where the respondent could choose a rate between 1 (lowest) and 5 (highest), “yes” or “no” questions, closed-ended questions, usually followed by a field where the respondents could add their answer if it was not one of the possible options, open-ended questions, multiple choice questions where the respondents could choose one or more answers.

In the first round the questionnaires were distributed (dropped in the mailbox) among all the houses in the Garden City which are considered as monuments. Two months later a reminder was sent to the households who had not participated in the survey or had not provided the full address. One month after the first reminder, 100 addresses were picked using the random function of Excel, and the chosen addresses were contacted in person and were requested to fill in the questionnaire. After consultation with the Garden City Cooperative, respondents were asked to return the filled-in questionnaires to one of the former representatives of the Cooperatives who lives in the area. In order to potentially increase the response rate, and before carrying out the survey, the inhabitants of the Garden City became aware of the ongoing research with the help of the Garden City Cooperative and through an announcement in the regular magazine (*Freude am Wohnen* 2017) published by the Cooperative.

Out of 646 households, 138 questionnaires were filled in and returned which gives us a response rate of 21.4%, with a confidence level of 95% and a 7% error margin based on the Cochran’s formula (Cochran 1963). After receiving the surveys, the data was inserted into an Excel database, it was then analysed and when possible compared with the overall trend in Germany (using the data from SOEP and Eurostat). The survey was carried out in 2017 and therefore the results were compared with the available data from 2017.

2.5. Results

The relevant results of the survey are discussed here in two different categories, inhabitants and their relationships and interactions in the Garden City. In each part the respective question from the questionnaire is mentioned:

Demographic data

On average 2.2 people live in each household in the Garden City, higher than the average household size in Germany (2.0). The highest share corresponds the households with two people (47.9%) and 24.8% accommodate only one person. These values are respectively 33.8% and 41.4% for Germany. The responding households include inhabitants between the age of 1 and 96 years old, with a mean and median value of 49.5 and 54 years, respectively. The mean age in Germany is 45.9 years (Eurostat 2020b). Figure 2.2 and Figure 2.3 compare the values in the Garden City and Germany. At least 28.6% of the participants in the survey have a university degree, 22.6% have done a vocational training and 17.3% have a high school diploma. The rest have either a secondary education or no certificates. More than half of the participants in the survey must travel to work and the average distance from home to the place of work is around 23.3 km.

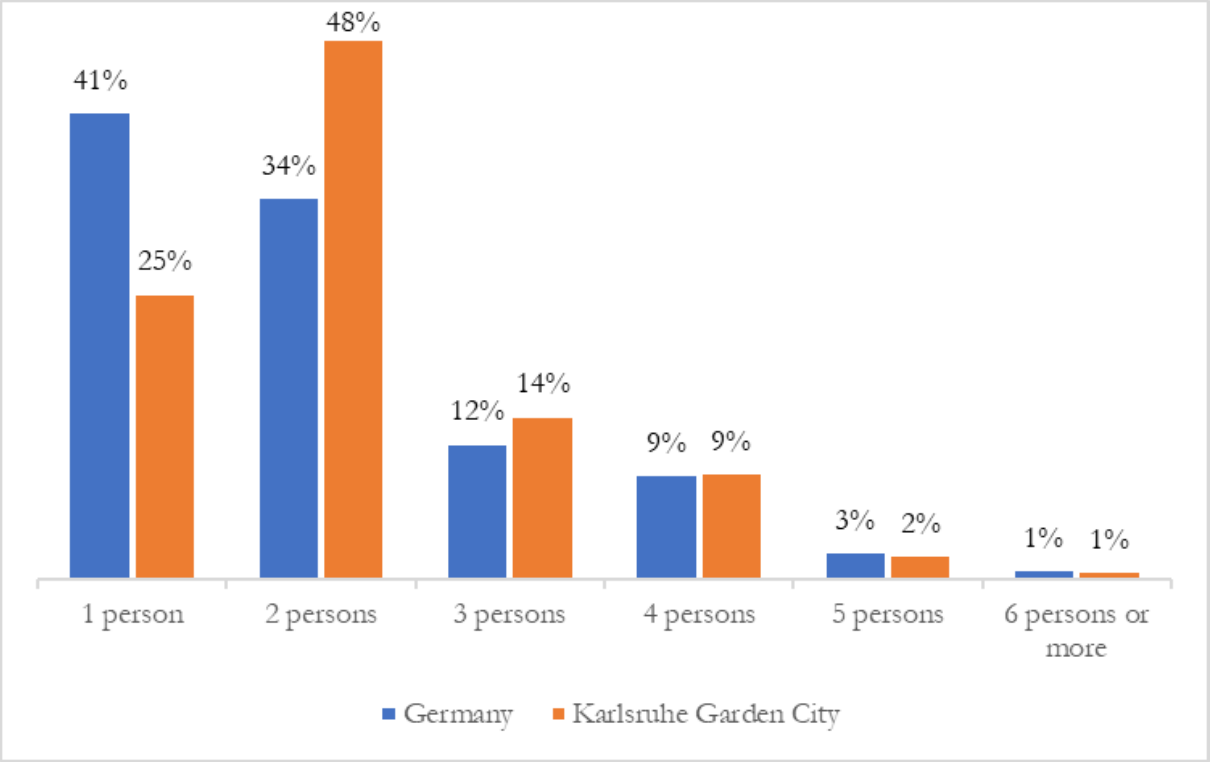

Figure 2.2: Household size Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and (Eurostat 2020a))

What was the initial reason for you to live in the Garden City?

The inhabitants were asked about the motivation for living in the Garden City. 61.0% of the inhabitants made their own decision to live in the Garden City, out of which 5.6% have inherited the house where they live in. It is to be noted that in the Garden City of Karlsruhe the rental contract can be inherited to the tenants' children. After own-decision, birth (20.6%) is the

second common reason for living there, followed by marriage (11.8%) and moved in with the parents (6.6%).

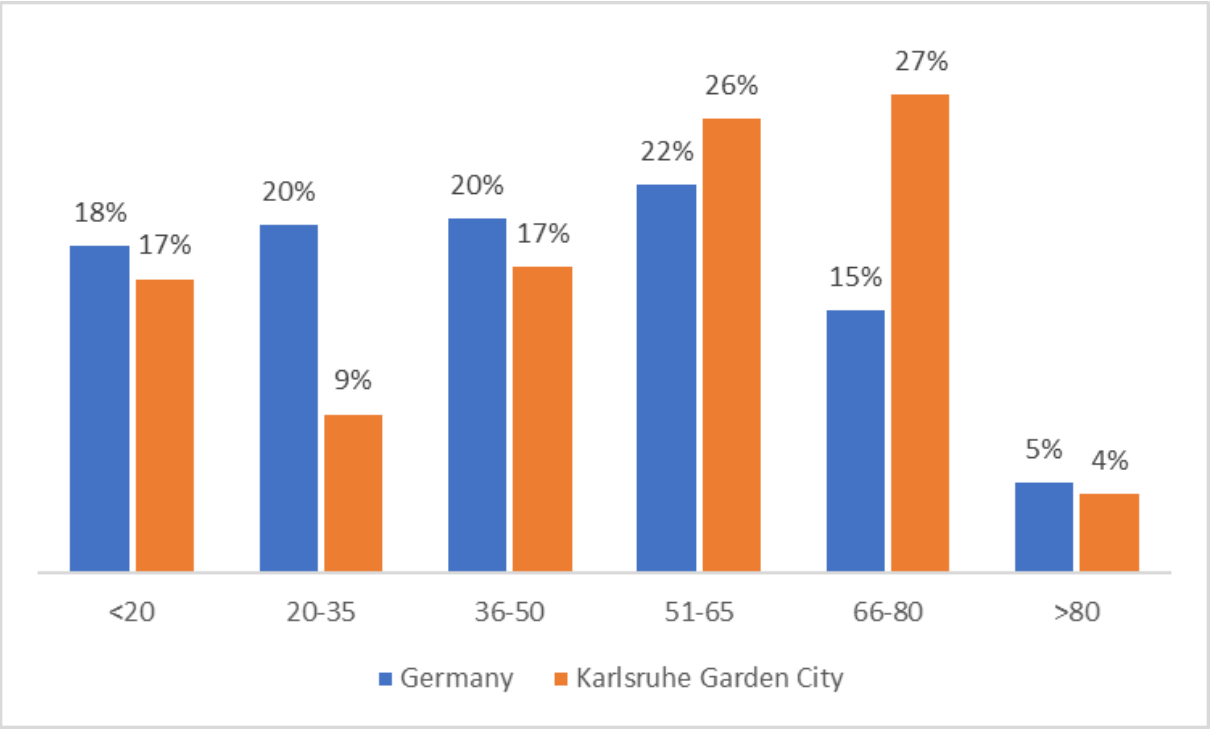

Figure 2.3: Age of the inhabitants Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and (Eurostat 2020c))

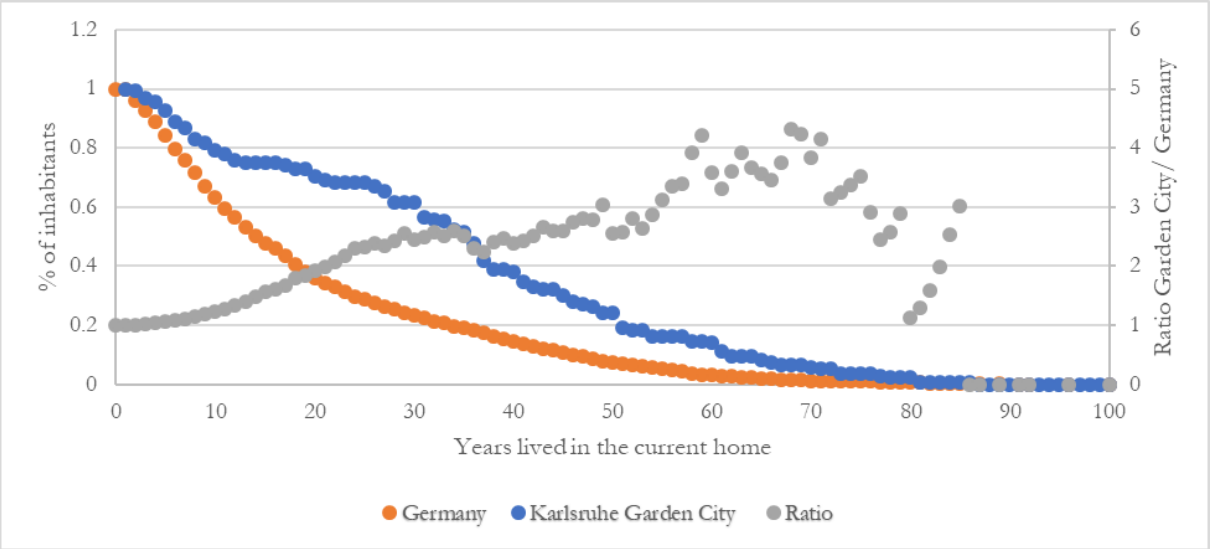

Figure 2.4: Duration of living in the current home- Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and SOEP)

How long have you lived in the Garden City?

A comparison between the collected data from the Garden City and the available data for Germany (SOEP) shows a noticeable difference between the ongoing trends (Figure 2.4). The

participants in the study have lived in their houses in the Garden City on average for 33.8 years. This figure is almost half (18.5 years) for Germany. In both cases the share of the inhabitants gradually decreases by increasing the period of living in the current home. However, in case of the Garden City the share is constantly higher up to the point of 70 years. Moreover, the trend shows more consistency between the years 13 and 26. The graph clearly shows a positive and increasing ratio between the values for the Garden City and the overall trend in Germany, indicating a more sustainable trend in the Garden City. In total 50% of the participants have resided in the Garden City for more than 35 years and 25% have lived there for almost 50 years or more. These figures are respectively 14 and 28 years for Germany (Table 2.1).

Table 2.1: Mean relative duration of living in the current home (source: own calculation based on collected data and SOEP)

	Quartile 1	Median	Quartile 3
Germany	7	14	28
Karlsruhe Garden City	11	35	49.5

Would you recommend others to live in the Garden City?

A 5-point Likert scale was used to define the extent to which the inhabitants of the Garden City recommend living in this area. More than half of the residents absolutely recommend it to other people to live in the Garden City. One fifth of the inhabitants would still recommend it however with a lower certainty. This means 75% of the inhabitants highly recommend moving to the Garden City. Only 7.5% of the participants do not make such a recommendation.

Are there any interesting activities organised in the Garden City?

The Garden City Cooperative offers some activities in the neighbourhood and residents were asked about their impression of those activities. Moreover, they were requested to name the interesting offers by the Garden City. Among all 138 participants, 47 have provided a valid answer to this question. Neighbourhood Breakfast was the most mentioned activity with 64%. After that offered excursions are the second most interesting, mentioned by 34% of the participants. 15% of the inhabitants had mentioned that they do not participate in the events and 6% were not aware of the available options.

How is your relationship with the neighbours?

A 5-point Likert scale was also used for this question. Roughly two thirds of the residents have a (very) close relationship with their neighbours (scales 4 and 5); among those 42.1% are in very close contacts with the neighbours. The data for Germany shows a much lower figure; only 8.4% have a very close relationship with their neighbours (Figure 2.5). Around half of the people in Germany have a moderate contact with the neighbours, in contrast to 18% in the Garden City. On the other hand, only around 15% of the residents do not have a lot of interactions with the neighbours (scales 1 and 2).

What do you like in the Garden City?

This was an open question and the participants could write what they liked in the Garden City. In total 126 participant have provided an answer to this question. As expected, the highest share

relates to the greenery in the Garden City (54.8%). Among those, 36.2% of the inhabitants have specifically mentioned "living in green" as one of their favourite characteristics. It is however not usual that only 54.8% of the participants have considered the green areas as a favourable element of the Garden City. The next favoured characteristics are the central location (34.9%) and having a peaceful and quiet environment (23.8%). Having own share of the garden is what 19.8% of the residents like about living in the Garden City. Other interesting figures in this list are reasonable rent (13.5%), social mixture (7.9%), village feeling (7.1%), dismissal protection (7.1%) and community living (5.6%).

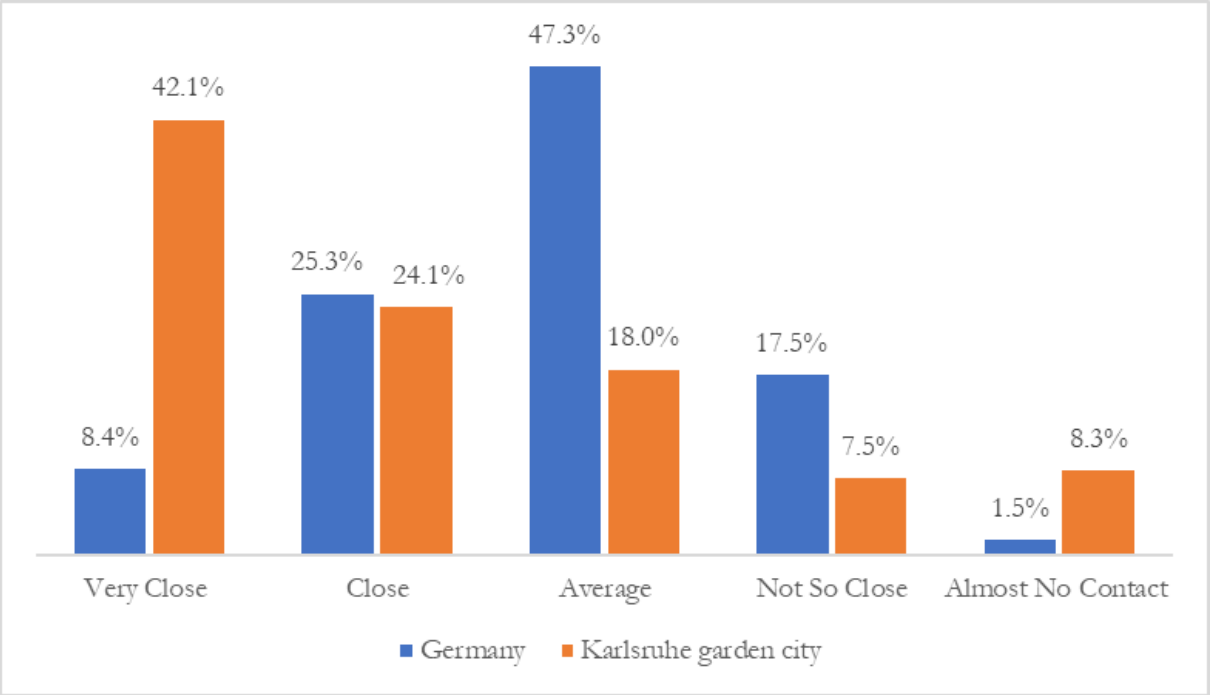

Figure 2.5: Relationship with the neighbours- Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and SOEP)

What do you not like in the Garden City?

The parking situation in the Garden City (too many cars and narrow streets) is what bothers the inhabitants the most; mentioned by almost half of the 98 participants who have answered this question. 15% are unhappy with the way the problems are dealt with by the Cooperative. In addition to that 10% of the residents consider their current rent expensive and they complain about increases of the rent the reason for which is not always clear and traceable. Some of the older tenants have expressed their willingness to move into a smaller flat as their family size has shrunk and their current dwelling has more living space than their needs. What they mention as the obstacle on the way is the higher rent that they will pay if they start a new contract even if they will be living in a smaller flat.

2.6. Discussion

Bramley et al. (2003) believe that the sense of belonging to the surroundings is stronger in the homeowners compared to the renters. Similarly, research on geographic mobility in the EU (European Union 2015) shows that there is a lower likelihood for the homeowners to move home than the renters. The same study reveals that people living in the cities are more likely to

change places than the ones in rural areas. Kemper (2008) analyses the type of destination dwellings to which the inhabitants move. The results show that the highest share in West Germany corresponds the residential buildings with 5-8 apartments and the least favourable is the terraced house. According to the results of this study, the most observed destination quarters are the ones with mostly new buildings; with a slight difference comes the quarter with mostly old buildings (built prior to the second world war) in the second place. The points mentioned here do not match the characteristics of the case study of this paper, as the Garden City of Karlsruhe is run by community ownership in which none of the inhabitants of the settlement owns their property. It consists of mostly old buildings and terraced houses.

Sustainable communities are defined as the places where existing and future generations would like to live and work. This paper analysed the Garden City which was developed following the idea of sustainable living long before the idea of sustainability became prominent in order to find out if it is still able to keep up with these promises. The presented survey provides strong support for this assumption. First of all, it has shown the willingness of the residents to not only live for a long time in the Garden City but also recommend living in the Garden City to others. About two-thirds of all 138 participants in the survey have lived in the Garden City for more than 25 years. Among all the participants 60.1% have freely decided to live or to continue living in the Garden City. Several factors could be the possible reasons behind these observations, e.g. community ownership, architectural and urban features, the history behind the Garden City. It could be argued that although the inhabitants do not own the properties, they have the feeling of homeowners due to the special circumstances in the Garden City, namely membership in the Cooperative and the long waiting times for receiving a house. On the other hand, the street structure and the design of the houses might encourage the residents to have a closer relationship with the neighbours, what was referred to as the “village feeling” by some of the respondents.

Like all empirical work, the study design also has some limitations. The most important one is probably that it is likely that the survey sample is biased towards more engaged renters as participation in surveys in voluntary. Second as participants were asked to provide their names this may have increased social desirability as well as the fact that the survey was handed in via a former representative of the cooperative. However, this design was chosen after weighing different alternatives. The aim of this paper was then to share those observations and to raise the interest for further research about the underlying reasons. Socially enhancing the situation in the communities and settlements like Garden Cities would count as a crucial step toward social sustainability and it is hence essential to identify the relevant indicators of social sustainability in the Garden Cities. The results of this study will be used as the first dataset to develop a framework specifically suitable for the Garden Cities.

Although the Cooperative publishes the news and updates about the Garden City regularly, it seems that some of the problems and dislikes mentioned by the inhabitants are indeed due to the lack of communication about the ongoing projects and policies within the Garden City Cooperative. Hence it would be essential to communicate the observations of this survey with the Garden City Cooperative and to tackle these issues from the Cooperative’s point of view. Although the satisfaction rate is already high in the Garden City, it is assumed that making people more involved and improving the ways of communication, would improve their satisfaction level even more. Therefore, this paper has tried to investigate the ongoing concerns and impressions of the inhabitants and will communicate them with the Garden City Cooperative.

2.7. Conclusion

This paper focuses on sustainable communities as one of the indicators of urban social sustainability. Considering the similarities between the definition of a sustainable community and the objectives of the Garden City movement, e.g. the concerns about higher quality of life and providing opportunities and services for all, the study tries to find the traces of social sustainability in one of the first examples of the Garden City in Germany. Building on the results of this paper, the next step would be to study other indicators of the social sustainability in this type of settlement. The results of the survey will then serve as the initial dataset for developing a framework for studying social sustainability in the Garden Cities. The findings of this study will be made available to the Garden City Cooperative.

3. Investigating the influence of current trends and behaviours on household structures and housing consumption patterns[2]

Abstract: As a major contributor to overall carbon emissions and energy consumption, the housing sector has great potential to reduce energy consumption, whether by reducing the number of appliances, heating temperature or floor space. Consumption patterns encompass how people choose and consume products that satisfy their needs and wants. However, wants, and to some extent needs, are influenced by various factors and existing material and non-material (infra)structures, especially in the housing sector. Focusing on the floor area, this paper aims to identify potentials towards lower consumption lifestyles by applying the Avoid-Shift-Improve framework in the residential sector. Through a conceptual review, the paper explores what shapes current patterns of space use and outlines potential future pathways. Starting from the macro level, the paper examines existing and emerging (societal) trends with (potential) impacts on housing consumption. It then looks at the structural development of households affected by the studied trends. At the micro level, the paper provides an overview of the potential impact of individual behaviour on space use patterns within different categories of housing behaviour. The paper identifies the potential for social and technical change in the housing sector and concludes that promoting non-materialistic narratives (avoid), offering alternative and innovative solutions to satisfy people's spatial needs (shift) and designing flexible buildings (improve) appear to be effective ways for fostering behavioural change towards more efficient use of space.

[2] This chapter has been published as Bagheri, Mahsa; Tröger, Josephine; Freudenberg, Charlotte (2024): Investigating the influence of current trends and behaviours on household structures and housing consumption patterns. In: Consumption & Society. DOI: https://doi.org/10.1332/27528499Y2024D000000025.

3.1. Introduction

The housing sector is a major contributor to CO_2 emissions. In 2020 all phases of construction, use and operation, accounted for at least 37% of global CO_2 emissions and heating and cooling, cooking, and the use of appliances are responsible for at least 28% of these emissions (United Nations, Human Rights Council 2022). The increase in the per capita of living space, that has been observed worldwide in the recent decades, results in, on the one hand, the need for more building materials and on the other hand, an increase in energy consumption during the use phase of the dwelling. Reducing the floor area therefore not only reduces the energy demand in the use phase of the building but also has the largest potential for reducing the emissions from materials in the buildings sector (Zhong et al. 2021). This type of demand reduction is therefore the most effective approach to reducing the carbon footprint of the housing sector.

A household is defined as a social unit consisting of a person living alone or a group of people living together in the same dwelling (Merriam-Webster 2023; Eurostat 2017). Household structure, which refers to household demography, living arrangements and household economics (Sociology 2019), varies across cultures and countries and evolves over time, influenced by dynamic socioeconomic trends. Housing satisfies the need for shelter, one of the basic needs to which every individual is entitled (Doyal et al. 1984). However, in addition to satisfying this basic need, the form of housing and housing-related behaviours play a role in the self-expression and sense of belonging of individuals, making a house a symbol of self (Newmark et al. 1977).

The link between consumption patterns and lifestyle has been discussed in several studies in recent decades (e.g. Reusswig et al. 2003; Gram-Hanssen 2012; Oliveira et al. 2020). Gram-Hanssen (2012) argues that an individual's values and attitudes shape their lifestyle and can be observed through their different types of consumption in all areas, from food to housing to clothing. Similarly, Bosserman (1983) defines lifestyle as a pattern of consumption that reflects values, tastes and preferences. Many studies have addressed this link in different sectors such as energy, food, housing and transport (Reusswig et al. 2003; Hubacek et al. 2007; Gram-Hanssen 2012; Saleem et al. 2019). Moreover, the ever-increasing environmental impacts of Western lifestyles and consumption patterns, especially in the housing sector, have already been addressed (Bjørn et al. 2018; Saleem et al. 2019).

The way we consume and how these patterns relate to our needs has also been addressed in the literature. Coelho et al. (2020, p. 21) define consumption patterns as: “The process by which people search, purchase and consume products in a way to meet all their needs or desires”. Consumption patterns are directly defined by how and which needs and desires we want to satisfy, which in turn should be an indicator of a growing quality of life. While classical economic theories predict a linear correlation between our consumption growth and quality of life, recent empirical evidence suggests a weak link between the two, showing no or even a negative contribution of consumption to quality of life (Vita et al. 2019a; Jackson 2005). Moreover, at the macro level, after a certain threshold, the satisfaction of human needs increasingly depends on non-material factors (Vita et al. 2019a; Sen 1988), such as social ties and psychological well-being (Sirgy 2002).

Considering the fluidity and changeability of lifestyles, theories recognise that people are not determined by static parameters at a personal or situational level but by dynamic and interactive ones (Walters 2006). Studies show that housing needs and preferences are influenced by factors

such as societal norms, working styles and income levels (see e.g. Højrup 2003 and Benedikter 2012). Social structures, on the other hand, are shaped by individuals' "habitus", as they continuously find new solutions and solve problems based on their intuition and past social experiences (Bourdieu 1987). Meadows (1999) refers to "leverage points" as the places in a complex system where small interventions can lead to large changes. The author lists several "places to intervene" in the systems to evoke transformative changes, e.g. changes in parameters, information flow and the system's goal. Tröger et al. (2022) support this framework and argue that changes in situations, such as infrastructure and available options, as well as changes in people's mindsets, can lead to fundamental changes in behavioural patterns.

Investigating the trade-offs of selected actions and their possible effects on energy consumption in residential buildings, Pérez-Sánchez et al. (2022) emphasise the significance of incorporating both social (concerning the household) and technical (concerning the dwelling) changes to address environmental challenges in the buildings sector. Our paper builds upon their findings and delves deeper into identifying the potential for these social and technical changes in the EU housing sector, aiming to achieve reduced energy consumption. To accomplish this, the paper:

1. explores the potential and important routes of influences between different factors in the housing sector that affect the amount of space used in dwellings (Figure 3.1) and
2. applying the Avoid-Shift-Improve (ASI) framework, identifies the social and technical solutions that can potentially orient the impact of those factors towards such positive changes.

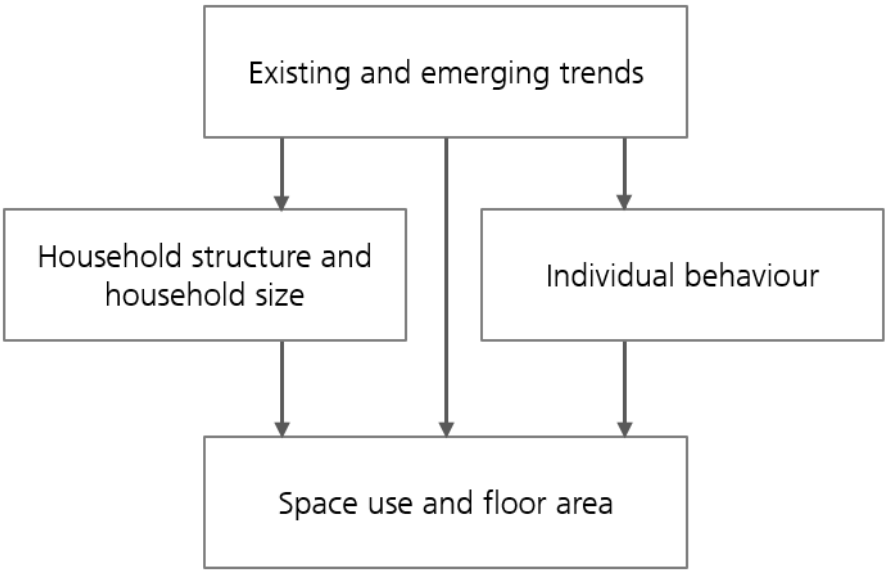

Figure 3.1: Potential routes of influence between different factors in the housing sector (only one-way relationships considered)

With its origins in the early 1990s in Germany, the ASI framework introduces an approach to structure the policy measures to reduce energy consumption and GHG emissions in line with the 1.5 Paris Agreement goal (Dalkmann et al. 2007). With a focus on the demand side, the framework consists of three pillars: "avoid" refers to reducing the need for services (e.g. the need for motorised travel), "shift" addresses changing to more energy-efficient and environmentally friendly means (e.g. modal shift from private cars to buses or trains) and "improve" focuses on increasing the efficiency of the service provider (e.g. fuel and vehicle

efficiency). Initially the framework targeted the transport sector. However, it has been taken up in some other domains as well. For instance, Creutzig et al. (2018) and IPCC (2022a) use the ASI approach in the discussions for mitigating climate change and illustrate service-oriented solutions in sectors and services such as clothing, appliances, goods and nutrition. Even within the transport sector, the framework is used with different foci (e.g. a conceptual framework for transport in response to COVID-19 in TUMI 2020 and telecommunication in Corral Naveda 2022).

In line with the ASI framework, the present work reflects on the impact of selected factors on space use and propose recommendations for improving the social and technical infrastructure to achieve space use reductions as a contribution to reach the Paris climate targets and increase societal well-being. We apply a conceptual review of qualitative and quantitative literature at multiple levels to identify the affecting factors. Figure 3.2 illustrates the research design and highlights the steps of analysis. The methods and data sources used for the analysis are explained throughout the paper in each chapter.

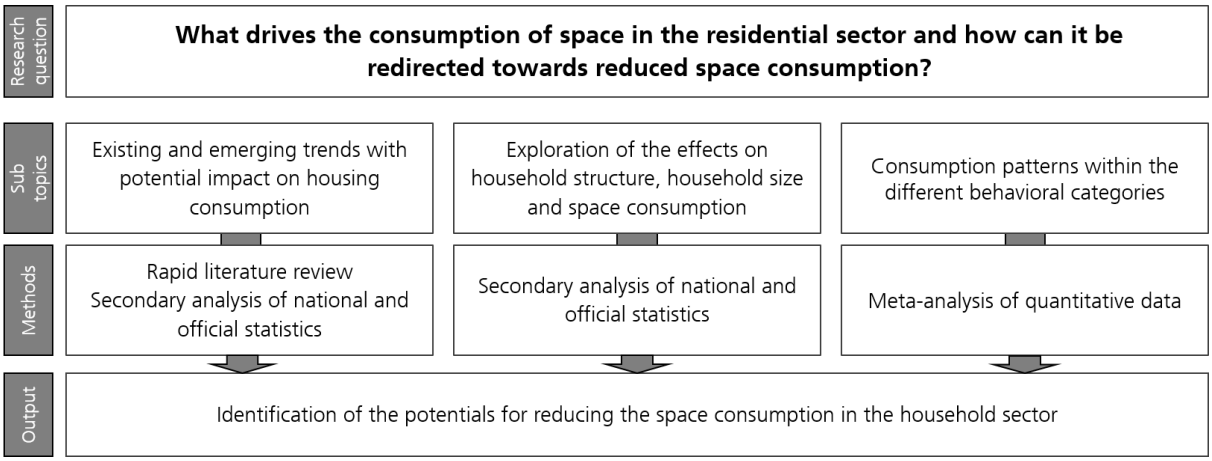

Figure 3.2: Research design for studying the drivers of residential consumption

3.2. Existing and emerging trends

This chapter examines the selected trends that may have an impact on the use of space in the housing sector, either directly or indirectly through changes in household structure that in turn affect the space use. To select these trends, a rapid literature review was conducted using various combinations of the following keywords in search engines such as Google Scholar and Scopus: *trends/factors, effects, residential space use, household structure/composition*. The titles and abstracts of approximately 150 studies were scanned, of which 25 were considered potentially relevant. The main text of these studies was analysed with the aim of extracting factors that were considered to have an impact on space use or household structure. Nine studies discussing such factors and the list of trends and factors mentioned in these studies are presented in Table 3.1. The listed trends and factors were harmonised (e.g. wage rates, economic well-being and income are all collapsed into income) and the recurring trends (i.e. mentioned more than once) were examined. The resulting factors are ageing population, income, employment, marriage, divorce, births, digitalisation, urbanisation and sharing economy. Additionally, the historical development of these trends was studied through secondary analyses of official national and EU statistics from reputable sources such as the Statistical Office of the European Union (Eurostat) and the Federal Statistical Office of Germany (Destatis).

Table 3.1: Selected literature on factors influencing space use or household structure

Source	Mentioned factors/trends
Blau et al. (2013)	wage rates, tax and transfer incentives, legal environment, state of the marriage market
Mason (2023)	economic well-being
Greenwood et al. (2017)	fertility, women employment, marriage, divorce, assortative mating, children living with a single mother, shift in social norms
Wulff et al. (2004)	ageing population, birth rates, divorce and marriage rate
OECD (2021)	teleworking, digitalisation, ageing population, climate change
OECD (2022)	COVID-19 pandemic, digital sharing platforms, e-commerce effects, rapid population ageing, urbanisation
Williams (2009)	ageing population, couple forming later in life, divorce rates, income, house prices and availability, employment opportunities, social provision for children and the elderly, the age at which young people move into their own homes
Xie et al. (2020)	urbanisation
Stewart (2006)	birth rates, longevity, family disintegration, life expectancy, childhood mortality rate, income, ageing population, employment rate, homeownership
Pérez-Sánchez et al. (2022)	shareability and economies of scale, flexibility of time and level of services

Ageing population

Rising life expectancy and low birth rates mean that the proportion of older people in Europe's total population is increasing. The median age in the EU-27 is projected to increase by 4.5 years between 2019 and 2050, reaching 48.2 by the end of this period (European Parliament 2021). The proportion of the EU population aged 80 and over is projected to increase two and a half times between 2021 and 2100, from 6.0% to 14.6%. The over-65s will account for 31.3% of the EU population by the end of the century. In 2021, their share was only 20.9%, which was already 17% more than a decade before (Eurostat 2023s). In contrast, the population group aged 15 to 65 will shrink by about 10 percentage points over the same period (Eurostat 2023r). An increase in the median age in Europe has also been observed in recent decades: from 38.4 years in 2001 to 43.7 years in 2019 (European Parliament 2021).

Income

Economic conditions, including income trends, vary across European countries due to factors such as economic policies, global economic dynamics, and regional circumstances. According to recent data from Eurostat (2023o), the EU countries with the highest median disposable

incomes in 2022 were Luxembourg, the Netherlands, Austria, Belgium, Denmark and Germany. In contrast, Bulgaria, Slovakia, Romania, Hungary, and Greece reported the lowest values. This indicates that income varies considerably across Europe with the Nordic countries having higher per capita income than the Southeastern and the Baltic States. Furthermore, the Gini coefficient was 29.6 in 2022. In tendency, the Gini coefficient slightly declined over the last 10 years across Europe (Eurostat 2023o). However, many studies highlight a widening gap between rich and poor in many European countries and outline increasing inequality over recent decades (e.g. Blanchet et al. 2019; Hung 2021; and Eurostat 2010). This gap may be influenced by factors such as changes in labour markets, technological advancements, globalisation, and policy decisions. Furthermore, growing income disparities in the EU have led to economic consequences, including migration from poorer to wealthier countries and shifts in industrial production, which has also fuelled discontent and support for populist movements, posing a threat to cohesion and democracy within the EU.

Employment

In 2020, 72.3% of the EU population aged between 20 and 64 were employed, 10% more than the rate in 2000. In the same period, with the exception of Greece and Denmark, in all EU countries the employment rate has increased. The absolute employment rates in 2020 separated for males and females of the same age group follow almost the same pattern in the member states with an average EU level of 78.0% for men and 66.5% for women. However, the relative rates compared to year 2000 differ significantly for men and women. The female employment has risen in all the EU countries except for Romania and the highest jump is observed in Malta where the female employment in 2020 is double that of 2000, followed by Bulgaria and Spain with an increase of around 35.0% in the number of employed women. The change in the male employment rate in the same period ranges between -10.3% in Greece and 29.2% in Bulgaria. The EU average has risen by 3.7% for the male population compared to the major increase of 19% for the female population (Eurostat 2023h).

Marriage, divorce, childbirth

While the crude marriage rate, i.e. the number of marriages during the year per 1000 persons, in the EU has fallen from 5.2 in 2000 to 3.9 in 2021 (Eurostat 2023p), the crude divorce rate has fluctuated over the same period, peaking in 2006 and then falling slightly. In 2022, an average of 1.7 divorces per 1000 persons were reported, showing almost one divorce for every two marriages. Between 2000 and 2017, the average age at first marriage increased in EU member states with available data for both men and women between around 2.1 and 5.5 years. The average age of women at the birth of their first child has also increased over the last two decades in all EU countries between 1.3 and 4.6 years, reaching an average of 29.5 years in 2021. In that year, women in more than a third of EU member states gave birth to their first child at an average age of 30 or more.

Digitalisation

One of the most influential trends of recent decades has been increasing digitalisation. The term refers to the widespread transformation of formerly analogue processes, assets, goods and services into digital ones, enabled by underlying innovations in information and communication technologies (ICT). Across different sectors of the economy and society, the increasing

integration of digital technologies is shaping the way businesses and public administrations operate and the way individuals interact with each other and the world around them.

The trend shapes the way people carry out everyday tasks, gather information or communicate in a globalised world. Digital technologies have also helped to reduce transaction costs, increase process efficiency, productivity and competitiveness in various economic sectors and support the creation of entirely new digital goods and services of the so-called “digital economy” (Kravchenko et al. 2019). Disruptive machine learning and artificial intelligence technologies support breaking new scientific ground and creating new industries and markets, ultimately affecting the organisation of societies around the world. As such the digitalisation trend is not only changing technology landscape but is also fundamentally driving socio-economic transformation processes.

Sharing Economy

In traditional markets, consumers buy products and acquire ownership (Dervojeda et al. 2013). However, the sharing of goods and services has become increasingly important in Europe in recent years (Hamari et al. 2016) and the demand for sharing models is expected to grow in the future. While the emergence of new technological capabilities is accelerating the growth of the sharing economy, the literature identifies key motivations for consumers to prefer the sharing economy. In contrast to ownership which often involves a high financial burden for purchase and maintenance reasons, the sharing economy is financially profitable for consumers, who only have to pay for what they actually use. Owners of shared items have also the opportunity to generate income by sharing them. Motivation in terms of norms such as environmental sustainability is seen as an important predictor of participation in sharing economy business models (Hamari et al. 2016) as sharing economy models are generally expected to be highly sustainable (Prothero et al. 2011). The use of the sharing economy can involve a significant level of personal interaction and community experience, particularly when products are offered by individuals rather than “faceless” companies. There is a growing demand for this type of consumption, leading businesses to shift from transaction-based (i.e. primarily focusing on completing a transaction or exchanging goods or services) to experience-based services (i.e. the focus is on creating a positive experience for and a sense of connection with customers) that rely on trust (pwc 2015). Another important consumer trend influencing the development of the sharing economy is the change in what is seen as a status symbol. While property used to be a kind of status symbol, there is a trend away from this understanding, especially among young people (pwc 2015). In contrast to owning property, users of access driven business models are far less tied down and enjoy the ability to switch products and services at any time.

Urbanisation

Urbanisation has been identified by the European Commission as one of the most influential megatrends for some time. At a global level, the population living in cities, defined as high-density places of at least 50,000 inhabitants, has more than doubled in the last 40 years, from 1.5 billion in 1975 to 3.5 billion in 2015. It is projected to reach 5 billion by 2055, almost 55% of the world’s population. In Europe too, the trend towards urbanisation has intensified in recent decades, with more and more people moving to urban areas (European Commission 2023). By 2021, more than 70% of Europe's population already lived in urban areas (World Bank 2022), and Europe's urbanisation rate is expected to increase to around 83.7% by 2050

(United Nations 2018). However, this process is uneven across the continent. While urbanisation rates are already high in Western and Northern Europe, there is still a significant level of rural-urban migration in Eastern Europe and certain rural areas. (World Bank 2022).

There are many reasons for urbanisation in Europe. One the one hand, cities offer a wider choice of jobs and career opportunities in different sectors, especially in services, technology and creative industries. Proximity to businesses, universities and research institutions fosters innovation and economic growth. In addition, urban areas offer a wide range of educational, health and cultural opportunities. High-quality schools and universities, medical facilities, museums, theatres, restaurants and shopping opportunities attract people who value the urban lifestyle and want to benefit from the diverse opportunities (European Commission 2023).

3.3. Impact of trends on household structure and consumption

3.3.1. Household structure

Traditional family structures have changed in many European countries. There is an increase in non-marital partnerships, single parent families, patchwork families and same-sex partnerships. These changes have implications for social support systems, childcare, housing and legal recognition of partnerships. The nuclear family, with the traditional concept of partners committing to live together and share their lives, remains the dominant family type across Europe but is losing ground in terms of numbers. With the higher number of non-marital cohabiting couples, the proportion of children born out of wedlock is also increasing (Kapella et al. 2010).

The trend towards starting a family later is noticeable throughout Europe. This is particularly evident in a higher age at first childbirth among women as well as in later first marriages. In 2022, 5.5% of adult women aged 25-54 years, in the EU, were single parents with children, against 1.1% of adult men (Eurostat 2023l). In many European countries, the number of childless households is also increasing. The number of single-person households without children in the EU increased by 30.7% from 2009 to 2022 (Eurostat 2023l). This is the result of various factors such as demographic changes, occupational challenges, higher female participation in education, changing lifestyles and individual preferences.

The share of adults aged 18-24 who still live with their parents increased from 2007 to 2020 and started dropping afterwards. In 2021 an average of 80% was reported in the EU27. The similar trend is observed for the wider age range of 18-34, however in this age group the figures fluctuate more extremely among the countries, ranging from 16.0 to 76.5% (Eurostat 2023o). In most EU countries the figures have only changed slightly between 2007 and 2021. Few exceptions are Ireland and Portugal where children stay 3 and 5 years longer with their parents and Lithuania and Estonia where they leave the parental home around 3 years earlier than before (Eurostat 2023j).

3.3.2. Household size

The average size of households in the EU has been shrinking in recent decades, going from an average of 2.4 persons per household in 2007 to 2.2 in 2022 (Eurostat 2023l). The share of the households occupied by only one or two residents has increased reaching at least 60% of all EU households in 2022. While the EU average share of single-person households was 26 % in 2007, the figure had already risen to 36.2% by 2022, covering more than one-third of the EU

households. In the same period the share of two-person households inhabited by childless couples increased by around 5% reaching almost a quarter of all EU households (Eurostat 2023l).

The trend towards smaller households can be explained on the one hand by the decline in marriages and births and the spread of partnerships with separate living arrangements. On the other hand, the progressive demographic ageing and the improvement of the health condition of older people ensure that more and more senior citizens lead an independent household alone or in pairs. In addition to these socio-demographic factors, the high occupational mobility of workers has also promoted the trend towards smaller households (Destatis 2023).

3.3.3. Floor area and room per capita

While the EU population increased by only about 1.6% between 2009 and 2021, the number of households rose by 8% in this period. The per capita floor area has also increased in recent decades reaching 48.7 m^2 in 2021 compared to 41.4 m^2 in 2009 and 35 m^2 in 1990 (Odyssee-Mure 2023a) and the number of rooms per person has increased from 1.5 in 2009 to 1.6 in 2021. However, this increase in space is not evenly spread across age groups, household types and income groups. In 2021, the lowest overcrowding[3] rate in the EU was observed among those aged 65 and over, at 7% compared with an average of 17%, while the younger generation lived mostly in overcrowded dwellings (e.g. 28.4% of 12-17 year olds and 25.7% of 20-29 year olds) (Eurostat 2023o). The same trend is observed for the number of rooms per person. On the other hand, almost half of the oldest age group have too many rooms in their dwelling, compared with only 25% of the under 18s. Single and double households in which all or one member is aged over 65 occupy the largest number of rooms per person. A comparison of household composition shows that childless single or double adult households occupy the highest number of rooms per person. Any increase in the number of adults or children reduces the share of rooms per person. The overcrowding rate is also negatively related to the income level, with the lowest income households (quintiles 1 and 2) above the average.

3.4. Areas of lifestyles affecting the space use patterns

This chapter explores how certain behaviours and individual habits affect the space use in the housing sector. We built categories and argue how they have a direct effect on floor space (Figure 3.3). A meta-analysis is conducted to synthesise quantitative data on consumption patterns across these different behaviour categories. Search terms such as *space requirements for remote working* and *frequency of home cooking among EU/German citizens* were used to identify relevant studies. Data was obtained from studies, scientific papers, existing databases, and official national and EU statistical portals.

Food-related behaviour

The frequency and style of dining can impact the space dedicated to the dining area. If individuals or households prefer formal dining, a separate dining room may be desired, while those who have casual or informal eating habits may use multipurpose spaces for dining or opt

[3] According to Eurostat (2011), a dwelling is defined as overcrowded if the household living in it has at its disposal, less than the minimum number of rooms equal to: one room for the household, one room per couple in the household, one room for each single person aged 18 or more, one room per pair of single people of the same gender between 12 and 17 years of age, one room for each single person between 12 and 17 years of age and not included in the previous category, and one room per pair of children under 12 years of age.

for smaller dining rooms. Food behaviour plays also a significant role in the kitchen design and layout. If individuals frequently engage in cooking meals from scratch, they may prefer ample counter space for food preparation and have additional food processing appliances such as a blender. In contrast, if the individuals rely more on ready-made or take-out meals, a smaller kitchen with less emphasis on cooking space may be preferred, however they might have larger freezers and appliances such as a microwave that also need space and energy. According to the German BMEL (2022) nutrition report, 45% of Germans cook daily, 36%, 2-3 times a week and only 18% once a week or less. When it comes to eating out, 15% say they go out frequently, 72% rarely and 13% never (ifd Allensbach 2022).

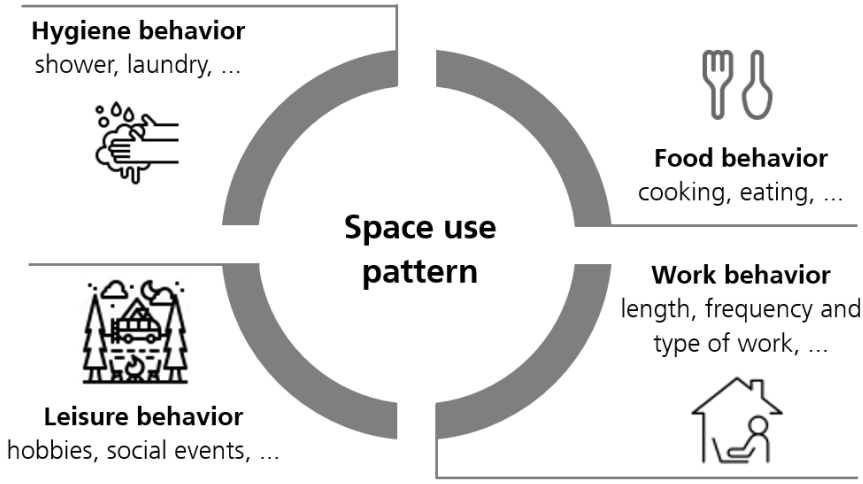

Figure 3.3: Behaviour categories influencing residential space use pattern

The complexity of cooking and number of people eating the meals, can also influence the need for specific or larger appliances. People who cook regularly, or for more household members may need larger kitchens with larger ovens, freezers and storage. Especially big appliances like big refrigerators, standalone freezers, ovens and dishwashers require additional space and larger kitchens. Kitchen size in the UK for example tends to be relative stable, having gone up from 12.27 m^2 for houses built in the 1930s, to its peak of 15.37 m^2 for houses built in the 1960 and back to 12.61 m^2 for houses built in the 2010s (Thomas 2019). Storing and preserving food uses space and energy, while cooling and refrigeration food is especially energy intensive (Eurostat 2022c). Different types of diets or culinary interest may require specific storage areas for ingredients, spices and kitchen tools. The proximity of supermarkets or fresh food stores in urban areas can increase the number of shopping trips and reduce the need for food storage and refrigeration, resulting in less space usage and energy consumption for refrigeration.

Work behaviour

In 2022, around 75% of the EU population aged between 20-64 was employed (Eurostat 2023g) from which more than 10% worked usually from home (Eurostat 2023f). However, occurrence and intensity of working from home varies across countries. In a global survey conducted in 2021 and 2022, respondents from European countries worked weekly between 1.2 (Greece) to 1.8 days (Netherlands) in the home office. In Germany, the proportion of employees working at least partly in a home office fell from just under 30% at the beginning of 2021 to around 25% at the end of 2022 (ifo Konjunkturumfragen 2022). Regarding the daily working time,

more than one-third of Hungarians surveyed spent three to five hours a day working from home, 41% spent six to eight hours and 13% more than eight hours (statista 2022).

Teleworking has become increasingly common in recent years, especially in the wake of the COVID-19 pandemic (Eurostat 2022d), with individuals being sometimes forced to use different areas of their homes as offices. The change in the working pattern continued even after the pandemic with more employees willing to work from home and more employers offering this possibility. The arrangement of working space can vary depending on personal preferences, spatial feasibility, occurrence and intensity of working from home as well as type of the work. It can range from using the kitchen table as a desk in the times that it is not used as a dining table, to dedicating a separate room with all office equipment to the home office.

Therefore, the impact of typical home office configurations on housing space consumption can vary widely depending on the setup. A teleworker who moves to a larger house to accommodate their home office can have a significant impact on the household space consumption. In households with several teleworkers, efficient use of existing space (such as a kitchen table) can lead to more energy-efficient home office configurations. Teleworkers use 6.5 m^2 exclusively (or 4% more than non-teleworkers) and 12.5 m^2 generally for home offices. 45% of telecommuters have a dedicated office, while the rest uses shared space in their home (O'Brien et al. 2020). However, the need for a working space at home is not limited to the employees with teleworking possibility, but also self-employed people and the employees who actually cannot work remotely but need some preparations for their work (e.g. teachers preparing the teaching material).

Leisure behaviour

According to the OECD Time Use Database (2016) the EU population aged between 15 and 64 spends from 241 minutes per day in Portugal to 368 minutes a day in Norway on leisure. Leisure time includes indoor and outdoor activities such as recreation and entertainment that take place during free time. The type and intensity of hobbies people pursue can have an impact on space requirements. Indoor leisure activities may require specific spaces within the home, for example people who enjoy playing musical instruments may require a designated music room or area with adequate space for their instruments and equipment. Similarly, those who pursue hobbies such as painting or crafting may need a dedicated workspace or studio. However, some other hobbies may not require a dedicated space and allow for multifunctional rooms, such as turning the living room into a gaming area. Outdoor activities require less living space than indoor activities, however some may be less flexible than others. Individuals who enjoy gardening and outdoor games may allocate space for a garden or patio, while people who enjoy outdoor hobbies such as hiking, skiing and surfing may need less space in their home for these activities, and more for storing the necessary equipment.

Some leisure activities allow for some flexibility and leave room for individual preferences in how they are carried out. For example, people who like to exercise may use multipurpose rooms in their homes to do their exercises, create a dedicated fitness area or choose to go to a gym. Leisure behaviour often involves entertainment activities such as watching movies, playing video games, or hosting gatherings. This can influence the allocation of space, with the living room or media room being designated as an entertainment hub, equipped with comfortable seating, audiovisual equipment, and storage for media. According to Destatis (2013) people in Germany use media (e.g. TV, radio, smartphone) for an average of three hours in their leisure

time. The impact of the organisation of leisure time on the living space has been a topic of interest in recent studies. The question of whether a separate living room is necessary for leisure activities or socialising has been raised. In the UK, the average living room size is reported to be 17.09 m^2 (Thomas 2019).

Hygiene behaviour

Hygiene behaviours include activities related to personal hygiene and household cleanliness, such as showering and laundry. How long and how often we shower or bathe, and how we wash and dry our clothes, can have an impact on space and energy use, particularly in the bathroom. For example, the average room size for newly built bathrooms in the UK is 5.55 m^2 (Thomas 2019). The size and layout of residential bathrooms can be influenced by the choice of bathtubs or shower, as the bathtubs tend to be larger than showers. Currently, for example, 35% of all Dutch households have a bathtub (TNS Nipo 2022). The availability and use of bathroom space can vary according to the showering patterns of household members, i.e. how often and for how long they shower. In Germany, for example, people shower for 6-10 minutes on average, with 53% of people saying they shower 2-4 times a week or less, 14% showering 5-6 times and 27% showering daily (Yougov 2021). When multiple household members have similar showering routines, it is probable that they prefer having more than one bathroom.

The frequency of laundry may also have an impact on space use, with the vast majority of respondents (82%) in Austria doing laundry at least once a week and 10% doing so daily (MindTake 2018). This can impact the amount of laundry-related clutter in a home, and the space required for laundry equipment and supplies. As the convenience of frequent laundry appears to be important, washing machines are common household appliances in many European countries, with more than 90% of households in Romania, Austria, Poland, Portugal, Italy, Spain, Germany, the United Kingdom, and the Netherlands owning one (Statista Global Consumer Survey 2022). This could lead to larger bathrooms or kitchens as personal washing machines take up more space than shared ones such as those in laundry rooms.

The way of drying clothes can affect the use of space in a home. Clotheslines and racks can take up significant amounts of space depending on their size and placement, while tumble dryers are typically installed in a specific location in the home and may require additional ventilation or plumbing. Although many households choose to use clotheslines or drying racks instead, the ownership rate of tumble dryers in Germany, for example, has increased from 32% in 2000 to 43% in 2021, remaining still much lower than the ownership rate of washing machines (Destatis 2022b).

3.5. Discussion and Conclusion

The housing sector accounts for a large share of total final energy consumption, mainly driven by the amount of space in this sector and the energy required to heat it. This paper examines the trends and factors influencing space use in the housing sector and, by analysing their (potential) impact, suggests social and technical solutions for facilitating the reduction in space use.

The trends examined in this paper can have varying direct and indirect impacts on residential energy consumption and space use. For example, the growth of the sharing economy in the housing sector may lead to a reduction in the average size of dwellings per person due to reduced ownership of appliances and storage needs. However, it could also lead to an increase

in floor area if certain parts of the dwellings are only rented out occasionally and are not used otherwise. Another example is the urbanisation and densification of urban areas, which often result in limited available living space. Rising rents and property prices in urban centres push people towards smaller living spaces. This shift in consumption patterns is also accompanied by the adoption of sharing models, such as car-sharing and co-working spaces, which encourage sharing resources rather than individual ownership.

Potential changes in household structure resulting from such trends could also impact space use patterns. The growing number of households with only one or two adults and a high per capita area is a consequence of the increasing proportion of people over 65. Delayed childbearing and higher employment rates among women also play a role in forming childless households, which have an above-average per capita area. Higher divorce rates are another trend that increases the need for housing, as more dwellings are required for the same number of people. This situation is exacerbated when shared custody of children requires space in each parent's home.

In addition to the existing trends outlined in this paper, other consumption or behavioural trends may emerge or accelerate due to, or facilitated by, unforeseen adverse events such as those observed in recent years, namely the COVID-19 pandemic and the Russian invasion of Ukraine. In response to these unexpected circumstances, individuals and companies showed signs of short and long-term behavioural, lifestyle and strategic adjustments that could disrupt historical trends (e.g. the increase in teleworking (Lund et al. 2021), digital health seeking (van Kessel et al. 2023) and online shopping (Said et al. 2023) following COVID-19 and the adoption of energy-saving behaviours (EEA 2023) and changes in household expenditure trends (Menyhért 2022) following the energy crises as a result of the war in Ukraine).

On one hand, the household structure and the (space use) consumption patterns in the residential sector are influenced by external trends and factors; on the other hand, household needs and behaviours are dynamic and constantly evolving, influenced by these factors. Therefore, solutions for reducing consumption in the housing sector should consider these constant changes and their underlying reasons.

Some of the trends analysed in this paper (i.e. the ones regarding the ageing population, employment, marriage, divorce, and childbirth) have an impact on the household structure, which in turn changes the spatial needs of households. Therefore, more flexibility is needed to accommodate the changing living situations. However, the existing buildings that are supposed to satisfy the needs of households are typically designed with static features, resulting in a mismatch between supply and demand (Greden 2006). As a response, adaptability should be considered a key principle in designing new buildings to achieve resource efficiency. Adaptability refers to the capacity of a building to be modified to accommodate new situations or conditions (Schmidt III et al. 2016). This can encompass regular changes such as varying day-night uses or utilising (re)movable partitions to connect the rooms when larger space is needed, as well as long-term adjustments like designing modular apartments that can be combined or separated to align with household needs. Integrating flexibility and adaptability into the design process (as suggested by Özinal et al. 2021 and Hosseini Raviz et al. 2015) creates spaces that can be easily modified and reconfigured to meet changing needs. Improving the design of the buildings, eliminates the need for constant expansion or reconstruction, as spaces can be adapted to meet evolving user requirements.

Some other trends (i.e. digitalisation, sharing economy and urbanisation) do not necessarily have a direct impact on the household structure, but they lead to changes in households' needs and habits and, therefore, influence the space use pattern in the residential sector. While these trends may have the potential to reduce space consumption (e.g. higher prices and limited available space in cities leading to decreased living space), they may also increase the need for more space (e.g. the uptake of digitalisation leading to the need for additional space to work from home). New approaches and innovative solutions are needed to counteract this increase in space need. To address this, alternatives for more flexible use of existing housing should be promoted. This would involve rethinking how space is used and encouraging individuals to adapt their behaviour to make the most efficient use of available space. Maximising the use of existing space can reduce the need for additional construction and minimise resource consumption. This could include providing communal spaces (recreation facilities, co-working spaces, social events) to reduce the need for additional individual rooms in each dwelling or promoting collective living arrangements. The role of such social innovations in reducing consumption has already been discussed in the literature (e.g. Lorek et al. 2019 and Jaeger-Erben et al. 2015). Raising environmental awareness and reducing barriers for changes could help promote this approach and shift from traditional space use patterns to more innovative ones.

Lastly, consumption patterns, lifestyles and behaviours are influenced by, among other things, social norms and values, which play an important role in shaping our perceptions of what is desirable or acceptable in society. These perceptions are influenced by factors like income, as higher income usually results in higher consumption. Non-materialistic values have been suggested to lead to attitudes of sufficiency and consumption of "just enough" (see e.g. McDonald et al. 2006 and Boulanger 2010). Reorienting social norms towards value-driven and non-materialistic norms may lead to less resource and material-intensive behaviour. By understanding these influences, we can avoid the need for high consumption and work towards promoting sustainable lifestyles and creating a built environment that supports both individual well-being and environmental sustainability.

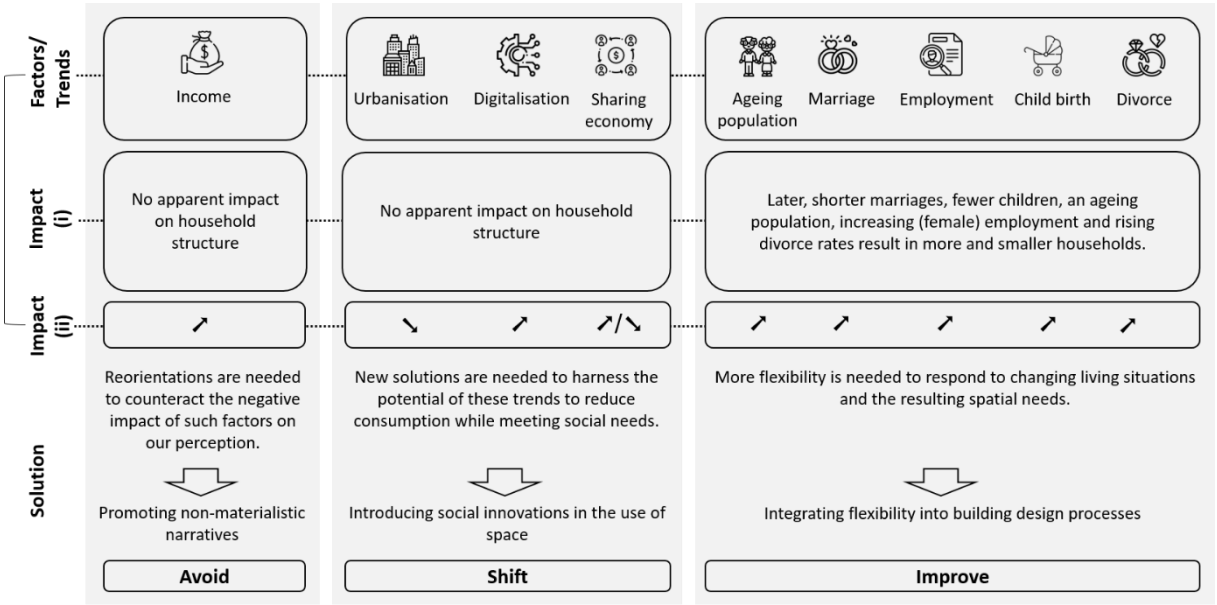

Figure 3.4: Summary of the studied trends and their impact on household structure and consumption

To summarise, this paper highlights potential social and technical changes that could facilitate space use reduction as illustrated in Figure 3.4. From the social perspective, focusing on households, the need for space consumption can be avoided by promoting non-materialistic narratives and shifted by introducing social innovations in the use of space. From a technical point of view and focusing on buildings, integrating flexibility into design processes can improve space efficiency. It is essential to acknowledge that individual behaviours and habits are shaped by a variety of factors at different levels, including socio-demographics, as well as cultural and geographical identities. Variations in thermal comfort needs across different ages and genders, the tendency in certain cultures to live in large families or host substantial gatherings, and the higher consumption levels typically seen in high-income households are just a few examples of how these factors can impact energy consumption. Recognising and addressing these diverse needs and backgrounds is crucial for understanding and developing effective solutions to the residential sector's significant space and energy consumption challenges.

3.6. Limitations and outlook

We could identify some important trends based on our literature search. Nevertheless, this conceptual overview has a number of shortcomings. First, we were not able to quantify the importance of each trend based on our analyses as we only selected them qualitatively and derived some implications. Future studies should try to quantify the influences over time and build a more complex framework of influences and effects of these trends on space use. Furthermore, we only analysed the relationships in one direction as illustrated in Figure 3.1. However, one may assume that the effects are not linear, but are mutually reinforcing, not only in a top-down manner but also in a bottom-up way. We do not suggest the existence of a causal effect as shown in this figure, nor do we deny causality in the other direction. Furthermore, the behavioural categories examined in this paper relate to standard and common activities carried out in an average household. Our conclusions highlight the significant impact of habits and behaviours on space requirements and use. However, a more in-depth study of activities, such as childcare or eldercare with specific space requirements, may provide further insights into other types of impacts on space use and should be stimulated by the current research. Additionally, our focus has been solely on activities within dwellings. Yet, there are other behavioural categories that occur outside the home and can significantly influence space use. For instance, mobility behaviour, including transportation preferences (e.g. car ownership and having a garage, bike, public transportation), can impact location choices (e.g. proximity to the tram lines), the need for specific spaces (e.g. parking space) and spatial dimensions (e.g. smaller affordable flats in the city centre). Including such activities in future research would provide a comprehensive overview of factors affecting space use pattern and reveal inter-sectoral connections, such as those between the transport and residential sectors.

4. Exploring residential space use pattern: Findings from a multi-country survey[4]

Abstract: The residential sector significantly contributes to total energy consumption in the European Union. Over the past decades, the average floor area per person has increased steadily, resulting in higher energy demand for building materials, heating and cooling. However, the distribution of floor area is not equal across different demographic groups and household compositions. Redistributing floor area offers a significant opportunity to save resources and reduce the need for new construction by avoiding unnecessary consumption. Strategies such as moving, sharing and rearranging can facilitate this redistribution in the residential sector. In order to assess the feasibility of these strategies, this paper examines the current residents' behaviour in the residential sector regarding space use and explores the potential for change. It draws on empirical data from an online survey conducted in Germany, Sweden, Poland and Portugal. By conducting a cluster analysis of the collected data, the paper identifies two groups with the highest potential for change in residential space use. It examines their willingness to change their space use patterns and investigates the acceptance of specific strategies that could lead to a reduction in the need for new construction in the residential sector. In order to promote more efficient use of space in the residential sector, the paper recommends encouraging space sharing, supporting structural changes in dwellings, and providing incentives for moving from under-occupied dwellings. It advocates for the implementation of tailored policies that consider the characteristics of each group, along with targeted awareness-raising efforts to increase policy acceptance.

[4] This chapter has been submitted to an international peer-reviewed journal as Bagheri, Mahsa; Pröpper, Alexandra; Klein, Geneviève (2024): Exploring residential space use pattern: Findings from a multi-country survey

CRediT authorship contribution statement: Mahsa Bagheri: Conceptualisation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualisation, Writing – Original Draft; Alexandra Pröpper: Formal analysis, Methodology, Software, Validation, Visualisation, Writing - Review & Editing; Geneviève Klein: Investigation, Resources, Writing – Original Draft

4.1. Introduction

Climate change is a growing concern, contributing to environmental problems such as rising global average temperatures, ocean acidification and extreme weather events (Yong et al. 2022). The International Panel on Climate Change (IPCC) has indicated that our best chance of avoiding irreversible impacts of climate change is to limit the global average temperature increase to 1.5°C above pre-industrial levels (IPCC 2023). Anthropogenic activities are likely the main contributor to climate change, as many sectors, such as energy and material production, rely heavily on the combustion of fossil fuels and emit large amounts of CO_2 (Hoeller et al. 2023).

Reducing greenhouse gas (GHG) emissions is challenging, given the widespread combustion of fossil fuels across sectors and countries. Nonetheless, innovative technological solutions, such as energy efficient buildings, electric vehicles, and renewable electricity for heating and cooling, pose alternatives to conventional fossil fuel fed systems (Cherubini 2010). In addition to technological innovation, altering societal consumption patterns is an essential strategy that should be considered in parallel to technological innovation to reduce GHG emissions (Cherubini 2010). The IPCC emphasises that mitigation pathways in line with warming targets are characterised by reductions in energy demand (among other strategies) and do not solely rely on modifications to the supply side (IPCC 2023). Furthermore, uncertainties remain about the deployment and efficacy of some technologies. Therefore, applying multifaceted strategies to reduce emissions is appealing, ensuring the efforts are diversified and not reliant on a single solution.

The residential sector is a large emission contributor, accounting for 39% of process-related CO_2 emissions and 36% of final energy use in 2018 (IEA 2019). This high share of emissions is due to the carbon intensive materials often used in construction (i.e. cement, steel), energy use (heating, cooling) and the operation of appliances (Hoeller et al. 2023). Many strategies and solutions in the framework of sufficiency, consistency, and efficiency (Huber 1995) are actively being deployed or promoted to reduce the emissions from this sector. Some of these strategies include using renewable energy instead of fossil fuels and using alternative materials or construction methods (i.e. wood, modular designs) (Hoeller et al. 2023). Both supply and demand side interventions are being applied; an example of supply-side modification might be using renewables as energy sources, and a demand-side modification might be encouraging consumers to keep their thermostats below a certain temperature.

A factor that significantly influences the material and energy use (and therefore CO_2 emissions) in housing is the space or size of the dwelling, as larger living spaces generally require more building materials and have higher energy consumption during the use phase (mainly for space heating). In recent decades an increase in living space, i.e. floor area per capita, has contributed to a rise in carbon-intensive activities within the residential sector (Thomas et al. 2019). In 2018, the EU average floor area per capita ranged from 20 m^2 (in Romania) to 55 m^2 (in Cyprus), showing an increase of 16% compared to 2000 (Gynther 2021). It was inferred that changes in comfort preferences (i.e. a larger living space is more “comfortable”), increases in one-person households, and changes in family structures drove this increase. An earlier study in the UK found an increase in living space from 38 m^2 to 44 m^2 per person between 1991 and 2001.This increase is also likely connected to the increase in one-person households (from 18%

to 29% of dwellings) (Williams 2009), which in turn could be related to a multitude of factors, such as a higher divorce rate and an ageing population.

The *under-occupation* (or *over-consumption*) of a dwelling, where there is more space or rooms than the household uses or needs, can limit housing availability for those who need more space. Certain groups may over-consume while others may under-consume. The typical pattern observed is over-consumption among those living alone and in older age groups, creating a bottleneck that restricts younger households' access to more suitable, spacious housing on the market at affordable prices (Costa-Font et al. 2022). This inefficient use of space exacerbates existing pressures on housing, creating more energy and material demand. There is already a general shortage of suitable, affordable housing in many European countries. In major German cities, for instance, there is a shortage of around two million affordable dwellings (Dgb 2018). To address this deficit, the government has planned to build 400,000 new dwellings per year (Fillies 2023).

Given the positive relationship between living space use in residential housing and CO_2 emissions, it is imperative to consider strategies to reduce total housing related emissions. One such strategy could be to improve space use efficiency and reduce the total amount of space consumed in housing. Such a strategy would especially rely on changes in the demand side, in particular consumer demand and behaviour with regard to space in housing, keeping in mind that housing should meet the needs of its residents. Ibem et al. (2015) consider both housing adequacy and residents' satisfaction as important factors in assessing the extent to which the housing meets the needs of its residents. One could therefore assume that the perception of residents towards their living space could have an impact on their space-related behaviour, also including any changes to their living space. Therefore, a better understanding of high space users and their motivations could advance efforts to reduce over-consumption. Knowledge of groups that generally show high space use or over-consumption in housing can be found in the literature. For instance, Destatis (2018) identifies the highest living space per person in single-person households and Costa-Font et al. (2022) observe the phenomenon of under-occupation, which is most common among older age groups. However, there is a significant gap in literature when it comes to understanding the attitudes and perceptions of these individuals, as well as their willingness to change their behaviour. In order to address this gap and to identify the potential for reducing residential space use, this paper aims to answer the research question, 'How could consumer behaviour be changed to reduce space use in the residential sector'. The objective of the research question is to investigate

1. the current housing consumption behaviours related to space use,
2. key target groups for modifying behaviour and
3. possible strategies for improving the efficiency of how we use space in housing.

After introducing background concepts on consumption and modifying human behaviour in Chapter 4.2, Chapter 4.3 presents the methods and data sources used to find answers to different parts of the research goal, also illustrated in the research design in Figure 4.1. The structure of the results in Chapter 4.4 follows the research objectives. These are discussed and presented in Chapter 4.5 and used as input for policy recommendations. The paper concludes with Chapter 4.6, by summarising the findings and the key takeaways.

4.2. Modifying consumer behaviour

Consumption is particularly important in today's affluent societies, where it is seen as essential to prosperity (Priest et al. 2013). While everyone is a consumer, there are differences between consumers, resulting from differences in individual behaviour, which, in turn, is influenced by factors such as income, culture, and lifestyle. Behaviour is also strongly affected by social influence. Social influence theory discusses how the behaviour of others affects how we behave and how this effect is often unconscious (Goldsmith et al. 2011). People have a desire to conform and 'fit in' with socially accepted norms and have a fear of disapproval. Social influence has also been shown to impact sustainable behaviour significantly. Examples include positive reinforcement from neighbours for kerbside recycling or shame for particularly environmentally damaging actions such as flying (Goldsmith et al. 2011). This social influence can also have a major impact on individual behaviour in the context of housing. For example, having a larger house or a garden is often seen as a sign of wealth and status and provides a sense of achievement. The decision to buy a house that meets these "criteria" may therefore be driven not only by individual desires but also by external social pressures. These social influences can be strong enough to create social norms, characterised as social behaviours and widely accepted or considered appropriate by a group and thus influence how the group behaves. When behaviour does not conform to what is considered acceptable by the group, it can lead to exclusion (McDonald et al. 2015). Understanding the motivations behind the behaviour is well researched in fields such as psychology and is particularly useful for those working in business and marketing. In the context of this research, an understanding of consumer behaviour is necessary to identify appropriate policies that could trigger changes in behaviour, primarily to reduce space consumption in housing.

Modifying human behaviour can be a challenging task. Various external factors often influence behaviour, and individuals are naturally inclined to resist change. This resistance stems from the fact that deviating from established routines often requires more energy than continuing with familiar patterns (Ford et al. 2008). While people are generally resistant to change, there is variability in this resistance, with some people being more resistant to change and others being more tolerant or accepting (Oreg et al. 2008). This variability is often a function of individual dispositions, personalities and experiences. Moreover, dissatisfaction with the status quo can also lead to changes. However, the field or system in which the change occurs also influences the resistance level (Lewin 1947). High restraining forces within the system, such as financial or infrastructural barriers, are likely to create more resistance. The combination of resistance to change, on the one hand, and the many factors influencing the behaviour, on the other hand, makes attempts to change behaviour challenging. This is also true of modifying consumer behaviour to achieve environmental benefits. However, many factors, such as income and education, influence an individual's attitude towards sustainability (Ishangulyyev et al. 2019). Additionally, while there is often an intention to act more sustainably, this intention often needs to be translated into action. This phenomenon is defined as the intention behaviour gap (Stefan et al. 2013). This gap is usually due to a lack of tangibility of the benefits (i.e. whether they are economic or symbolic), an overestimation of environmental ideology (how important people perceive the environment to be), or an oversimplification of the factors that contribute to the adoption of the sustainable behaviour (i.e. financial constraints are more important than initially thought) (Carrigan et al. 2001 and Devinney et al. 2010). Thus, to bridge this gap, strategies for behavioural change should focus on addressing these key areas,

whether through educational campaigns, initiatives or policies that target the critical barriers to change.

Strategies to modify consumer behaviour can vary, from policies implemented by governments to nudging techniques enacted by companies or campaigns arranged by grassroots organisations (Wilkinson 2013). The Energy Sufficiency Policy Database (Best et al. 2022) provides a comprehensive overview of the initiatives and policies addressing the living space in residential buildings. The measures listed range from fiscal to regulatory and informational strategies and are targeted at individuals, households, administrations, and organisations. The measures aimed at the efficient use of space include those related to moving, sharing and modification and vertical densification of the dwellings. These are the strategies that the paper focuses on when examining the potential for changing the behaviour of space users. Moving measures include bonuses for moving to smaller dwellings and the promotion of living in alternative forms of housing (e.g. shared flats, ecovillages). Modifications include fiscal benefits for subletting an unused room or subsidies for structural partitioning of the dwelling (so that another household/individual could live in a separate part of the dwelling). Vertical densification is related to alterations of the dwelling, but focuses on extensions such as attic conversions. Extensions mainly focus on improving the efficiency of space use (vertical rather than horizontal), i.e. instead of buying a completely new dwelling, the existing one can be modified. Instruments such as subsidies, reduced approval requirements or support for organisational matters can promote such extensions. This type of policy is generally targeted at those with excess space in their dwellings and could promote and enable more efficient use of space and reduce overall space consumption in housing. Sharing is a concept or initiative that is receiving increasing attention to improve the efficiency and sustainability of using and consuming goods and materials (Hossain 2020). The sharing economy or sharing society involves reducing private ownership and increasing communal access or sharing of goods and services (Cheng 2016).

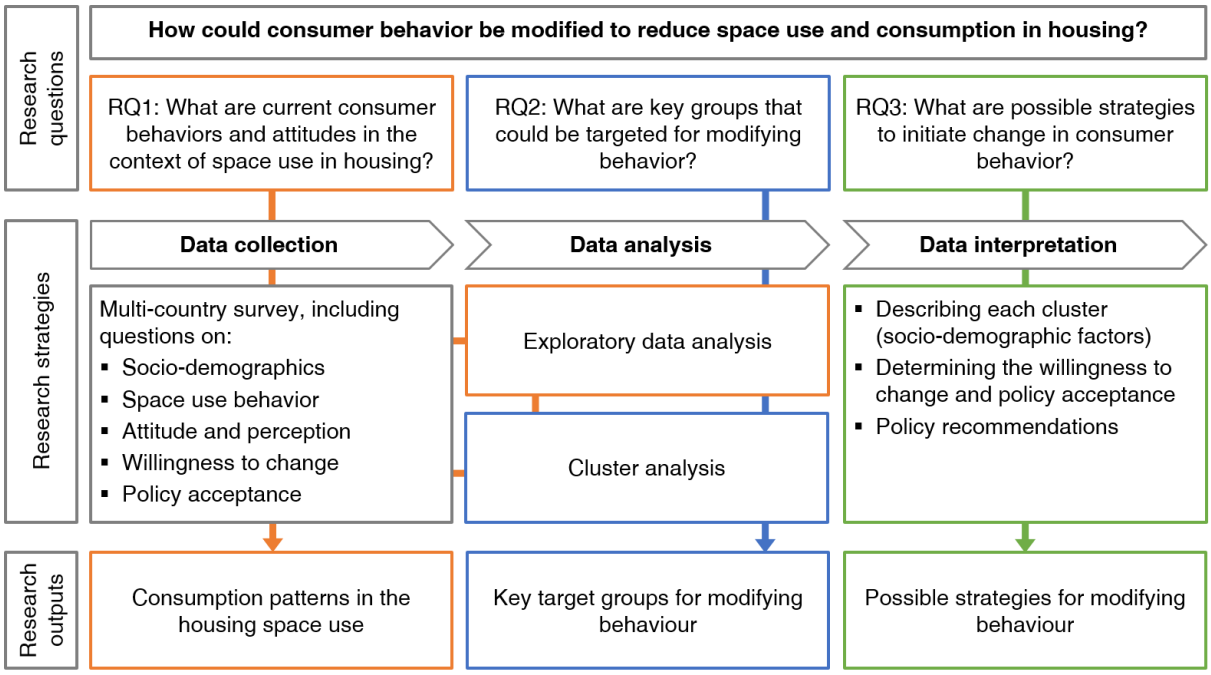

Figure 4.1: Research design- the different colours show the method and output for each research questions

4.3. Methodology and data

This paper applies a quantitative method following a three-step approach, including data collection, analysis, and interpretation. After presenting the scope of the study, each of these steps is further explained in this chapter. The research design of the paper is presented in Figure 4.1. The colour code in this figure shows the methods and the output for each research question.

4.3.1. Scope of the study

The countries studied in this paper were carefully selected following a criteria-based selection process. Firstly, a set of indicators that either define or influence a country's per capita residential space use were selected (presented in Table 4.1), and their values, extracted from Eurostat datasets, were compared across the EU-27. Countries were then ranked from best to worst for each indicator. The ranking was decided based on two criteria: the value of the indicator and the positive or negative impact on the average floor area per person. For example, if a country had a higher average household size (i.e. number of people per household), it had a higher position in the ranking compared to a country with a lower household size. Conversely, a country with a higher proportion of single-family houses in its building stock had a lower ranking, as single-family houses have a higher average floor area than multi-family houses. After ranking the countries for all indicators, the countries with the highest number of occurrences in the top five best or worst countries were listed as potential study countries. The list was narrowed down, taking into account data availability and the aim of having representatives for each of the four regions of Europe: North, East, South and West. The four countries selected are Sweden, Poland, Portugal and Germany.

Table 4.1: Categories and indicators considered in the selection process of the studied countries

Category	Indicator
Building stock	Share of single-family houses
Population	Share of groups with high saving potential (Childless couples and singles)
Housing size	Household size
	Average floor area per person
	Change in the average floor area per person (2019 vs. 2000)
	Rooms per person

4.3.2. Data collection

Data for this paper was collected through an online survey conducted in four EU countries: Germany (DE), Sweden (SE), Poland (PL) and Portugal (PT). Respondents were carefully selected by a Market Research institute that conducted the fieldwork between 4 and 31 August 2023. Specific quotas were defined using official statistics to ensure a representative sample in terms of building type, ownership structure, income, age, gender, location, and household structure. The survey questions were available in English and in the local language of each country surveyed. To avoid misinterpretation of the survey questions, the translated versions of the survey were reviewed by native speakers, and the survey was pretested and piloted prior to starting the fieldwork. The collected sample included 6012 observations, which were reduced to 5766 (DE: 1440, SE: 1442, PL: 1444, PT: 1440) after data cleaning explained in Chapter 4.3.3.1.

4.3.2.1. Survey questions

Five comprehensive categories of questions were included in the survey: socio-demographics, current space use behaviour, attitude and perception, willingness to change, and policies. Table 4.2 provides the reasoning behind each category and the examples of included questions. Depending on the information needed in each category, a wide range of question types were used in the survey, including yes/no questions, multiple choice, Likert scale and open-ended questions. The English version of survey questions can be found in supplementary material in Chapter 4.8, including also the questions that are not considered in this paper.

Table 4.2: Categories, examples of questions and justification for their use in the survey

Category	Examples of questions	Justification
Socio-demographics	Questions regarding: • Age • Household composition • Household income	Understanding differences in socio-demographics can be a helpful tool in providing suggestions for action points or policies to modify behaviour.
Space use behaviour	Questions regarding: • Size of residence (m^2) • Number of rooms • Available spaces	To get an overview of the available spaces and the ways they are used.
Attitudes and perception of space	Questions regarding: • Perception towards size of residence (too large, small, or just right) • Lack of space for specific activities • Flexibility in using the space	Understanding individuals' perception of their residence can also help guide action points and provide an indication of those that may be more willing to modify behaviour. For example, an individual with high m^2/capita who believes their dwelling is "just right" is less likely to want to make a change than someone who perceive the residence as "too large". Merging objective information (i.e. how much space an individual has) with subjective information (i.e. their perception of their residence) helps generate a better understanding of the potential for modifying behaviour and action points.
Willingness to change	• Would you rent out a room in your residence? • Would you share communal spaces?	The purpose of this section of questions was to investigate how respondents would respond to certain suggestions for using space more efficiently. These questions were given to those that indicated their dwelling was too small or too large. It was assumed that those that indicated their dwelling was "just right" would lack motivation to seek alternatives to meet their needs. Three categories of questions were asked within this section, "Sharing" (including also renting [a]), "Rearranging" and "Moving", as these were identified as the main possible areas for change. Depending on whether a respondent responded with "too large" or "too small", specific questions were asked within each category.
Policy acceptance	• Do you support Policy X? • Can you make use of Policy X? • What factors may limit you in acting on the policy?	This category of questions was aimed at investigating how respondents answered certain policy suggestions. Four main areas of policies were included in the survey, "Renting", "Extending", "Moving" and "Structural Changes". These areas were chosen based on current policy suggestions from the Energy Sufficiency Policy Database (Best et al. 2022). Policy instruments for these measures include fiscal relief and subsidies for subleasing and structural partitioning, tax advantages, reduced legal

requirements (i.e. for an additional storey), promoting alternative housing. It should be noted that most of these measures are not targeted at those that live in residences that are on the smaller side, but rather for those that live in larger residences.

Using this information as a base, below is an example of the policies that were presented to the respondents of the survey (see supplementary material in Chapter 4.8 for a full overview of the policies):

(Renting an existing room)

*Policy 1: If someone **rents out an existing room/space** in their own home on a long-term basis and not for tourist purposes, the person receives **financial benefits** such as tax reductions on the rental income.*

[a] **The term "rent" in this paper refers to both renting (i.e. paying for the use of someone else's property) and renting out (i.e. allowing someone else to your own property in exchange for payment)**

4.3.2.2. Description of the collected sample

The youngest respondents (18-24 years) and the oldest (over 65 years) account for the smallest (7%) and largest (22%) shares, respectively. The remainder is almost evenly distributed between 25 and 65 years. Males and females are also equally represented in the sample. Two-person households have the highest share (39%) and around 61% of the households consist of couples with (30%) or without (31%) children. More than half (53%) of the respondents reside in multi-family houses and 65% of dwellings are owner-occupied. All income groups (Quintiles 1-5) are almost equally represented in the sample. The characteristics of the respondents at the country level broadly follow the distribution observed in the whole sample, with some deviations. Table 4.5 in Chapter 4.7.1 shows a detailed overview at both aggregated and country level.

4.3.3. Data analysis

4.3.3.1. Data cleaning and processing

Following the completion of the survey and before starting the analysis, a data validation process was conducted to increase the validity and reliability of the data used in the analysis. This process was completed for five components: survey completion time and responses to four open-ended questions. The validity of the responses for these components was determined through literature and expert judgement. The data validation process is an alternative for considering outliers in the analysis. Since "valid" ranges were set for the data to be analysed, identifying outliers was considered redundant because all data within the ranges were considered valid and to be included in the analysis. For details concerning the validation process see supplementary material in Chapter 4.8. The data processed and cleaned in this step was used for further analysis.

4.3.3.2. Exploratory data analysis

After data validation, an exploratory data analysis (EDA) was applied to the dataset to gain a first understanding of the dataset characteristics and also discover the patterns and visualise the main trends (Gudivada 2017; Unwin 2010). Besides describing the characteristics of the

survey sample (presented in Chapter 4.3.2.2), the method was used to answer the RQ1, identifying the consumer behaviour in the housing space use (Chapter 4.4.1). The questions in the categories socio-demographics, space use, and perception are used in this step.

4.3.3.3. Cluster analysis

One of the main aims of this research was to identify groups of individuals that could be targeted for modifying behaviour to increase the efficiency of space use (RQ2). This was done using cluster analysis. Clustering is a technique used to group data points with similar properties such that the data points in one group have more similarities within the cluster than they do with data points in another clustered group. It is especially useful when handling large data sets (Gere 2023) as it can be used as a reduction procedure. It can also identify patterns, develop taxonomies or create typological frameworks (Frades et al. 2010). Algorithms used to create the subsets of data (clusters), are based on calculated similarities or dissimilarities. Various clustering algorithms exist, categorised into four types: partitioning (centroid), hierarchical, density or grid (Yadav et al. 2013; Frades et al. 2010; Rasyid et al. 2018 and Turčínek et al. 2012). In this paper the k-means clustering algorithm from the scikit-learn library in Python was used as the clustering method to group the data. K-means is widely recognised (Węgrzyn et al. 2024) and falls under partitioning methods, which involve dividing the main dataset into smaller datasets (clusters). The k-means algorithm assigns a predetermined number of k clusters at the start of the clustering operation, and this value remains constant throughout the process. Various techniques can be used to determine the optimal number of clusters, one of which is the commonly used Elbow method (Cui 2020), employed also in this paper (Figure 4.15 in Chapter 4.7.2). The partitioning process begins by inputting the chosen number of clusters. Initially, arbitrary mean (centroid) values are assigned to all clusters, and each data point is assigned to the closest centroid. The closeness or similarity is measured using a distance metric, such as Euclidean distance, commonly used for numeric data.

As mentioned in Chapter 4.1, in evaluating whether or not the housing satisfies its residents' needs and expectation, not only housing adequacy but also residents' satisfaction plays a role. Given that dissatisfaction with the status quo increases the likelihood of change, and assuming that the perception of the residents could reflect their degree of satisfaction, this paper considers both objective (actual space use) and subjective aspects (perception of space) as key factors in individuals' willingness to change. Therefore, the cluster analysis took into account variables from both categories (see Table 4.7 in Chapter 4.7.2).

As we collected data from four different countries, it was important to assess whether there were significant differences in the dependent variables due to country effects. One-way ANOVA test revealed significant differences across country means for several variables, suggesting that country membership could influence the responses. To further explore the between-country variance and account for nested structure of the data we used a multilevel model (MLM) approach. The null model allows to derive the intra-class correlation coefficient (ICC). The ICC estimates the variation attributable to the grouping structure, in this case, countries, relative to the variation at the individual level (Nezlek 2012). Our analysis revealed a low ICC for each dependant variable from 0.00-0.07, suggesting that the variation within countries is not significantly greater than the variation between countries (see Table 4.8 in Chapter 4.7.3). The nesting of data within countries is less significant than initially thought, meaning that country effects do not play a significant role in explaining the variance of the dependent variables. We

then introduced a fixed effects model that included the country parameter to assess its contribution to the variance in the dependent variables. Comparing the log-likelihoods between the null model and the fixed effects model, we observed no substantial improvement in fit with the inclusion of country. The p-values of the fixed effects model further suggested that country did not significantly predict the dependent variables. Those findings imply that although the ANOVA revealed statistical differences in the group means, these differences are not substantial enough to create significant variability between countries. To visually countercheck the MLM results, the clustering was conducted at the country level and the results were compared with the portions of the first clustering for each country. The results also showed no significant heterogeneity between the countries. This allowed us to neglect country-level effects and focus our cluster analysis on the individual level of the aggregated country data. Finally, to check the robustness of the clustering results, a hierarchical clustering was carried out on the full dataset, which showed a similar pattern in partitioning as the k-means. The results of these further analyses are presented as supplementary material in Chapter 4.8.

4.3.4. Data interpretation

This step combines the results from EDA and cluster analysis and aims at answering RQ3 (identifying possible strategies to trigger changes). As a result of clustering, the target groups are identified. Through a profile analysis and using the standardised means, the dominant variables that define each cluster are identified and used to label the clusters. Then, to better understand the characteristics and behaviour of the clusters formed, they are described according to their socio-demographic characteristics. For each factor (e.g. age, household composition, location), the category with the highest share is taken as the dominant characteristic. If two categories have more or less the same maximum range, both are used to describe the cluster. The willingness to change and perception towards policies is also analysed for the selected clusters. This step uses responses to the survey question categories socio-demographics, willingness to change and policies are used in this step. Based on the available information, strategies are recommended to trigger changes in the selected target groups.

4.4. Results

This section presents the findings of the study. It begins with providing key statistics related to space use and perception within the study sample and addressing RQ1 (Chapter 4.4.1). Subsequently, the clustering results and the distinctive characteristics of each cluster are presented, addressing RQ2 (Chapter 4.4.2.1). Furthermore, the section explores the willingness to change and policy acceptance among respondents, addressing RQ3 (Chapter 4.4.2.2).

4.4.1. Space use consumption patterns

4.4.1.1. Facts and figures

Two sets of questions were asked in the survey to determine the space use patterns in the studied households. The first set concerns the actual figures on the dwelling itself, namely the available living space in m^2 and the available rooms. To make the figures comparable between the countries and households, the per capita values are considered in the rest of the analysis. There is a similar pattern in the surveyed countries for both indicators, with Poland having the lowest mean values and the interquartile ranging between 20 and 42 m^2 for the area and from 1.3 to 1.7 rooms per person. The other countries have almost identical Q3 at around 60 m^2 and

two rooms per person, meaning that 25% of the respondents in these countries live in a dwelling with more than 60 m^2 per capita. However, the Q1 varies slightly between countries (area/capita: DE: 34, PT: 26, SE: 30). The figures show the threshold below which 25% of the surveyed households fall regarding the per capita floor area (Figure 4.2). At the aggregated level, the collected sample reports on average 52 m^2 of floor area and 1.7 rooms per person. The highest area per capita values are reported in the dwellings occupied by single adult without children (72 m^2), or in single-family houses (63 m^2) and located in the countryside (58 m^2). More details including average values per capita, can be found in Table 4.6 in Chapter 4.7.1.

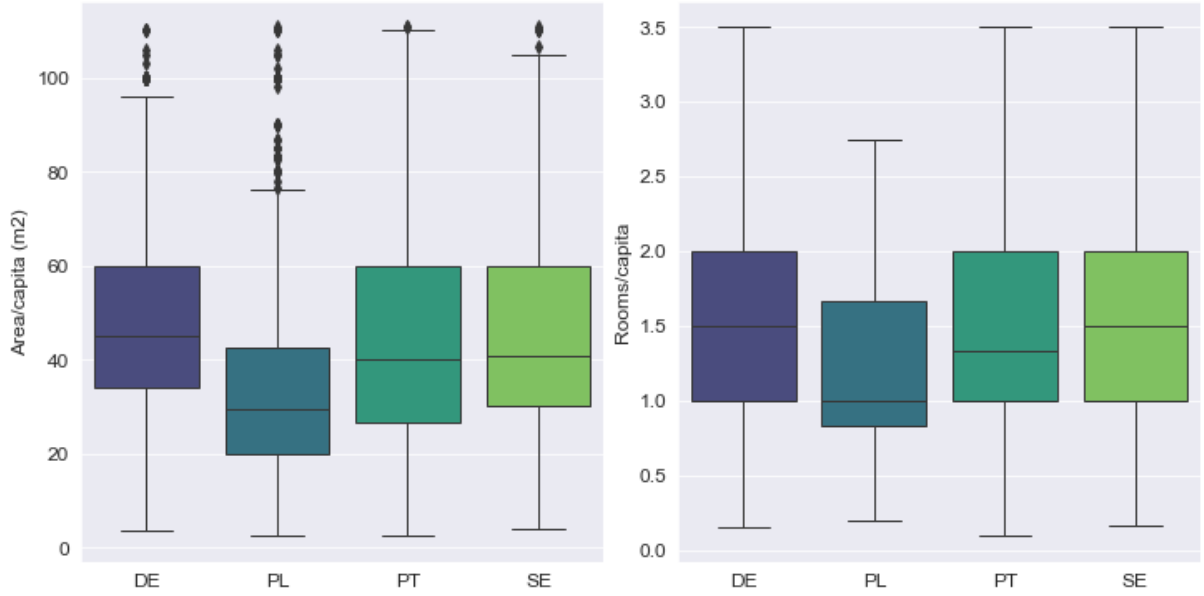

Figure 4.2: Five-number summary – Left: range of area/capita, Right: rooms/capita - after removing the outliers

The second set of questions aims to understand how the respondents use the available space in their residences. Figure 4.3 presents the detailed results of the questions asked in this category, at aggregate and country level. In the whole sample, the households are almost evenly divided into three groups regarding their facilities for guest accommodation: dedicated guest room, sleeping facilities (e.g. sofa bed, inflatable mattress) in one of the rooms usually used for other purposes (e.g. living room), and no facilities. Around 85-90% of the households never or rarely have guests sleeping over or organise gatherings at their dwelling. Of the households with a designated guest room in their dwelling, only 14% have guests sleeping over more often than few times a year. Slightly below one-third of the households (strongly) agree that some rooms in their dwellings are rarely used, and almost three-quarters of the respondents (strongly) believe that they can find suitable spaces in their residences for their desired activities. To have a better picture of the occupied living space of the respondents, the existence of a second residence was also investigated, which was affirmed by 17% of the households, from which 37% had also indicated to have rarely used rooms in their current dwelling.

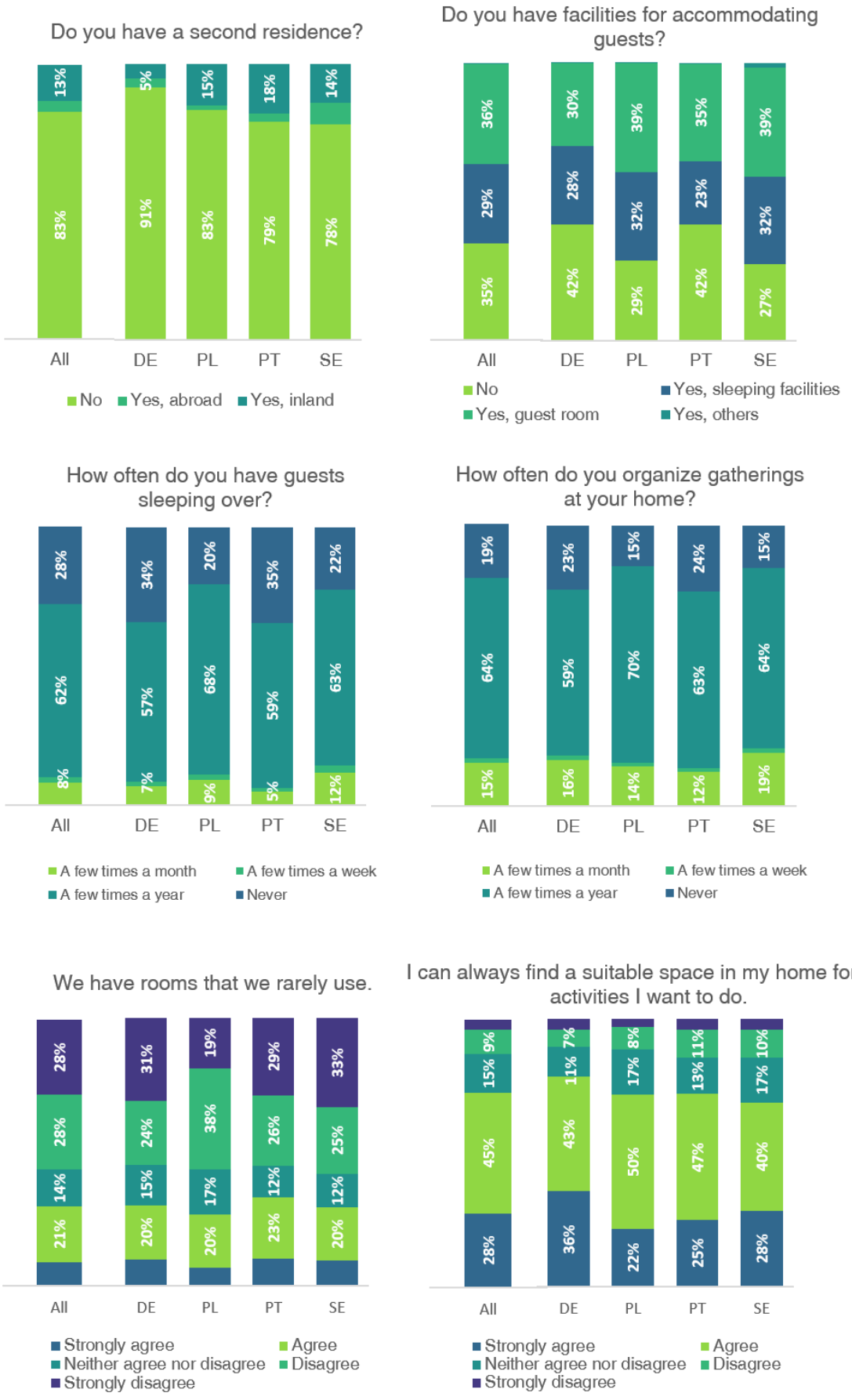

Figure 4.3: Use of the living space in the studied countries

4.4.1.2. Perception of the space

In order to investigate the respondents' perception of their dwellings they were asked first about their level of satisfaction with the residence as a whole and then about their perception of individual characteristics, namely size, layout, and number of rooms. Generally, the majority (78%) of the survey respondents are (very) happy with their dwelling (Figure 4.4**a**). However, their perception towards the layout and size of the dwelling and the number of rooms varies marginally (Figure 4.4**b**). While 77% of the respondents find the size of their dwelling just right, only 69% think they have the appropriate number of rooms. Additionally, the layout of 75% of the dwellings meets the needs of their residents. The differences can be seen in cases where, for instance, a large dwelling has only large separate rooms; in this case, the household may wish to have more rooms, even though they find the dwelling size just right or even too big.

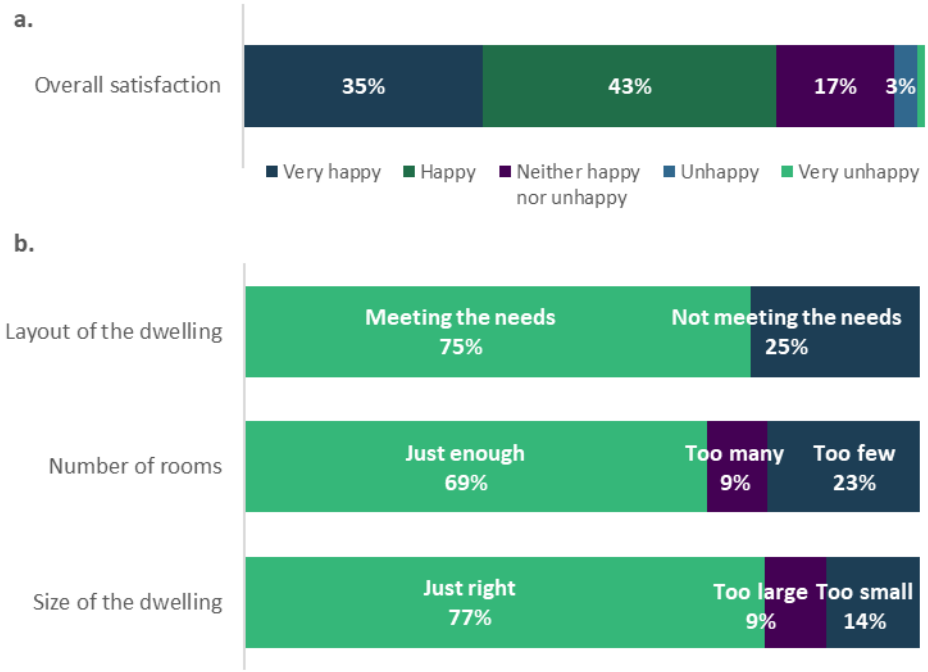

Figure 4.4: a) Overall satisfaction with dwelling, b) Perception of design, number of rooms and size of dwelling

To further focus on the analysis of the floor area of the dwellings, the respondents were asked about the desired size of the dwellings if they had indicated that their dwelling was either too small or too large. The link between the actual, perceived and desired size of dwellings shows that the respondents who consider their dwelling to be too small have a per capita floor area of 36 m^2 and wish for 100 m^2 per person. On the other hand, those who perceive their dwelling as too large have an average floor area of 85 m^2/capita and wish to have 56 m^2 instead. Respondents in dwellings perceived too small were asked about the activities for which they would need more space. In first place comes Receiving/accommodating guests, selected by more than half of the respondents, followed by Storage and Free time activities. The overview of all other activities is presented in Figure 4.14 in Chapter 4.7.1.

4.4.2. Consuming groups and their characteristics

The comprehensive descriptive analysis of the actual and perceived space use within the study sample was followed by a k-means cluster analysis. This analysis was instrumental in systematically identifying the groups with the potential to change their consumption patterns.

The cluster analysis revealed four distinct groups, each with its own characteristics. Each cluster is labelled based on their dominant variables (i.e. the variables which have the strongest impact on clustering results and the membership of an observation in a specific cluster): Cluster 1 as Room-optimiser, Cluster 2 as Perception-driven, Cluster 3 as Space-oriented, and Cluster 4 as Satisfaction-seeker (for more details see Figure 4.16 in Chapter 4.7.2).

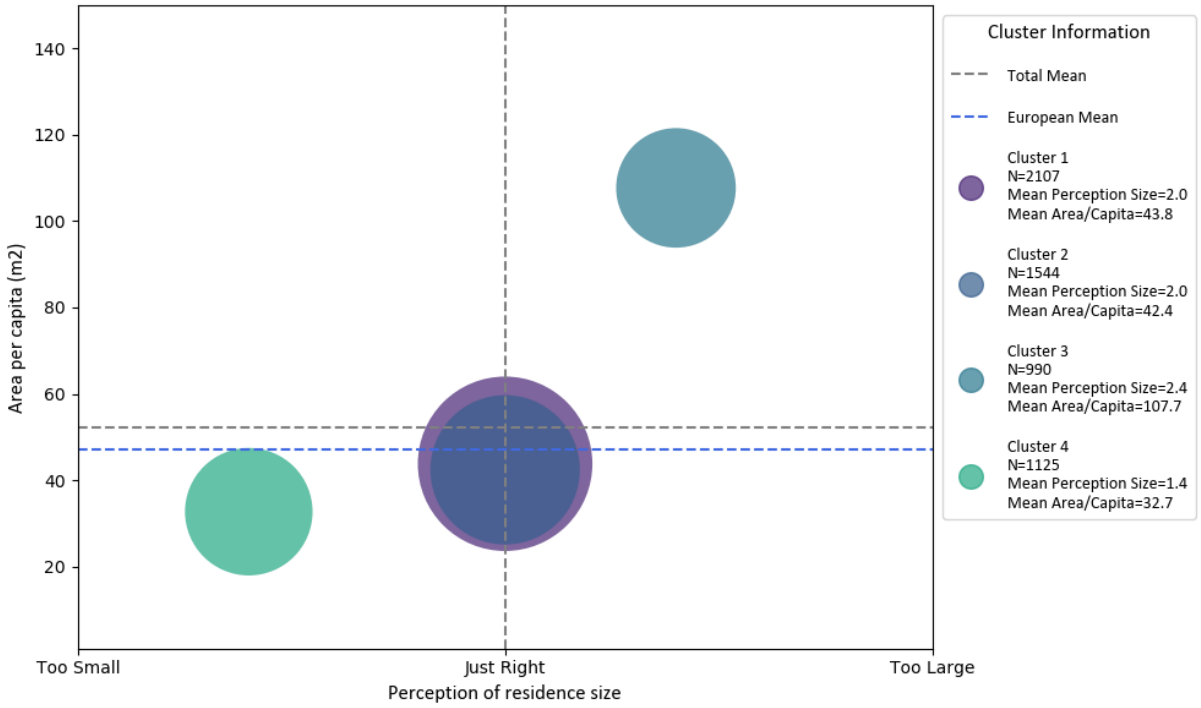

Figure 4.5: Average actual and perceived floor area in the clusters

As depicted in Figure 4.5, Cluster 1 (Room-optimiser) and Cluster 2 (Perception-driven) are quite similar in terms of their average floor area of around 43 m^2 and their neutral perception of the residence size. They comprise about 63% of respondents of the survey. Given our assumption that perception drives behavioural change, these clusters may not present a high potential for change. Respondents in these clusters live in dwellings of a size higher than the European average and appear satisfied with their living space, thus presumably seeing no need to change their circumstances. Conversely, Cluster 3 (Space-oriented) and Cluster 4 (Satisfaction-seeker) stand out in this figure. The Space-oriented cluster, with a relatively high average floor area of 108 m^2, are individuals who perceive their dwelling as too large. Satisfaction-seekers, with a much lower average floor area of 33 m^2, consists of individuals who feel their dwellings are too small. These two clusters, with their unique characteristics, present a higher potential for change as their average floor area significantly deviates from the sample average, and the respondents are not satisfied with the size of their dwelling. As a result, the remainder of the analysis focuses on these two clusters, and examines their socio-demographic characteristics, willingness to change, and level of policy support.

4.4.2.1. Socio-demographic characteristics

Respondents in the Space-oriented cluster are mostly over 45 years old and come from one and two-person households. They are mainly singles or couples without children, living in their own single-family houses in the suburbs or in the countryside. In terms of financial situation, there is a slight tilt towards the high incomes in this cluster. This cluster is dominated by employed

respondents with an academic degree. In contrast, Satisfaction-seekers consists mainly of respondents aged 25-45, who are couples with children living in the cities. They live in their own dwelling in multi-family houses and are evenly distributed among all income groups. Most respondents within this cluster are employed and either have an academic degree or completed secondary education. A detailed overview of the socio-demographic characteristics of these clusters is presented in Figure 4.6.

Figure 4.6: Socio-demographic characteristics of the selected clusters

4.4.2.2. Willingness to change

Survey respondents were asked about their perception of the size of their residence, with the possibility of choosing between “too small”, “just fine” and “too large”. Further questions were presented to the respondents sequentially, with each question depending on the answer provided to the previous question. The number and type of follow-up questions and options varied according to the strategy under consideration. In order to understand the level of willingness to follow one of the strategies for optimising the space use, introduced in Table 4.2, the approach presented in Figure 4.7 was followed.

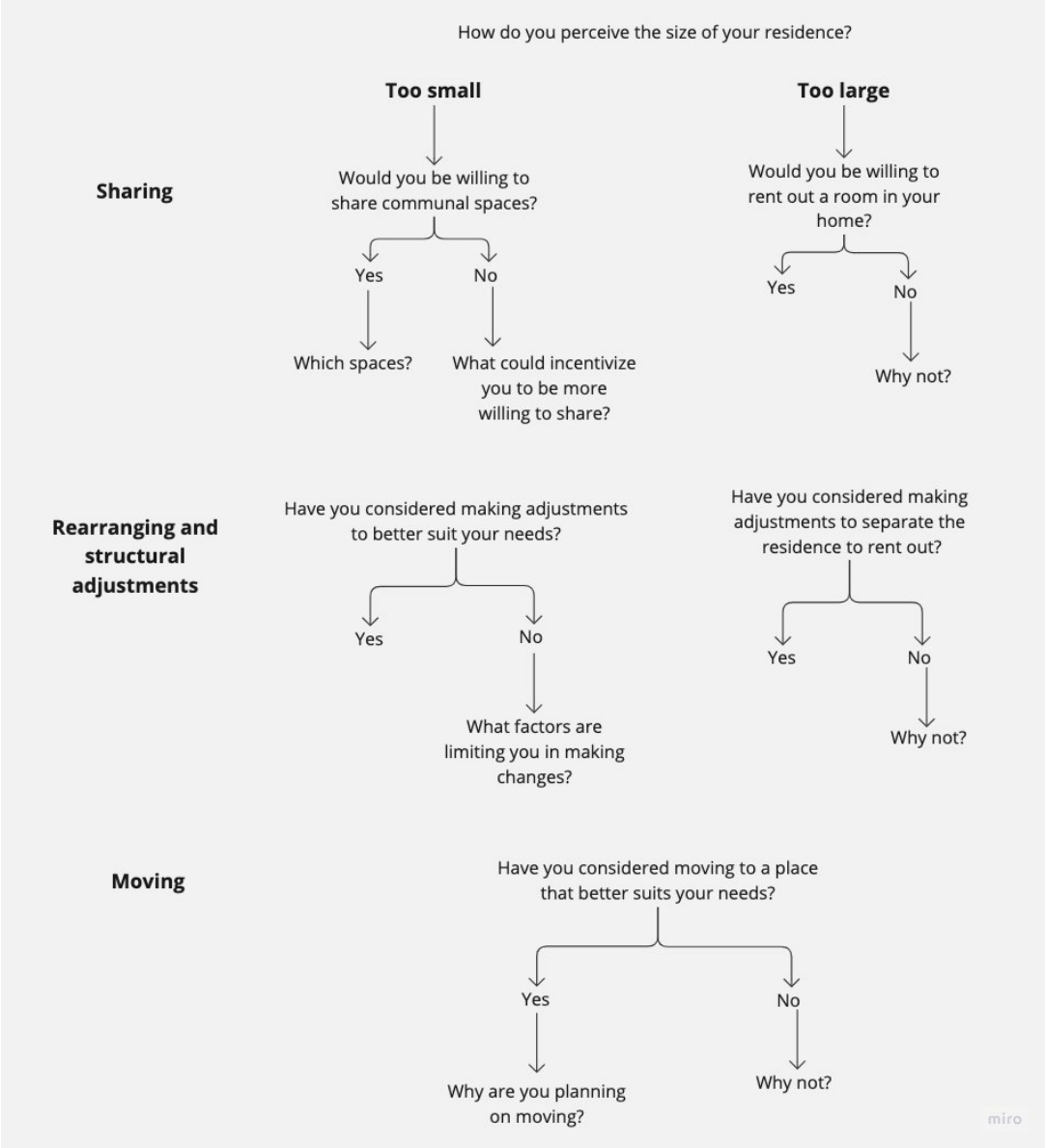

Figure 4.7: Approach for studying the willingness to change

Figure 4.8 to Figure 4.11 illustrate the stepwise results for the strategies studied in this paper. For instance, if a respondent from the Space-oriented cluster perceives the residence size as too large, the subsequent question will inquire whether they are willing to share certain common spaces. If they indicate a willingness to share, they will be asked which spaces they would consider sharing. Conversely, if they express a reluctance to share, the follow-up question will inquire about the factors that would motivate them to consider doing so. Respondents who find the size of their residences just fine would not receive any follow-up question on willingness to change and are also excluded from further analysis in this section. Only a negligible number of respondents in the Space-oriented cluster find their residences too small; similarly, among the Satisfaction-seekers, very few perceive them as too large. These are also excluded from the analysis. 39% of the respondents in the Space-oriented cluster (hereafter called *Potential downsizers*) consider their residences as too large, and 58% of the Satisfaction-seekers find their residences too small (hereafter called *Room-seekers*). The remainder of this section presents the willingness to move, share space, rent, and rearrange the space among the Potential downsizers and Room-seekers portions.

Sharing

One-third of the Potential downsizers and 43% of Room-seekers are willing to share some space with others. Potential downsizers are keen to share the service areas such as the garden, garage and basement. Room-seekers would be willing to use common spaces primarily for hobbies, socialising activities, home office and laundry. The majority of those unwilling to share spaces say nothing can change their mind in this regard. Financial benefits followed by trust in the other users could motivate one-third of Potential downsizers towards space sharing. For Room-seekers, the main incentive is found in the cleanliness and comfort of the shared space, and the attractive prices come only at the third place.

Moving

Around two-thirds of Room-seekers and 44% of Potential downsizers have already considered moving out of their current residence. However, 75-80% of them have not yet found a suitable dwelling despite searching for one. The rest has found a new place and either will move soon (12-13%) or has decided not to move (8-13%). The ones who have never considered moving have indicated various reasons. For Potential downsizers, this is predominantly (66%) due to the attachment to the current residence or neighbourhood. The dominating reason of Room-seekers is financial barriers, namely not being able to afford a different residence (48%) and high moving costs (15%).

Rearranging

Half of Potential downsizers and 30% of Room-seekers have considered rearranging their dwelling to match their spatial needs. Among those, 22-23% will soon realise their plans for a rearrangement. In the rest of the cases, either no decision was made yet (43-50%) or the plans were not realised even after the decisions were made (35-48%). Around 70% of Potential downsizers and more than half of Room-seekers have never considered rearrangement in their dwelling. The most often mentioned reason for Potential downsizers is that the idea has never occurred to the households. For Room-seekers, the rental contracts are to blame as most of the respondents cannot make such decisions as tenants. More than half of the respondents in this group do not consider such changes feasible, and one-third cannot afford such changes.

Renting (out)

One-quarter of Potential downsizers could consider renting out an unused room or part of their residence. In contrast, a rough two-thirds of them do not want strangers to live in their homes. For 12% of Room-seekers, renting an additional room in the same building or the vicinity of their dwelling could be an option to compensate for the lack of space that they are perceiving. However, around half of Room-seekers think having a room outside of the dwelling will not be convenient. The rest either cannot afford an additional room (25%) or think finding such a room to rent would not be feasible (12%).

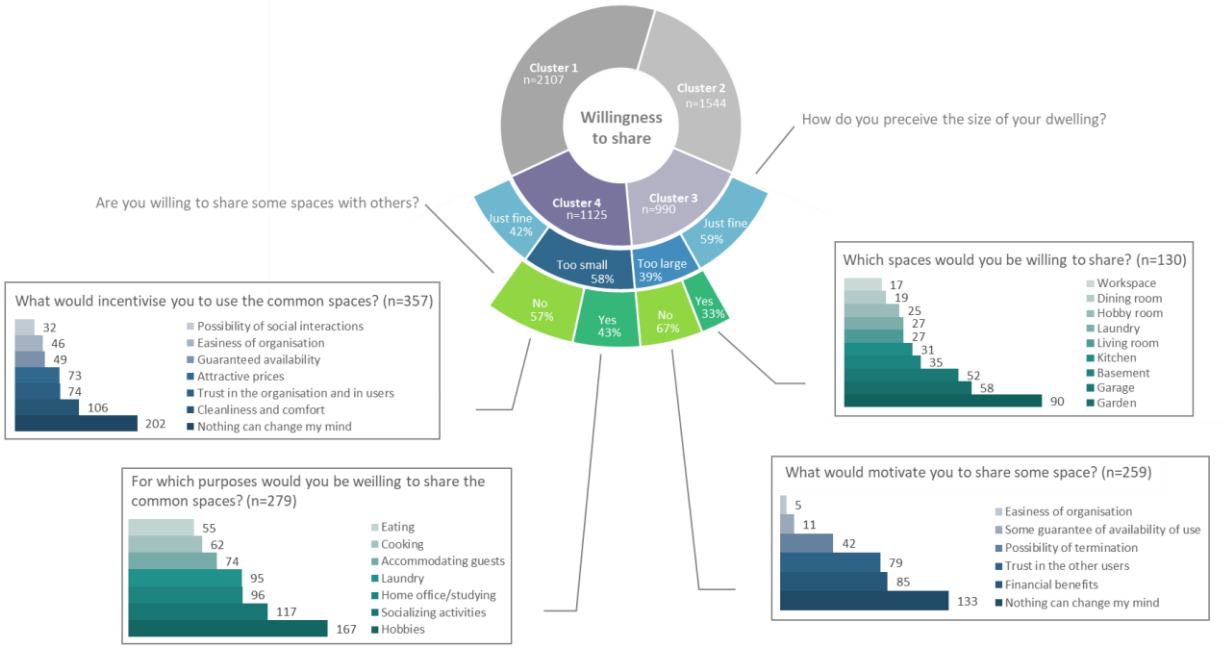

Figure 4.8: Willingness to share in the selected clusters

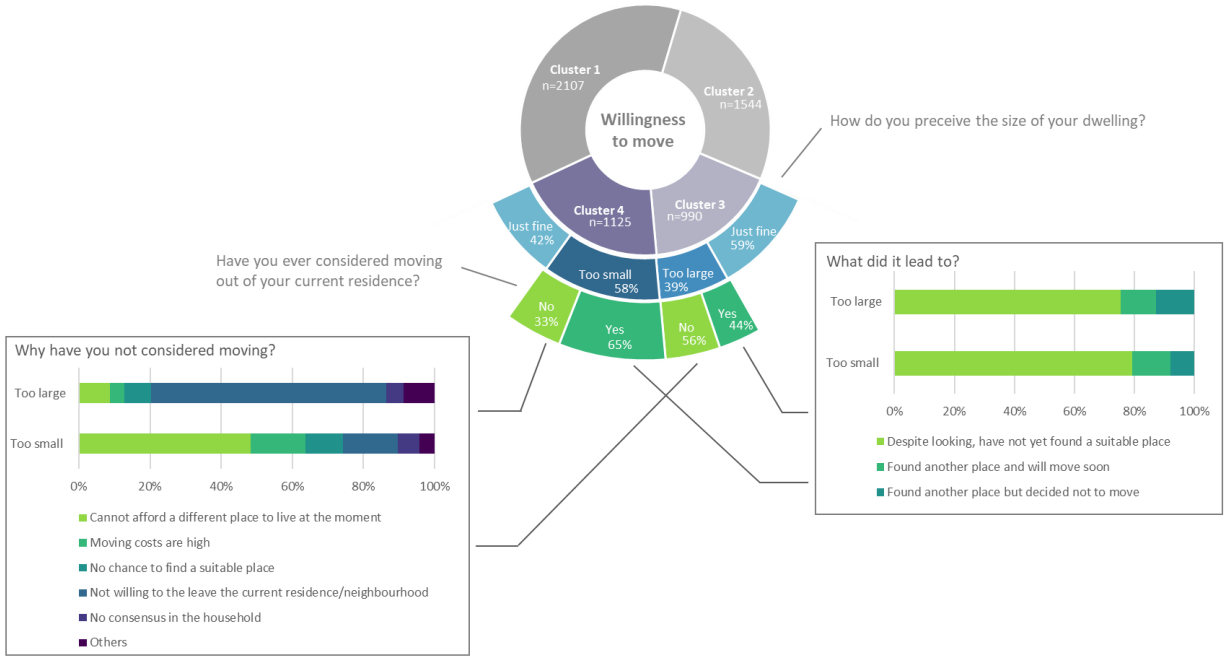

Figure 4.9: Willingness to move in the selected clusters

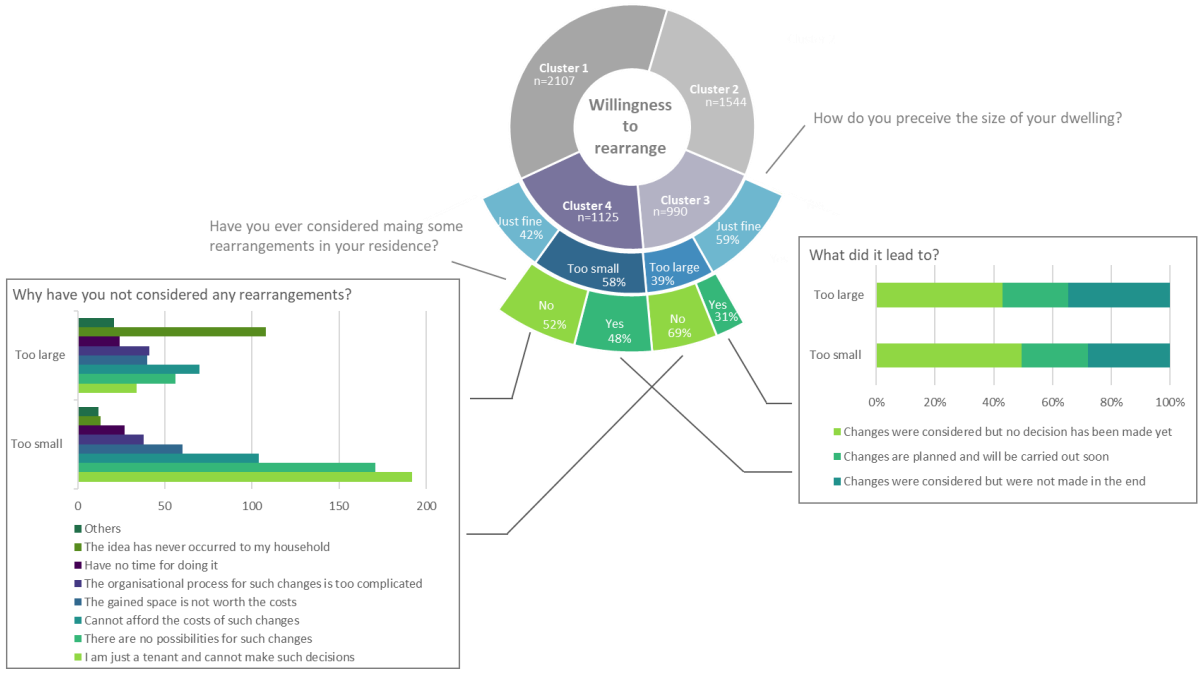

Figure 4.10: Willingness to rearrange in the selected clusters

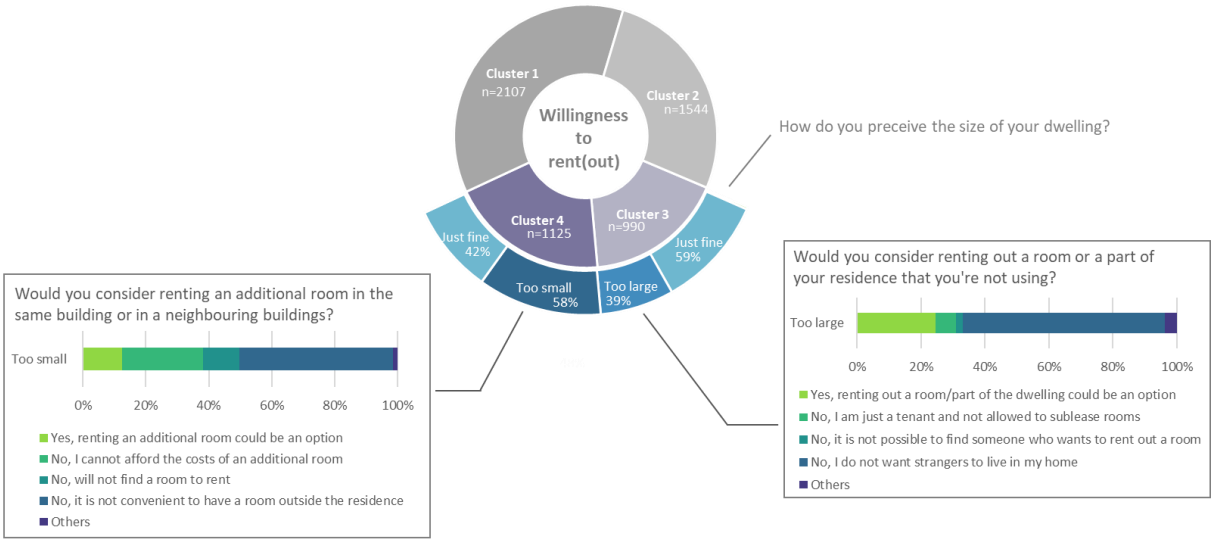

Figure 4.11: Willingness to rent(out) in the selected clusters

4.4.2.3. Policy acceptance

Following the different strategies for changes indicated in Table 4.2, the respondents were asked three types of questions for each group of policies: first, to which extent they support the policy, second, whether they are affected by the policy, and third, what they consider barriers to the policy. Contrary to section 4.4.2.2, the analysis of this section considers all respondents in the Space-oriented and Satisfaction-seeker clusters.

Around 20% of the respondents in the Space-oriented and Satisfaction-seeker clusters oppose the suggested policies. The rest either support or have a neutral opinion about the policies. The highest support rates in both clusters are for the policies related to renting (42-45%) and moving (40-42%), and the highest opposition rates are for extensions (43-49%) and structural changes (41-46%) (Figure 4.12). These figures are much different when considering only the

respondents who could use the proposed policy (see Figure 4.13). They support all the suggested policies to a high extent (57-70%). Also here, the highest support rates are for renting and moving. Only between 4 and 11% of the respondents oppose the policies.

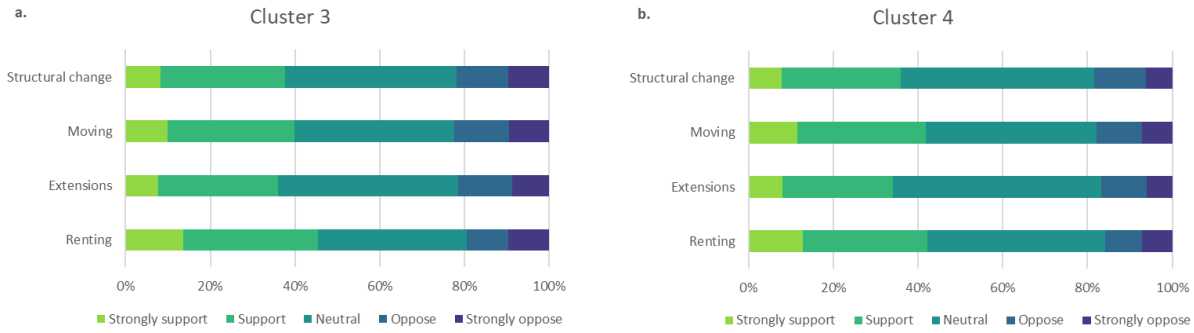

Figure 4.12: Degree of policy support in Clusters 3 (Space-oriented) and 4 (Satisfaction-seeker)

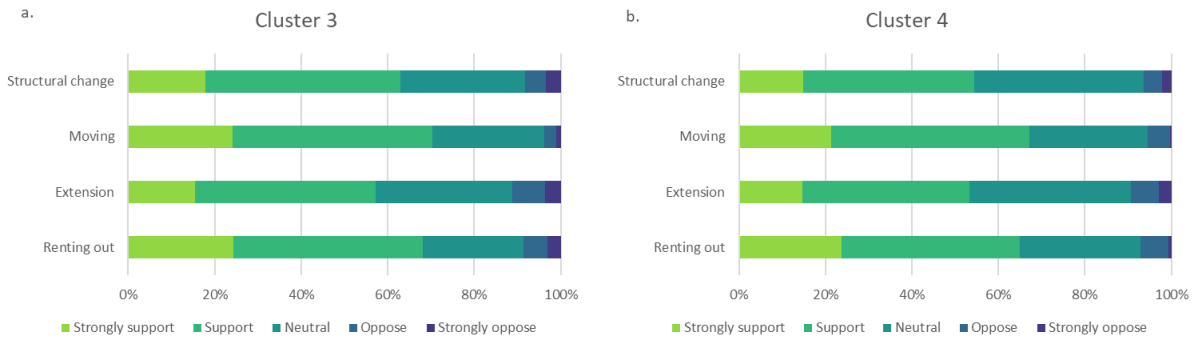

Figure 4.13: Degree of policy support for the households that can make use of the policies

The respondents in the Space-oriented cluster mainly named organisational effort as a barrier to following the policies; regarding the extensions in the dwelling, they see financial effort as the main barrier. The occurrence is almost similar for different strategies. The pattern is almost the opposite for Satisfaction-seekers, where financial effort is the main reason for not following the policies except for renting, where organisational effort is seen as a barrier. Here, however, the occurrence fluctuates significantly among different strategies, ranging from 360 for renting to 560 for extensions. The legal requirements are less problematic in both clusters, and lack of time is considered the least common reason for not following the policies (for more details, see Table 4.3).

Table 4.3: Barriers in supporting the studied policies (Total number of respondents Cluster 3 =990, Cluster 4 = 1125)

		Lack of time	Legal requirements	Organisational effort	Financial constraints	Others
Cluster 3 (Space-oriented)	Renting	17%	20%	40%	16%	29%
	Extensions	17%	29%	34%	41%	19%
	Moving	17%	14%	38%	28%	30%
	Structural change	17%	26%	37%	32%	24%
Cluster 4 (Satisfacti on-seeker)	Renting	19%	25%	32%	28%	25%
	Extensions	18%	33%	30%	50%	17%
	Moving	18%	17%	38%	41%	22%
	Structural change	18%	29%	33%	42%	22%

4.5. Discussion and policy implication

This section aims at answering the research questions of the paper presented in the Introduction and Figure 4.1, by discussing and interpreting the results presented in Chapter 4.4. The section ends by discussing the limitations of the study and remarks for further research.

4.5.1. Consumption patterns in the residential sector (RQ1)

The findings on space use and the number of rooms per capita are consistent with existing literature, indicating that single adults without children and couples without children tend to have the highest space use. Targeting these two groups could be an effective approach to effectively using the space, as they are theoretically the two groups with the greatest potential to make a change in their living space. Conversely, the groups with the lowest space use were couples with children (similar to what is reported in literature, e.g. in Destatis 2018 and Gleeson 2021 the lowest per person floor area is observed for the couples with dependent children), but also multi-generational households and households with multiple adults (i.e. shared flats). This points to the promotion of multi-generational households as an approach to reduce the per capita space use. Although this concept is generally uncommon in Europe (as was also reflected in the survey), increasing housing pressures and ageing populations may lead to more people willing to live in such arrangements (Liu et al. 2021). Encouraging sharing between known individuals, such as friends or family members, could support this concept, since many respondents with excess space do not want to live with strangers.

Around a quarter of households feel that they do not have enough rooms, while only 14% consider their dwelling too small. This discrepancy between the satisfaction with the number of rooms and the size of dwelling could be addressed by (minor) structural changes, such as dividing large rooms. Furthermore, the discrepancy between the households that consider their dwelling to be too large and the ones who need more space is also observed in the study sample of this paper. While 14% of respondents find their dwelling to be too small, 9% perceive their dwelling as too large.

The paper highlights the potential for optimising space in the residential sector. On one hand, 86% of the families with a designated guest room never or only rarely have guests sleeping over and one third of the households have a room that they rarely use. On the other hand, some households do not have enough space in their dwelling for activities such as receiving and accommodating guests, storage, free time activities. This imbalance presents an opportunity for behaviour modification. Rooms that are seldom used have the greatest potential for sharing through innovative solutions. By promoting space sharing, unused or rarely used spaces can be utilised by others when not in use.

4.5.2. Groups of interest identified in the cluster analysis (RQ2)

The results of the cluster analysis provided two key groups of interest: first one consist of respondents in the Space-oriented cluster, with high space use and perception that their residence is too large (affluent suburban homeowners with an average area per person of 108 m^2) and second one, Satisfaction-seekers, with low space use and the perception that their residence is too small (urban residents with limited space of 33 m^2/capita). Table 4.4 provides a summary of the characteristics of the selected clusters. The high space use group has a high proportion of older, retired individuals leaning towards higher incomes. The low space use group mainly comprises of younger individuals, often with children, with variable incomes. In

terms of improving space use efficiency and reducing total space consumption, the group with high space use is the main target for modifying behaviour. In addition to having high space use, this group is aware that they have too much space. However, there is a gap between this knowledge and acting on it (similar to the intention behaviour gap). This gap poses an area of potential for modifying behaviour. However, it should be noted that although this group has a generally high level of awareness that their residence is too large, most were also quite happy with their residence. This high level of satisfaction means that they would probably need strong incentives to be motivated to change. The group of low space users, which indicated that their needs in terms of space and number of rooms are largely not being met also poses as a group that could benefit from certain initiatives or policies and behaviour modification to better address their needs.

Table 4.4: Characteristics of selected clusters

			Cluster 3 (Space-oriented)	**Cluster 4 (Satisfaction-seeker)**
Size of cluster			990	1125
Space use and perception	Floor area (m^2/capita)		108	33
	Number of rooms/capita		3.3	1.2
	Perception of residence size		Too large	Too small
Socio-demographic characteristics	Age group		Above 45	Between 25-45
	Household size		1 and 2-person households	2-person households
	Household composition		Singles or couples without children	Couples with children
	Building type		Single-family house	Multi-family house
	Ownership structure		Owners	Owners
	Location		Suburb or countryside	Cities
	Income level		Slight lean towards high income	From all income groups
	Employment		Employed	Employed
	Education		Academic degree	Academic degree
Willingness and limitations to change	Sharing	Yes	Garden, garage, basement	Hobbies, socialising activities, home office
		No	Nothing can change their mind	Nothing can change their mind
	Moving	Yes	Despite looking have not found a suitable place	Despite looking have not found a suitable place
		No	Not willing to leave the current residence	Cannot afford a different place at the moment
	Rearranging	Yes	Changes are considered but no decision made yet	Changes are considered but no decision made yet
		No	The idea has never occurred to my household	I am just a tenant and cannot make such decisions
	Renting out		No, I don't want strangers to live in my home	No, it is not convenient to have a room outside the residence
Policies acceptance	Support for policies	All	Opposition rate 21%, Highest support renting (45%) and moving (40%)	Opposition rate 17%, Highest support renting and moving (42%)
		Only affected	Opposition rate 8%, Highest support renting (68%) and moving (70%)	Opposition rate 7%, Highest support renting (65%) and moving (67%)
	Barriers		Mainly organisational efforts (Extensions: financial constraints)	Mainly financial constraints (Renting: organisational effort)

4.5.3. Strategies for motivating change in consumer behaviour (RQ3)

The results of the sections on willingness to change (Chapter 4.4.2.2) and policy acceptance (Chapter 4.4.2.3) point to a set of strategies that could be recommended for each of the clusters, which are referred to as target groups here.

Sharing

A willingness to share spaces is observed in both groups. While Potential downsizers are willing to share service areas (garden, garage and basement), Room-seekers are willing to use the communal space mainly for free time activities (hobbies and socialising) and the home office. The willingness to share in both groups points to the potential for sharing communal spaces and the need for more sharing platforms. While space for a home office was not as popular as a response for "activities needing more space", 25-35% of respondents were still interested in more space for a home office. This high willingness rate to share this space suggests that, for those without a home office but wanting or needing to work remotely, there could be more potential for communal workspaces to alleviate some of the spatial needs of those in residences which are too small. Communal workspaces have been on the rise, with nearly 2.2 million people reportedly using them globally in 2019 (Berbegal-Mirabent 2021). It can alleviate housing pressures, as, with the rise of working remotely, more people want an at-home office space, which can lead to people moving to larger dwellings for such a space (Mukherjee et al. 2023). Thus, increasing and promoting communal workspaces could be a good strategy to reduce the desire to move to a larger dwelling. Furthermore, communal workspaces also foster connections and creative environments for workers, providing social and environmental benefits (Berbegal-Mirabent 2021). Respondents noted some important factors that would encourage them to use them, including attractive prices, cleanliness, and equipment. Therefore, these elements should be paid special attention when integrating and using such communal spaces.

Moving

Many respondents in both clusters have considered moving to another place but have not yet found a suitable dwelling despite looking for one. Although the share of the households wanting to move from the smaller dwellings is much higher than that of those wanting to move out of the larger dwellings, the fact that, there are households in both groups willing to move out of their dwelling should be addressed by promoting and facilitating flat swap (platforms). For Potential downsizers, the sense of belonging and attachment to the current neighbourhood hinders the willingness to move. To better reach this group, specific types of flat swaps should be promoted, and the swap should occur only within the current building or neighbourhood. The financial constraints for Satisfaction-seekers can be addressed by fiscal support, such as moving bonuses or swaps while maintaining the rental conditions.

Furthermore, high-consumers planning to move (53.1%) are mostly in between 25 and 45 years old. Interestingly, only 10% are over 65, despite this age group having a high proportion of individuals in the clusters with high m^2/capita and the perception that their residence is too large. The survey results suggest that this is due to a combination of factors, including attachments to their current residence and environment, a lack of suitable alternatives and interest, and costs. However, current findings indicated that financial incentives could encourage more people to move to a smaller residence. Therefore, policies including such initiatives could facilitate more movement to open up under-occupied dwellings. However, financial incentives alone may be unlikely to encourage people to move. This was identified in previous unpublished research, which found that households that received a moving bonus would have moved anyway. Thus, addressing the emotional attachment to the current residence and environment may be equally important when motivating change, particularly for older households. Assisting in finding an available dwelling close by, as well as identifying a dwelling

with more suitable features (particularly for older people, i.e. having a lift or a dwelling with few stairs) and helping with the actual physical act of moving, could be effective strategies (Bergstra 2021).

Rearranging

A significant proportion of both groups have considered rearrangements but have not made a decision. Consultation offers for this group can provide information, identify barriers and try to resolve them, thus increasing the chance of a rearrangement in the residence. Upon closer examination, those who have considered or are planning changes for the near future are more likely to do so if they find their residence too small rather than too large. This suggests that people are more willing to make changes when they feel they need more space than when they have too much. Having extra space may not cause them much distress, apart from cleaning and heating costs, whereas not having enough space is more likely to cause distress. Among the groups with low space use, individuals more often desire more rooms rather than more space. Therefore, policies or initiatives that assist in making structural adjustments to the residence, such as divisions, could be beneficial and result in fewer households seeking larger dwellings.

On the other hand, those who have not considered rearrangements have different reasons. Potential downsizers are mainly unaware of this option. Increasing information campaigns and providing consultation services could help to improve the situation. Among the Room-seekers, however, no changes have been considered due to the restrictions of being a tenant. To encourage tenants to follow the measures to use space more efficiently, changes need to be made to tenant-landlord relationships and the freedom of tenants to make some changes.

Renting (out)

One-third of Potential downsizers are unwilling to rent out their excess space due to concerns about privacy and security, as they do not want strangers living in their homes. Convincing them otherwise can be challenging, as previous research suggests that choosing to live with others is typically driven by social reasons, such as alleviating loneliness. Therefore, promoting shared flats or intergenerational housing formats could be an effective strategy, as people are more likely to share their homes with familiar individuals. However, current findings indicate that financial incentives can also be effective in encouraging more shared housing arrangements. Initially, 24% of those in the high space use cluster expressed willingness to rent out a room, which increased to approximately 50% when the policy for renting out a room was suggested. Thus, combining the social and financial incentives in policies or initiatives could be particularly effective in promoting shared housing in under-occupied residences. By changing social norms and developing innovative solutions, renting out and sharing the available space in such households is possible while maintaining privacy. Half of Room-seekers find it inconvenient to have an external room. This barrier can also be addressed by thinking out of the box and introducing innovative solutions.

There is a high support rate for the strategies discussed above. However, the rate of policy support significantly increases when the policy is addressed to the targeted groups, i.e. the ones for whom the policy could be relevant. This proves the need for tailored policy design to increase the effectiveness and acceptance of the policy instruments. Moving and renting could be low-hanging fruits due to their high support rate. There is a clear direction for the policies; in the Space-oriented cluster, offering organisational support will increase the probability of following

the instruments more, whereas for the Satisfaction-seekers, more financial support would promote that. Besides the discussed policies, the following strategies could also encourage the more efficient use of the space.

Bonus-Malus system

While providing a benefit is often a good incentive to encourage specific behaviour, some studies suggest a punitive approach as a more effective approach to discourage unwanted behaviour. A case study comparing the impact of charging people for plastic bags and providing a bonus for using reusable ones found the former a more effective approach (Homonoff 2018). This is rooted in the behavioural economics theory of *loss aversion*, which states that people tend to be more resistant to losing than to gaining something of equal value (Smelser et al. 2005). This sort of punitive tax has already been applied to housing in some countries to deter people from over-occupying. The *bedroom tax* in the UK poses extra taxes on spare rooms in social housing. This is 14% for one and 25% for two or more spare rooms (UK Government 2013). Similarly, Zurich has set a minimum occupancy rate for renting subsidised flats in the city, so the number of people in residences should not fall below the number of rooms minus one (Wirtz 2013). In the new German property tax, the properties are valued according to a value-dependent model in which the land area is among the decisive factors (Bundesministerium der Finanzen 2022). Applying such taxes could encourage the residents with excess space to move to more appropriately sized dwellings or to share the space with others. It should be noted that applying such a tax should be coupled with providing assistance and sufficient living alternatives. For instance, applying a bedroom tax to encourage leaving to smaller residences cannot be effective without offering suitable alternative living places. Similar policies could be applied to reduce the vacancy rate. Examples of those are the speculation and vacancy tax in Canada (Government of British Columbia 2024) and in France (Information, Directorate for Legal and Administrative 2024), tax benefits in Australia for renting a residence or only a part of it (Australian Government 2019) and extra taxes in Singapore when buying the second residence (Liew 2024). In general, a bonus-malus system used already in other sectors, such as transport, to promote the use of low-emission cars (e.g. IEA 2021) and industry to increase the rate of recyclability (e.g. CITEO 2021) can also be effectively applied to the buildings sector. It can promote the efficient use of space by rewarding those who optimise their living space and penalising those with excessive space. However, to ensure its success, it is crucial to define baseline references for the system carefully.

Change of narratives

To better engage residents with excess space use, it would be beneficial to emphasise improving quality of life and well-being. The Swedish concept of *Döstädning*, or *death cleaning*, is a minimalism-related concept that promotes de-cluttering (Magnusson 2017). Applying this concept to housing would involve *downsizing* to smaller dwellings, which could incentivise people to make such moves. Instead of solely promoting downsizing, it is suggested that the narrative be shifted to “rightsizing” focusing on moving to a dwelling that improves quality of life rather than simply moving to something smaller (Hammond et al. 2018). This approach may be more effective for individuals who are emotionally attached to their homes, as a positive perception of the change and understanding of benefits increases acceptance (Lewin 1947). Combining these approaches, creating the rightsizing narrative and providing the necessary support and resources could potentially assist the older population transition out of dwellings that are too large.

4.5.4. Limitations

While most of the quotas set to ensure the representativeness of the study sample achieved a completion rate above 80%, some fell significantly short of their target. For instance, the over-65 age group in Portugal proved particularly challenging to reach, with the target share barely exceeding 50%. This difficulty may be attributed to the technological nature of the online survey. In such cases, one option to address the unmet quotas is to weight the data. However, in this paper, it was decided not to apply any weighting for the following reasons: first, given the different factors that were taken into account for representation, applying weighting to all of them would have been time-consuming, as it would have required a manual weighting process (Borkowicz 2023). Given that this research was already method-intensive, other methods were prioritised. Second, weighting introduces assumptions about the missing data, potentially leading to a biased representation. In the case of the over-65 group from Portugal, assuming that the "missing" 50% would have responded in the same way as the 50% surveyed could be highly misleading, especially given that many questions were perception-based. Finally, weighting adjustments can increase variance and error estimators, as highlighted by Kalton et al. (1986) and Pike (2008).

Furthermore, the assumptions made for the data validation are subject to some limitations. The chosen valid ranges for space (m^2), number of rooms and total number of people were partly derived from literature. However, no reliable sources were found for determining the "maximum size of a residence", "minimum room standard", "total number of people in a residence", or "maximum number of rooms". As a result, the valid ranges were partly based on literature but also based on expert estimation and assumptions. This approach may have inadvertently excluded data that could have been valid.

4.6. Conclusions

With the overall aim to analyse the potential for change to reduce the use of living space, this paper identifies two key target groups based on survey results and cluster analysis of residents' space use behaviours and attitudes in four European countries. The first cluster consists of individuals who are over-consumers and are aware that they have excess space. The second cluster comprises individuals whose spatial needs are not fully met. In each cluster, the paper examines the socio-demographics, willingness to change and acceptance of specific policies aim to reduce residential space use. The findings of this research indicate that the policies investigated could effectively reduce over-consumption, if the suitable frameworks are provided. It recommends targeting over-consumers by encouraging them to share unused space in their dwellings and providing incentives to move to smaller dwellings that meet their spatial needs. In order to target the group whose spatial needs are not being met, the paper recommends promoting communal spaces and providing financial support for structural changes. In order to increase the effectiveness of housing policies addressing space use, the findings of the paper point to the need for tailored policies, taking into account the characteristics of each target group and raising awareness of existing policies.

4.7. Appendices

4.7.1. Appendix A: Further results of the analysis

Table 4.5: Characteristics of the survey observations, in the whole sample and at the country level

		Aggregated	Germany	Poland	Portugal	Sweden
Total observations		5766	1440	1444	1440	1442
Age	18-24	7%	5%	10%	6%	7%
	25-35	18%	14%	23%	19%	17%
	36-45	18%	17%	18%	22%	14%
	46-55	19%	17%	17%	24%	17%
	56-65	17%	21%	14%	14%	20%
	Older than 65	22%	26%	19%	15%	25%
Gender	Female	50%	47%	54%	48%	52%
	Male	50%	53%	46%	52%	48%
	Others	0%	0%	0%	0%	0%
Household size	1 Person	21%	29%	19%	17%	20%
	2 Persons	39%	42%	30%	33%	52%
	3 Persons	20%	16%	22%	27%	14%
	4 Persons	13%	8%	17%	17%	8%
	5 Persons	4%	2%	7%	4%	4%
	6 or more persons	3%	2%	5%	2%	2%
Household composition	Couple with children	30%	24%	33%	40%	22%
	Couple without children	31%	38%	25%	19%	43%
	Single adults with children	7%	5%	6%	8%	11%
	Single adults without children	24%	31%	23%	23%	19%
	Others	7%	2%	13%	10%	5%
Location	City	42%	41%	38%	42%	45%
	Suburb	33%	38%	27%	35%	32%
	Countryside	26%	21%	35%	22%	23%
Building type	Multi-family house	53%	58%	50%	51%	54%
	Single-family house	46%	41%	49%	48%	45%
	Others	1%	1%	1%	1%	1%
Ownership structure	Owner occupied	65%	46%	83%	72%	60%
	Tenant-occupied	34%	54%	16%	27%	39%
	Others	1%	0%	2%	1%	0%
Income	Quintile 1	19%	21%	21%	16%	16%
	Quintile 2	19%	19%	18%	18%	22%
	Quintile 3	19%	20%	18%	22%	19%
	Quintile 4	21%	22%	21%	22%	21%
	Quintile 5	21%	19%	22%	22%	23%
Education	No school completed	0%	0%	0%	0%	1%
	Primary education	3%	1%	3%	2%	6%
	Secondary education	33%	19%	39%	39%	37%
	Vocational training	27%	48%	18%	17%	23%
	Academic degree	36%	31%	39%	43%	32%
Employment	Full-time employed	49%	44%	50%	58%	45%
	Part-time employed	8%	12%	7%	5%	10%
	Self-employed	6%	5%	5%	9%	4%
	In training/education	3%	1%	4%	3%	4%
	Housewife/house husband	2%	4%	4%	1%	1%
	Looking for work/currently unemployed	5%	4%	5%	7%	5%
	Retired	24%	29%	25%	16%	28%
	Others	2%	1%	2%	1%	2%

Table 4.6: Overview of the space use in different categories, including the area and number of rooms per capita

		Area/ capita (m^2)	Rooms/ capita
All		**52**	**1.7**
Building type	Multi-family house	43	1.6
	Single-family house	63	2.0
Income	Quintile 1	55	2.0
	Quintile 2	52	1.8
	Quintile 3	50	1.7
	Quintile 4	51	1.7
	Quintile 5	53	1.6
Ownership structure	Owner-occupied	57	1.9
	Tenant-occupied	44	1.5
Location	City	47	1.6
	Countryside	58	1.9
	Suburb	54	1.8
Household composition	Couple with children	40	1.2
	Couple without children	53	1.8
	Others	44	1.3
	Single adult with children	44	1.5
	Single adult without children	72	2.6

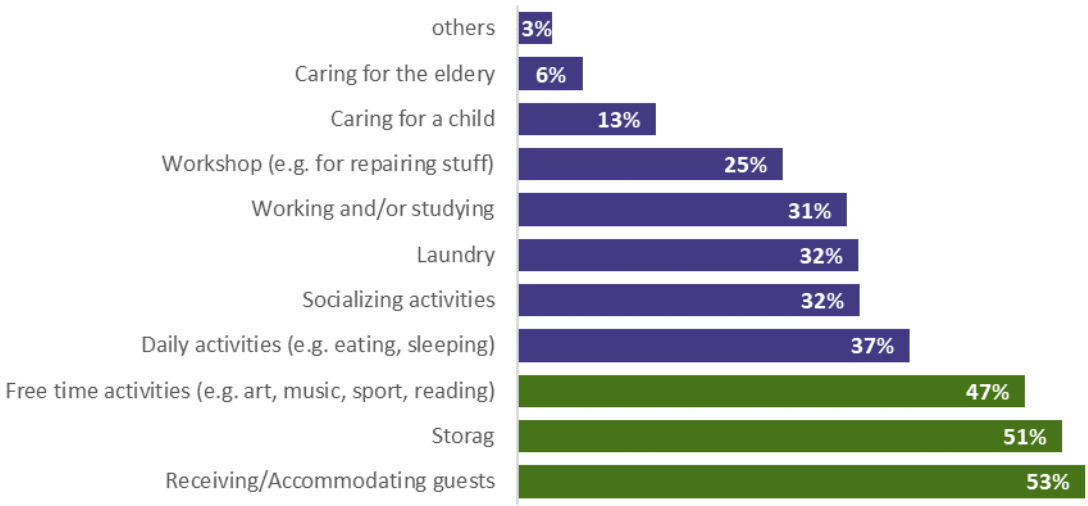

Figure 4.14: Activities for which not enough space exists in the perceived too small dwellings

4.7.2. Appendix B: Clustering details

Table 4.7: Variables considered for cluster analysis: both objective and subjective variables were considered in the clustering

Category	Variable
Objective	Area per capita
	Number of rooms per capita
	Existence of unused rooms in the residence
Subjective	Overall satisfaction with the residence
	Perception towards number of rooms
	Perception towards residence size

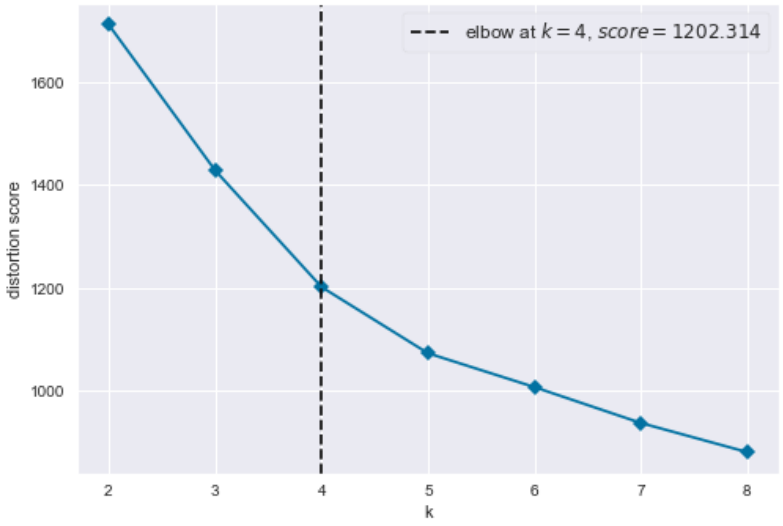

Figure 4.15: Distortion Score in the elbow method: the figure shows the optimal number of clusters (K=4) for the cluster analysis

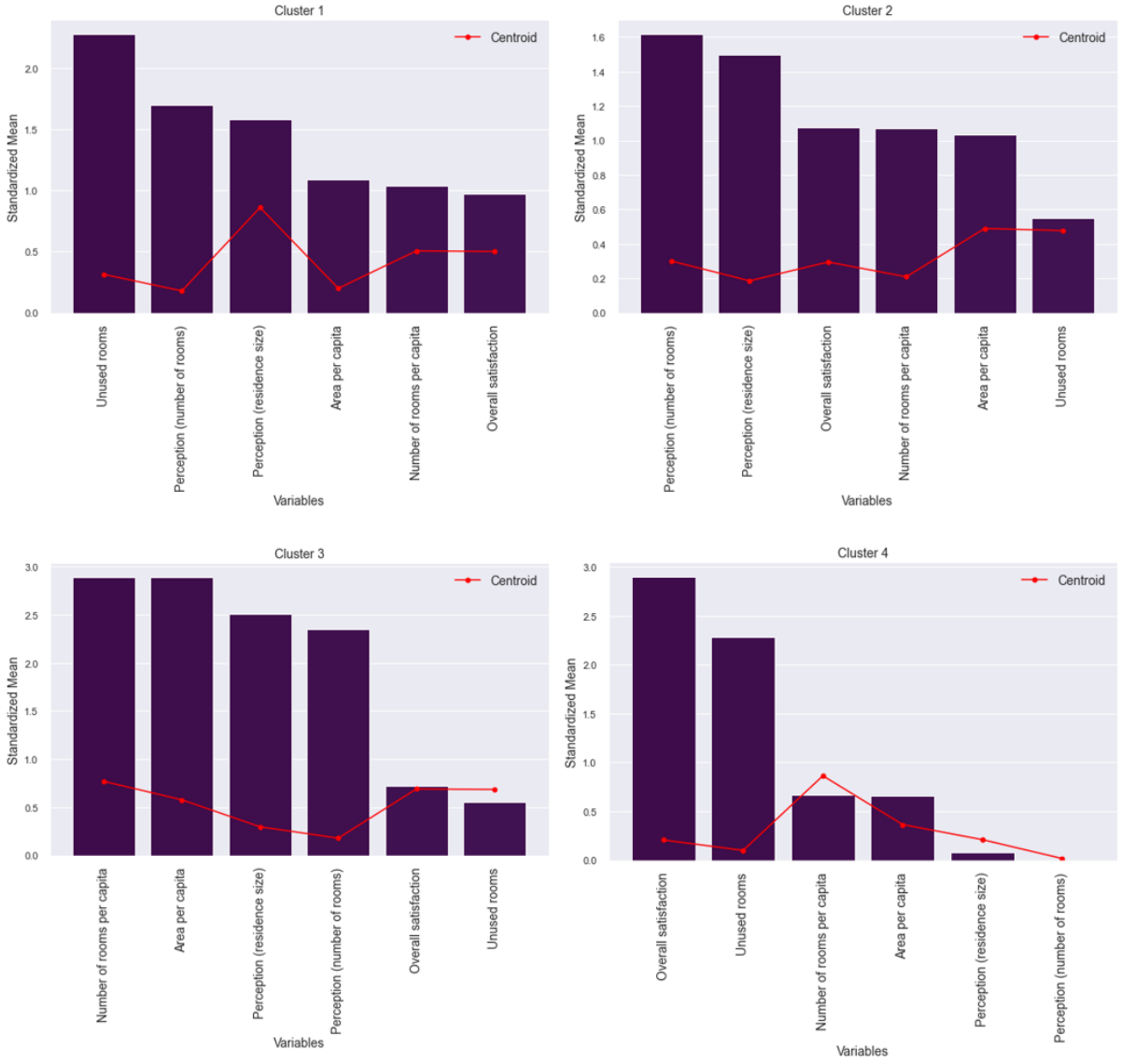

Figure 4.16: Standardised means and centroids in the formed clusters: it shows the standardised mean and the centroid of the clustering variables. The former is calculated by subtracting the mean of each variable from its original value and then dividing it by the standard deviation of that variable. The higher the standardised mean of a variable, the stronger the impact on clustering results. For instance, in Cluster 4, the variable “Overall satisfaction” has the highest importance in determining the cluster membership. Variable centroid is the mean of all observations for that variable. Cluster centroid, i.e. a vector containing one number for each variable, shows the multi-dimensional average of each cluster and allows for comparisons between clusters

4.7.3. Appendix C: Nesting within countries

We used the Python module statsmodels, and its implementation of mixed linear models (MIxedLM) (Seabold et al. 2010) to test whether individual-level data were nested within countries. We assumed a two-level MLM to assess the hierarchical structure of our data, with individuals (i) at the first and countries at the second level (j). We examined the results of the null model, which accounts solely for a global intercept to explain the dependent variable. The variance σ of the residuals at different levels allowed us to calculate the ICC.

$$ICC = \frac{\sigma_j^2}{\sigma_j^2 + \sigma_i^2}$$

The results of this analysis for the dependent variables of the survey data, are systematically presented in Table 4.8. The very low ICC suggests that the country-effect for the dependent variables are negligible.

Table 4.8: Results of multilevel analysis for survey variables

Dependent variables	Variance of random components		ICC
	Random Intercept Variance (σ_i^2)	Residual Variance (σ_j^2)	
Area per capita	83.93	1805.01	0.04
Number of rooms per capita	0.03	1.79	0.01
Second residence	0.01	0.24	0.02
Unused rooms	0.00	1.77	0.00
Available space for activities	0.01	1.09	0.01
Guests sleep over	0.01	0.40	0.03
Facilities for guests	0.01	0.75	0.01
Events	0.00	0.40	0.01
Overall satisfaction with residence	0.02	0.74	0.02
Perception (Residence size)	0.00	0.23	0.00
Perception (Number of rooms)	0.00	0.29	0.01
Perception (Layout)	0.00	0.19	0.00
Using little resources	0.04	0.74	0.06
Sharing habits	0.02	1.19	0.02
Flexible space use	0.02	0.96	0.02
Using little space	0.04	0.87	0.04
Policy (Renting)	0.05	1.11	0.04
Policy (Extensions)	0.03	0.88	0.03
Policies (Moving)	0.02	1.01	0.02
Policies (Structural change)	0.02	0.94	0.02

4.8. Supplementary material

Supplementary data to this chapter (survey questions, validation process of the collected data and results of hierarchical clustering) can be found at: http://dx.doi.org/10.24406/fordatis/353.

5. Reduction of gas demand through changes in heating behaviour in households: novel insights from modelling and empirical evidence[5]

Abstract: The geopolitical situation and the energy crisis caused by the Russian invasion of Ukraine have led to proposals for immediate reduction in energy consumption within the European Union. The REPowerEU Plan of the European Commission proposes behavioural changes as short-term measures to rapidly reduce the EU's dependence on Russian gas and oil. This paper investigates the energy saving potential resulting from changes in household heating behaviour. Through a comparison of modelling results with results of the analysis of empirical data collected in a survey of households in four EU Member States (Germany, the Netherlands, Greece, and Poland), the paper examines the adequacy of the short-term measures proposed by the EU and the instruments needed to leverage such measures and increase their potential impact. Although the reported changes in heating behaviour lead to a 2.0% to 3.5% reduction in residential gas demand in the countries studied, the study recognises that the EU targets for reducing the gas demand will not be met under current regulatory conditions, and considers the energy savings observed in this paper and in the literature as a short-term response to unexpected circumstances. The paper proposes a policy package to transform these responses into the long-term behavioural changes needed to achieve climate targets. Promoting uptake of household technical infrastructure, providing financial support and implementing information campaigns are suggested as effective approaches to achieving savings targets.

[5] This chapter has been published as Bagheri, Mahsa; Kochański, Maksymilian; Kranzl, Lukas; Korczak, Katarzyna; Mayrhofer, Lukas; Müller, Andreas; Özer, Ece; Rao, Swaroop (2024): Reduction of gas demand through heating behaviour changes in households: Novel insights from modelling and empirical evidence. In: Energy and Buildings. DOI: 10.1016/j.enbuild.2024.114257

CRediT authorship contribution statement: Mahsa Bagheri: Conceptualisation, Methodology, Formal analysis, Investigation, Writing – Original Draft, Writing – Review & Editing, Visualisation, Supervision; Maksymilian Kochański: Conceptualisation, Methodology, Writing- Original draft preparation; Lukas Kranzl: Conceptualisation, Methodology, Writing - Review & Editing; Katarzyna Korczak: Resources; Lukas Mayrhofer: Software, Writing - Original draft preparation; Andreas Müller: Conceptualisation, Resources; Ece Özer: Software, Formal analysis; Swaroop Rao: Formal analysis, Validation, Writing - Review & Editing

5.1. Introduction

Between 2013 and 2022, the share of natural gas in the total energy available for final consumption in the European Union (EU) slightly decreased, falling from 22% to 20% (Eurostat 2023a). In 2013, 27% of the gas consumed by the EU was supplied by Russia (European Commission 2014). In 2022, this share fell to approximately 23% (own calculation based on the Council of the European Union 2024). In the same decade (2013-2022), the natural gas consumption in residential buildings in the EU has been relatively stable, ranging between 825 and 1 020 TWh (Eurostat 2023k), making gas the most widely used energy carrier for space and water heating (Odyssee-Mure 2020). Between 2013 and 2021 Europeans enjoyed a trend of falling nominal gas prices (excluding taxes and levies), which decreased from 3.89 EUR/kWh in the first half of 2013 to 3.17 EUR/kWh in the first half of 2021 (Eurostat 2023k). With the Russian invasion of Ukraine in February 2022, this trend reversed. In the first half of 2022 gas prices drastically increased by 53% as compared to the first half of 2021.

In response to rising gas prices and the risk of supply disruptions, demand reduction measures became urgently needed. In this context, the European Commission and the Council of the European Union have put forward several proposals and regulations aimed at gas demand reduction (Council of the European Union 2022a, 2022b; European Commission 2022a, 2022b, 2021a, 2022c). The proposed policy measures addressing gas consumption in buildings can be grouped into the following two main categories:

1. Building-related energy efficiency improvements and roll out of heat pumps
2. Measures aimed at stimulating building occupants' behaviour changes, such as turning down heating, using less air-conditioning or adjusting boiler settings

The European Commission expects the first category of measures to provide nearly three times more savings than the second one: 37 bcm of natural gas saved versus 13 bcm of natural gas saved, with likely overlaps leading to overall savings lower than the sum of the savings from both groups of measures. Still, infrastructure changes in buildings would require a significant amount of time for implementation as well as investment, estimated at over 56 billion euros in addition to the investments planned in the previously announced "Fit for 55" (European Commission 2021b) measures. In this context, the second category of measures, i.e. building occupants' behaviour changes, comes to the spotlight, as they could be implemented (comparatively) quickly and, according to the European Commission, without any investment (European Commission 2022b). In April 2022, the International Energy Agency (IEA) and the European Commission started the *Playing my part* campaign with energy saving tips directed at households and building managers to help reduce the EU's reliance on Russian fuels (European Commission & International Energy Agency 2022).

Despite the paramount importance of behavioural changes in the EU policy targets set in response to the current energy crisis, there are several open questions regarding the potential impact and feasibility of short-term reductions in gas demand for space and water heating in the EU through behavioural measures. In this context, this paper:

1. analyses economic, energy-, environment-, building-, and occupant-related factors influencing household behavioural change and assesses the impact of energy saving measures, such as lowering the heating temperature, on the reduction of gas demand for space and water heating in EU households

2. evaluates the achievability of reducing the heating temperature in selected EU Member States, with different socio-economic contexts
3. makes recommendations for the EU's long-term energy policy to increase the impact of changes in household behaviour aimed at reducing gas demand for space and water heating.

Unlike previous studies that may have focused more on economic (e.g., price-related (Zhu et al. 2018)) or the technical aspects of energy savings due to behaviour change (e.g., heating systems changes (Sovacool et al. 2021)), this paper directly investigates the short-term behavioural changes households can adopt to reduce their energy consumption, particularly in heating, in response to the energy crisis prompted by the geopolitical situation in the EU between 2021 and 2023, specifically, following the Russian invasion of Ukraine. The novelty of the study concerns also the timely analysis of the adequacy of short-term measures proposed by the EU to rapidly reduce dependence on Russian gas. The inclusion of different EU Member States with varied socio-economic and climatic conditions adds depth to the analysis, recognising the heterogeneity within the EU and the need for tailored approaches in policymaking.

This paper is structured as follows. In Chapter 5.2, we provide a literature review of existing studies on heating behaviour and potential impacts of short-term behavioural measures, assessments of the achievability of such impacts, and available evidence on possible policy actions in this area. In Chapter 5.3, we present the methods employed in this paper as well as the empirical basis. In Chapter 5.4, we present the calculated savings potential of changes in heating behaviour (e.g. lowering indoor temperatures). We then analyse the attitudes of households across the EU towards space heating and the drivers of these attitudes. In Chapter 5.5, we compare the saving potentials derived from modelling and survey results and reflect on policy objectives for the short-term reduction of gas demand for space and water heating in the EU and discuss policy implications. Finally, Chapter 5.6 briefly presents the conclusions of our study.

5.2. Background

The Council Regulation (EU) 2022/1369 set a non-binding target for all Member States to reduce gas demand by 15% between 1 August 2022 and 31 March 2023, compared to the average of the same period in the previous five years (Council of the European Union 2022a). The reduction of indoor temperatures has been identified as a particularly important measure to reduce gas demand in buildings in the short-term (Harputlugil et al. 2016; European Commission & International Energy Agency 2022; Shamas et al. 2023). However, the potential effectiveness of this measure is highly dependent on social factors, including especially the user comfort needs, and has not yet been thoroughly investigated across the EU following the start of the war in Ukraine. In a study relying on modelling, Rohde et al. (2012) estimate that lowering the indoor temperature of buildings in the EU-27 by 1°C offers a potential 9% reduction in gas demand in terms of reduced heating degree days.

The energy savings from lowered indoor temperatures in buildings are not only uncertain, but they are also influenced by a variety of factors, including individual thermal comfort preferences, environmental attitudes, motivation to conserve energy, the cost and availability of energy, understanding of the impact of energy use, and the usability of installed thermostats (if installed at all). Some studies indicate that prompting individuals to voluntarily lower the temperature at which they heat their homes could be of limited effectiveness, since people

simply want their homes warm when the weather is cold (Sovacool et al. 2021). The scant scientific studies of the EU households' attitudes towards reducing indoor temperatures suggest that Europeans' willingness to lower temperatures is indeed limited. Households surveyed in Sweden in 2019 could not imagine allowing greater temperature variation in their homes to save energy (Hagejärd et al. 2021). A study of households in the Netherlands and Siberia found that people living in yurts care less about stable thermal conditions than typical Dutch sedentary dwellers, which indicates that psychological acceptance of a certain level of discomfort is challenging for modern societies (Khovalyg et al. 2023). Experiences from before the current energy crisis show that to manage inadequate space heating, people prefer to act on the energy supply side (e.g. install a bigger boiler), rather than to change their behaviour (e.g. wearing extra clothes to feel warmer), as evidenced by nationally representative surveys conducted in Sweden, Germany, Italy, Spain, and the UK (N = 10 109) in 2020, which reported that the mean preferred indoor temperature in winter in these five countries is between 20.88 °C and 21.83°C (Sovacool et al. 2021). These findings are consistent with prior findings by Stazi et al. (2017), which indicate that sometimes individual factors affect the heating use more than environmental ones, such as outdoor temperature. On the other hand, Canale et al. (2021) find that additional technical assistance improving user awareness, such as in-home displays, can help lower the consumption of heating by 17%. An information campaign in Italy led to a significant increase in the amount of time spent below 19°C, yet still the average indoor air temperatures were always between 18.7°C and 22.3°C (Canale et al. 2023).

While many studies attempt to identify the main drivers of heating behaviour (e.g. Belaïd et al. 2020; van den Broek et al. 2019) some scholars go further and analyse the role of such drivers in heating behaviour. In a review of the existing literature on drivers of occupant behaviour, Wei et al. (2014) identify 27 drivers that influence energy consumption in the residential sector. The authors categorise the factors as environmental, building-related, occupant-related and other, and examine whether a correlation between these factors and heating behaviour has been addressed in the literature. The results are partially shown in Table 5.1.

Following the Russian invasion of Ukraine in 2022, reducing gas demand became one of the key topics of energy policy and public debate in the EU and its Member States. Before the start of the 2022-2023 heating season, over a third of households in Germany said they would lower the temperature on their thermostat (Dena 2022). An EU-wide study on this question was conducted by a manufacturer of smart thermostats, whose users lowered the indoor temperature by various values compared to the previous heating season, ranging from 0.28°C (the minimum result, observed in Bulgaria) to 0.99°C (the maximum result, observed in the Netherlands and Belgium) (Tado 2023). Still, this study was restricted to smart-thermostat users and did not control for the respondents‘ heating source, making it difficult to draw conclusions for EU-level energy efficiency policy that should be reflective of households' economic status as well as the characteristics of household heating systems, which are important drivers of energy-related behaviour (Belaïd et al. 2020).

This study provides original research quantifying the impact of behavioural changes aimed at reducing gas consumption in the EU residential sector after the start of the war in Ukraine. Our modelling of the impact of behaviour change on gas consumption is compared with new empirical evidence on the heating behaviour of households in four EU Member States. For this purpose and inspired by Wei et al. (2014), the relationships between heating behaviour and five selected factors in three categories are examined: economic (heating price and income level), building and occupant-related (building type and ownership structure), and energy and

environment-related (energy carrier). Therefore, this research complements prior studies on consumer price elasticity of residential energy demand, which offer insight into the degree to which households are likely to adjust their energy consumption in response to price changes (Blázquez et al. 2013; Zhu et al. 2018 and Ohler et al. 2022). However, unlike the present study which offers new perspectives on price elasticity in relation to gas consumption, most previous research primarily examined price elasticity with respect to electricity usage. The figures shown in Table 5.1 indicate whether or not a correlation has been reported in the literature between the selected factors and hearing behaviour.

Table 5.1: Number of papers in the literature reporting on the correlation between the selected factors and heating behaviour (based on Wei et al. 2014)

Category	Factors	Correlation reported	No correlation reported
Economic factors	Heating price	2	1
	Income level	5	4
Building and occupant-related factors	Ownership structure	3	1
	Building type	7	0
Energy and environment-related factors	Energy carrier	1	1

5.3. Methodology

5.3.1. Selected measures

Among the proposed behavioural changes to reduce gas demand, the reduction of heating temperature was selected for in-depth analysis in this paper. This measure is mentioned, directly or indirectly, in the Energy Sufficiency Policy Database (Zell-Ziegler et al. 2022), the IEA "10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas" (IEA 2022a), and the "Playing my part" report (IEA 2022b), which aims to raise awareness of ways to save money and energy and reduce reliance on imported fuels. It is one of the behavioural changes that can be implemented in the short-term, and its impact on energy savings in the short and long-term can be quantified, building on existing models and methodologies. In addition to this main measure, other energy-saving behaviours and low-investment measures (e.g. reducing ventilation rates or closing curtains in front of windows) are addressed in the paper.

5.3.2. Regional scope of the study

To provide a multi-faceted analysis of the role of behaviour change in reducing gas consumption, the present study focuses on gas-based heating demand in the household sector in four EU Member States. The countries were carefully selected using indicators from Eurostat database (European Commission 2024), to ensure a balanced representation of various levels of factors influencing heating behaviours identified in Table 5.1. Within each category of factors, we consider the following indicators across the EU Member States: (1) in the category of economic factors, we investigate country-specific gas prices and household income levels;

(2) in the category of building and occupant-related factors, we analyse country-specific shares of multi-family residential buildings as well as shares of households that are tenants; (3) in the category of energy- and environment-related factors, we study country-specific final energy consumption for space heating in households (kWh/m^2) as well as the share of gas in final energy consumption in the residential sector. After comparing the country-specific levels of these indicators with their averages for the whole EU-27 (Figure 5.1), we select the following four EU Member States for the study:

Germany (DE)

Between 2011 and 2019, Germany had the highest annual average heating energy demand in the whole EU (441.4 TWh/year) (Veljkovic et al. 2023). In 2022 German households had a median equivalised disposable income above the EU average and gas prices below the EU average. In 2020 the share of German households living in multi-family houses (MFH) was higher than the EU average, and almost half of them (49.5%) were tenants rather than owners, which was also higher than the EU average. In 2020 the German residential sector was more dependent on gas than the EU average. Due to the relatively cold winters, the country's final energy demand for space heating per square metre was also higher than the EU mean value. The preferred mean indoor air temperature in winter in German households is 21.28°C (according to the study of Sovacool et al. 2021), while the requirement for indoor temperature in winter according to national legislation and building codes is 20°C (Brelih 2013).

Greece (GR)

Despite the relatively low median equivalised disposable income of Greek households, in the second half of 2022 they were exposed to gas prices that were higher than the EU average and almost two times higher than gas prices for households in Germany. This raised questions about the prominent position of natural gas in Greece's energy transition strategies (IEA 2023a). In 2020 a higher proportion of Greek households lived in multi-family houses than the EU average, while the share of tenants was lower than the EU average. In the same year, Greek households were less dependent on gas than the EU average. As the country generally experiences mild winters, the final energy demand for space heating in households was below the EU average. The requirement for indoor temperature in winter according to national legislation and building codes is 20°C (Brelih 2013).

The Netherlands (NL)

Similar to Germany, in 2022 Dutch households enjoyed a median equivalised disposable income above the EU average. However, unlike Germany, gas prices for household consumers in the Netherlands were above the EU average, reflecting the national energy mix, which relies heavily on gas-fired power stations, and the national gas market structure which is sensitive to changes in wholesale prices and hedging costs (Koenraadt 2022). In 2020 the share of Dutch households living in multi-family houses was lower than the EU average, and almost a third of them (30.9%) were tenants, slightly higher than the EU average (30.0%). In 2018, 90% of residential heating demand was covered by natural gas (IEA 2020), making Dutch households significantly more dependent on gas than the average in the EU. The country's final energy demand per square metre for space heating fell slightly below the EU average. This can be partly explained by the fact that the typical set point indoor temperature in the Netherlands is 18°C, which is the lowest in the EU (Veljkovic et al. 2023).

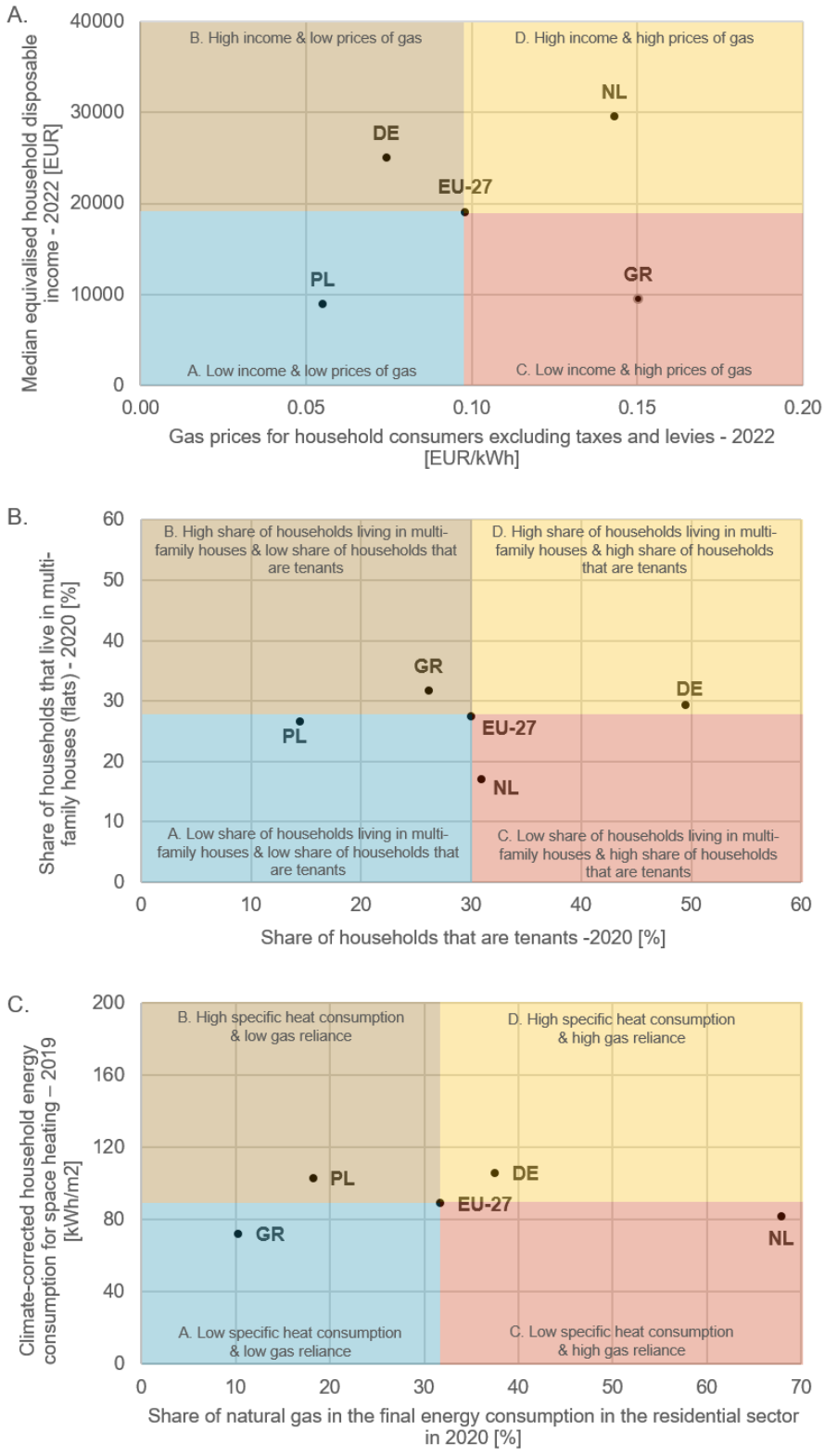

Figure 5.1: Factors influencing the heating behaviour of households in the countries selected for the study: A. economic factors, B. energy- and environment-related factors, C. building- and occupant-related factors. (own illustration based on data from Eurostat 2023k and Eurostat 2023q for A., Eurostat 2023e and Eurostat 2023d for B., and Eurostat 2022b and Invert/EE-Lab for C.)

Poland (PL)

The median equivalised disposable income of Polish households was below the EU average in 2022. In the second half of the year, they enjoyed significantly lower gas prices than the EU average due to the retail gas price cap introduced by the government (Euractiv 2022). In 2020 a lower share of households in Poland lived in multi-family houses than the EU average, and the share of tenants was also lower than the EU average. Although Polish households have a lower reliance on gas compared to the EU average, Poland's energy demand for space heating per square metre was comparable to Germany's, and above the EU average. The requirement for indoor temperature in winter according to national legislation and building codes is 20°C (Brelih 2013).

5.3.3. Methodological approach

To obtain a comprehensive view of the saving potentials of the studied measures, the paper used a multi-method approach (Kasirye 2021). Using a modelling approach, the study quantifies the energy savings resulting from the implementation of behavioural measures such as reducing the heating temperature. An online survey was used to investigate the heating behaviour of the residents. The savings potential suggested by the modelling exercise was then compared with the saving potential derived from the online survey, and with the policy changes set out in the European Commission and EU Council communications, legislative proposals, recommendations, and regulations published between the years 2021-2023 to tackle rising energy prices and to reduce the EU's dependence on Russian fossil fuels. The comparative analysis was used to draw conclusions on the adequacy of the proposed measures and the need for new ones.

5.3.3.1. Modelling

The modelling was carried out using the socio-techno-economic building stock model Invert/EE-Lab, described by Müller (2015). This model uses a dynamic bottom-up approach and simulates future energy demand for space heating, cooling, hot water, and lighting for a large number of building archetypes in EU Member States, taking into account parameters and boundary conditions such as economic incentives, regulatory instruments or technological progress (Müller 2015; Kranzl et al. 2019). Energy demand calculations follow a quasi-steady-state approach, using the same indoor temperature for all relevant building components (e.g. wall surface temperature, window surface temperature, and indoor air temperature) with monthly energy balance calculations. This reduction in complexity allows for modelling the building stock of entire countries, which would otherwise require significant computing power and time. In a direct comparison between an Invert and an EnergyPlus model of the energy consumption of different European cities, there were no systematic and significant deviations in heating demand between the two approaches (Mayrhofer et al. 2023; Zangheri et al. 2014), justifying the use of the model for the purposes of this paper. The effective indoor temperature in buildings is modelled as a function of dwelling size, energy performance of the building, heating energy costs and class of household income (see Müller 2015; Loga et al. 2003 and Loga et al. 2022). The model has recently been used and calibrated in several studies also for EU-27, which was taken as a starting point for this paper (see e.g. Kranzl et al. 2022). Details on the building stock data is provided as supplementary material to in Chapter 5.8.

Simulations with the Invert model were carried out for the residential sector in the EU-27 and the results are presented for the EU-27 as a whole and for the four selected Member States. We start from a climate corrected base year data of 2019 (i.e. assuming average climate data for the period of 2005-2019). Based on the corresponding demand, we implement a short-term behaviour change in several distinct scenarios by reducing the indoor temperature by 0.5°C to 4.5°C, in steps of 0.5°C, compared to a baseline scenario with a temperature set point of 21°C. This baseline set point is deemed more common in building than the oftentimes used set point of 20°C (Loga et al. 2001) and still in line with DIN EN 12831 which allows a comfort surcharge of indoor temperature set points up to 3°C above 20°C. In buildings that already have lower indoor temperatures to begin with (due to e.g. large floor area, high energy costs, low-income households), the indoor temperature was reduced by 0.125°C up to 1.25°C in 0.125°C increments. Thus, the results show the isolated effect of a short-term change in indoor temperature levels, without considering other effects such as changes in heating systems or building retrofits, which would require longer lead-times to be realised. The model considers the climatic conditions within each country as outdoor temperature levels. Thus, the difference between indoor and outdoor temperature levels varies between countries. Thus, a temperature reduction of 1°C in warmer climate leads to a lower relative reduction of this temperature difference (and the resulting energy needs for space heating) during the heating season. This effect is also discussed in the results section.

In additional scenarios, we consider ambitious energy efficiency measures and changes in the used energy carriers by energy carrier shifts. Energy efficiency measures include reducing the air exchange rate, e.g. by air tightening windows, reducing the ventilation rate, reducing the use of domestic hot water, and decreasing thermal exchange rates e.g. by closing curtains in front of windows or adding window films. The energy carrier shift scenario includes an increased use of secondary heating systems (e.g. coal or biomass fuelled systems) and an increase in installed solar surface area and heat pump capacity. The energy carrier shift scenarios (increased output of secondary heating systems, increased solar surface installation rate, and increased heat pump installation rate) are combined in the final analysis. Energy efficiency measures are analysed individually. Details of the scenario specifications are given in Table 5.2. Energy demand for all scenarios was calculated for the entire year.

Table 5.2: Description of additional model scenarios. The n50 value refers to the air exchange rate occurring as a result of air leakage through the building envelope at 50 Pa.

Scenario		**Description**
Energy efficiency measures	Air exchange rate	Reducing n50 value to $1h^{-1}$ in buildings where it was initially higher than that.
	Ventilation rate	Reducing baseline heating and ventilation air exchange rate by 30%
	Domestic hot water	Reducing baseline hot water consumption by 30%
	Thermal exchange rates	Reducing the heat loss of windows by subtracting 0.14 W/m^2K from the baseline u-value in 1/6 of all single-glazed windows

Energy carrier shifts	Secondary heating systems	Increasing energy output of installed coal and biomass fuelled secondary heating systems by 50%, assuming that 15% of current coal and biomass demand (according to Eurostat energy balances) is attributable to such systems.
	Solar surface installation rate	Increased solar surface installation rate, so that 70% of the installation decrease between the peak year 2008 (EurObserv'ER 2010) and 2019 (EurObserv'ER 2021b) is restored. For countries that increased their installed solar surface area between 2008 and 2019, an increase of 20% in their installation rate is considered.
	Heat pump installation rate	Increased heat pump installation rate to reach 70% of the EU target (EurObserv'ER 2021a) in gas heated buildings with an average of 12 kW and 1500 full-load hours

5.3.3.2. Survey

The survey data was collected in Germany, the Netherlands, Greece and Poland using an online questionnaire. Fieldwork took place in the selected countries between 16 December 2022 and 8 January 2023 and respondents were members of a research panel managed by Dynata Market Research. Quota sampling (Rukmana 2014) was used to ensure the representativeness of the sample in terms of household income, building type and ownership structure (tenant/owner). Eurostat datasets were used for defining the quotas. The survey questions were available in five languages (English, German, Dutch, Greek, and Polish) and the translation of the survey into the target languages was checked by native speakers to avoid misinterpretation arising out of translation errors. Pretesting and piloting ensured that the survey conveyed the authors' intentions. The English version of the survey questions is presented as supplementary material in Chapter 5.8.

The parts of the survey considered in this paper focused on heating behaviour in the heating periods 2021-2022 and 2022-2023. In the surveyed countries, the heating period usually starts in October and ends in March or April and can vary slightly from year to year. To avoid confusion and to avoid influencing the responses, no specific definition of heating periods was given. The heating behaviour was investigated in three areas, namely the heating temperature, the adopted non-technical energy saving measures (e.g. keeping the doors closed while heating, wearing more clothes), and the technical improvement (e.g. changing the thermostat from a manual to a programmable one). The questions relating to the 2021-2022 winter period were answered retrospectively.

In order to investigate the impact of the selected factors from Chapter 5.2 on heating behaviour, questions on ownership structure, income and the building type were included in the survey. In addition, some questions were asked to enable a comparison of the heating periods of 2021-2022 and 2022-2023, the technical improvements available in the building (e.g. thermostats),

and the level of information that the respondents have about the possibilities of improvement the heating system. It is assumed that the average occupancy rate of the dwelling (i.e. the average number of days during which the dwelling was occupied or unoccupied, taking into account, for example, daily indoor and outdoor activities of household members and average holiday periods) did not change significantly between years. Long-term unoccupancy of the dwelling (e.g. long holidays) in any of the survey years is considered to be exceptional and its impact on the survey results is considered to be negligible.

The collected sample consists of 3872 responses with the following contribution: Germany 998, Greece 900, the Netherlands 1000 and Poland 974. It was aimed to keep the samples from each country at roughly the same size to ensure representativeness of the sample and to increase statistical power in the tests. Although the primary focus of the present study is on gas users and their behaviour, to allow for a comparison between gas and non-gas users, data from users of all heating energy sources were collected in the survey.

Respondents were asked to report the heating temperature during both heating periods and for the periods when someone was at home and when no one was at home. These temperatures were used to identify invalid responses. Temperature ranges between 15°C and 30°C for occupied dwellings and between 10°C and 30°C for unoccupied dwellings were considered plausible and therefore valid (see Arsad et al. 2023 for a review of temperature ranges for thermal comfort). In addition to the absolute value in each year, the inter-annual difference was used as a second criterion to remove invalid responses. Only the values between -5°C and 5°C were considered realistic and valid. Whenever the average heating temperature is mentioned in the results, it refers to the average of the heating temperatures of occupied and unoccupied periods. The analysis of the energy saving measures was based on binary data, i.e. if a measure was selected, it takes a value of 1, otherwise it would take a value of 0. The final dataset, after removing 27 speeders and 274 invalid responses (42 invalid responses for absolute temperature and 232 invalid responses for temperature difference), contains 3571 responses (DE: 925, GR: 814, NL: 915, PL: 917).

In addition to the descriptive analysis of the results, where appropriate, hypothesis tests were carried out using t-tests and chi-squared tests to examine the statistical significance of the effects. The main findings of these tests are presented in the results section and are used to formulate the policy recommendations. An overview of the statements tested and the detailed test results are presented in Table 5.13 - Table 5.24 in Chapter 5.7.3. The analysis and hypothesis tests were carried out at two levels: (i) at the aggregate level, without distinguishing between countries, and (ii) by differentiating between the four countries considered in this study. Where the results are at country level, this is indicated, otherwise the presented figures refer to the whole sample.

5.4. Results

5.4.1. Saving potentials derived from bottom-up modelling

In the baseline scenario, i.e. with no changes in indoor temperature levels, the total final energy demand for space heating and hot water in residential buildings in the EU-27 is around 2500 TWh, of which almost 900 TWh (36%) is accounted for by natural gas (see Figure 5.2).

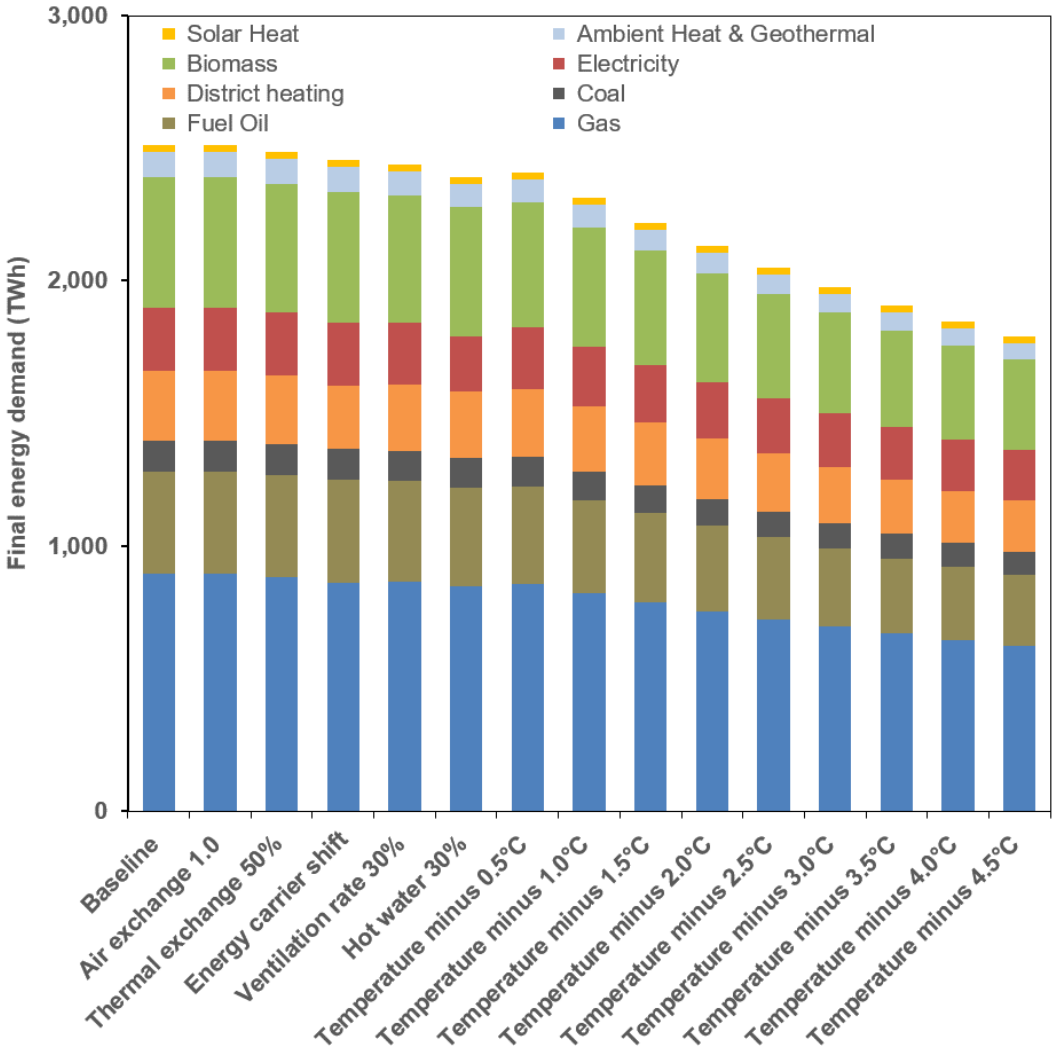

Figure 5.2: Final energy demand for space and water heating in different scenarios, EU-27

These results are in line with Eurostat (2023c), according to which households in the EU-27 consumed around 2200 TWh of energy for space heating and hot water in 2020, of which 850 TWh (39%) is accounted for by natural gas. In our model, space heating alone accounts for about 80% (2000 TWh) of this demand. Total energy demand can be reduced by 102 (4%) to 720 TWh (29%) in the 0.5°C and 4.5°C reduction scenarios, respectively. However, a 4.5°C reduction in indoor temperatures could be considered as a significant decrease in comfort. It is particularly important to consider households that are already unable to adequately heat their homes without the proposed measures. Nevertheless, this scenario shows the high saving potentials and the fact that high gas prices could force behavioural changes in at least part of the building stock. More realistically, final energy demand could be reduced by 199 TWh (8%) in the 1°C scenario and up to 292 TWh (12%) in the 1.5°C scenario. Correspondingly, natural gas demand could be reduced by 38 TWh (4%) in the 0.5°C scenario to 269 TWh (30%) in the 4.5°C scenario, with a saving potential of 74 TWh (8%) in the 1°C scenario and 108 TWh (12%) in the 1.5°C scenario. Furthermore, the reduction in energy demand does not follow a completely linear trend. The largest reductions in final energy demand were found between the baseline and the 0.5°C scenario (reduction of 102 TWh; 14% of total reduction potential), while the additional reductions between the 4°C and 4.5°C scenarios were only half as large (54 TWh; 8% of total reduction potential). The lowest reductions in final energy demand resulted from

the reduced air exchange scenario with a maximum saving potential of 0.06 TWh, followed by the reduced thermal exchange scenario with a total saving potential of 26 TWh, of which 10 TWh come from natural gas savings and a further 4 TWh from electricity and district heating savings. Improving ventilation behaviour leads to a total saving of 72 TWh, of which 43 TWh is from gas-related energy carriers (natural gas, district heating, electricity), and reducing hot water use leads to a potential saving of 121 TWh (46 TWh for natural gas, 29 TWh for electricity and 14 TWh for district heating). Shifting energy carriers leads to a reduction of 32 TWh for natural gas and 25 TWh for district heating, while the demand for solar heating increases by 0.7 TWh and for electricity by 1.1 TWh due to the electricity demand of heat pumps. A detailed overview of the results can be found in Table 5.8 in Chapter 5.7.1.

Looking at the four studied countries individually, the relative saving potentials for natural gas demand are highest in Greece with a reduction between 7% for the minus 0.5°C scenario and 50% for the minus 4.5°C scenario (see Figure 5.3). For the other countries, the saving potentials are quite similar for the low temperature reduction scenarios (e.g. between 3% and 5% for the minus 0.5°C scenario). Only for the higher temperature reduction scenarios (minus 2.0°C or more) the savings start to diverge between countries, but still remain in a similar range (e.g. between 24% and 31% for the minus 4.5°C scenario). The differences can mainly be explained by the different climatic conditions but are also related to the different effective indoor temperature levels in the baseline scenario and the different building stock constellations in each country. Poland shows the lowest saving potentials, followed by Germany and the Netherlands. For the EU-27 Member States combined, our models calculate saving potentials between 4% (minus 0.5°C scenario) and 28% (minus 4.5°C scenario), meaning that of the four countries studied, only Poland had a lower saving potential than the EU-27 average. One reason for the relatively strong effect of a 1°C temperature reduction in warmer countries such as Greece is that the average temperature difference between indoor and outdoor temperature over the heating season is lower than in colder climatic areas. Thus, by reducing the indoor temperature by 1°C, the relative decrease of the temperature difference between indoor and outdoor temperature in Greece is higher than in the colder countries.

Single-family houses (SFH) account for the majority of natural gas demand in the surveyed countries, with the exception of Greece, where 87% of the natural gas demand comes from multi-family houses as shown in Figure 5.4. For the EU-27, these shares are roughly equal, with 51% of natural gas demand coming from single-family houses and 49% from multi-family houses. The importance of the building categories for the impact of gas saving policies therefore appears to vary considerably between countries.

In 2022, Greek and Polish gas consumers experienced the highest (84%) and the lowest (29%) increases in energy prices respectively (Eurostat 2023k). The dotted lines in Figure 5.3 show the impact of the energy price increase as it occurred in the year 2022 on gas demand as estimated in the model Invert/EE-Lab (Müller 2015) and the underlying short-term price elasticity. The analysis reveals that, Greece again has the highest estimated saving (triggered by the 2022 price increase) of 10%. The estimated impact on price triggered savings for the other countries are in the range of the minus 0.5°C and minus 1.0°C scenarios, similar to Greece (PL: 3%, DE: 5%, NL: 5%). Further research is needed to gain insight into the price responses of different households in terms of energy consumption, which is beyond the scope of this study.

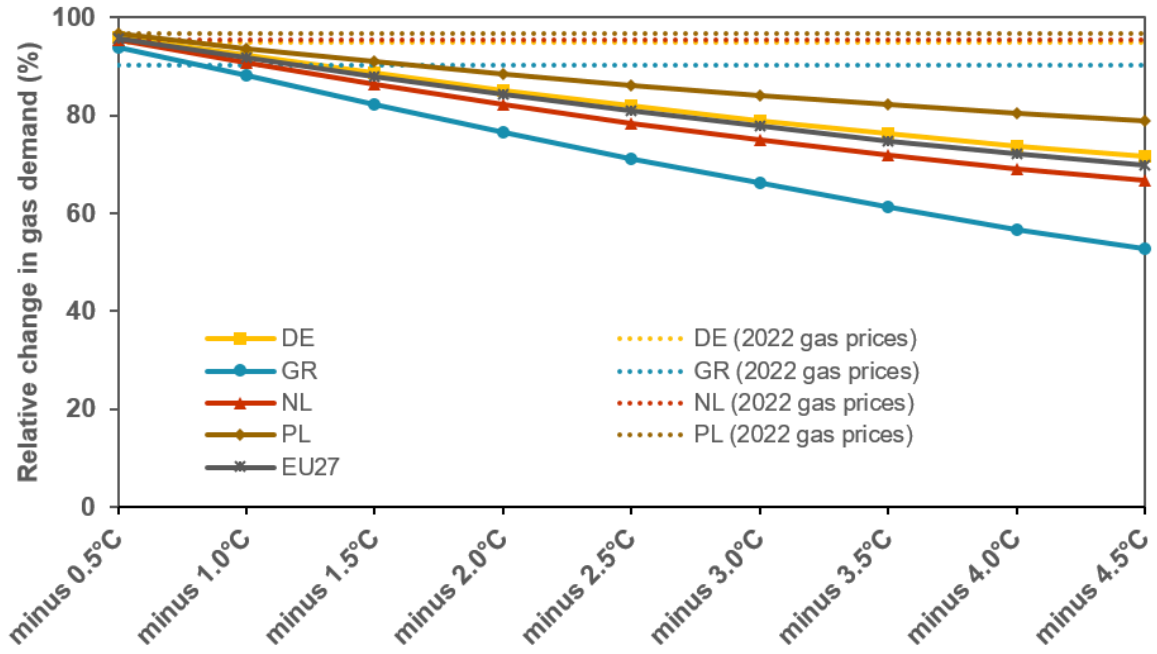

Figure 5.3: Relative changes in residential natural gas demand for space and water heating in different scenarios of indoor temperature (solid lines) and estimates of the impact of behavioural changes due to price increases (dotted lines)

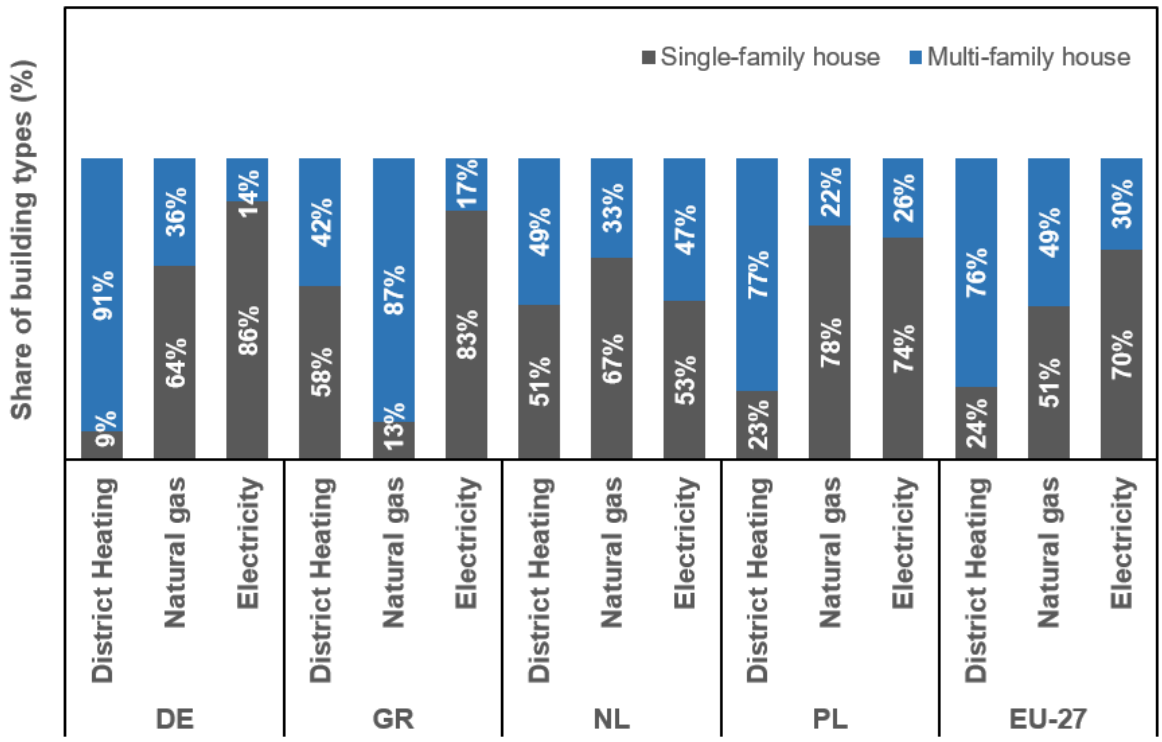

Figure 5.4: Share of building type in total final energy demand by energy carriers with high sensitivity to gas prices

5.4.2. Survey results and derived saving potentials

5.4.2.1. Socio-economic and building characteristics

The distribution of age groups among respondents varies from country to country. However, as the survey is addressed to the household as a whole (i.e. including all household members), the age of the respondent is not expected to influence the answers given. Residents living in all building age groups are represented in the sample. The quotas set for data collection in terms of building type, ownership structure and income (described in Chapter 5.3.3.2) were largely met (see Table 5.9 in Chapter 5.7.1), resulting in a maximum absolute deviation from official statistics of 7% (in only one case). For most groups there is a small deviation of up to 2% from the official statistics. The largest deviations are observed in Greece, where certain groups (e.g. low-income households living in rented single-family houses) proved difficult to reach. For building types and ownership structures, a negligible proportion of respondents fall into the "others" category. In the remainder of this section this category is not considered when presenting the results for these indicators. A detailed overview of the occupant and building characteristics of the survey sample is presented in Table 5.10 and Table 5.11 in Chapter 5.7.1.

5.4.2.2. Heating behaviour

Heating temperature

On average, the reported heating temperature in the heating period 2022-2023 is slightly lower than in the heating period 2021-2022 (Table 5.13). The stated indoor temperature decreased between the heating season 2021-2022 and the heating season 2022-2023 from 19.44°C to 19.16°C in Germany, from 19.02°C to 18.96°C in Greece, from 18.00°C to 17.70°C in the Netherlands and from 20.37°C to 20.20°C in Poland.

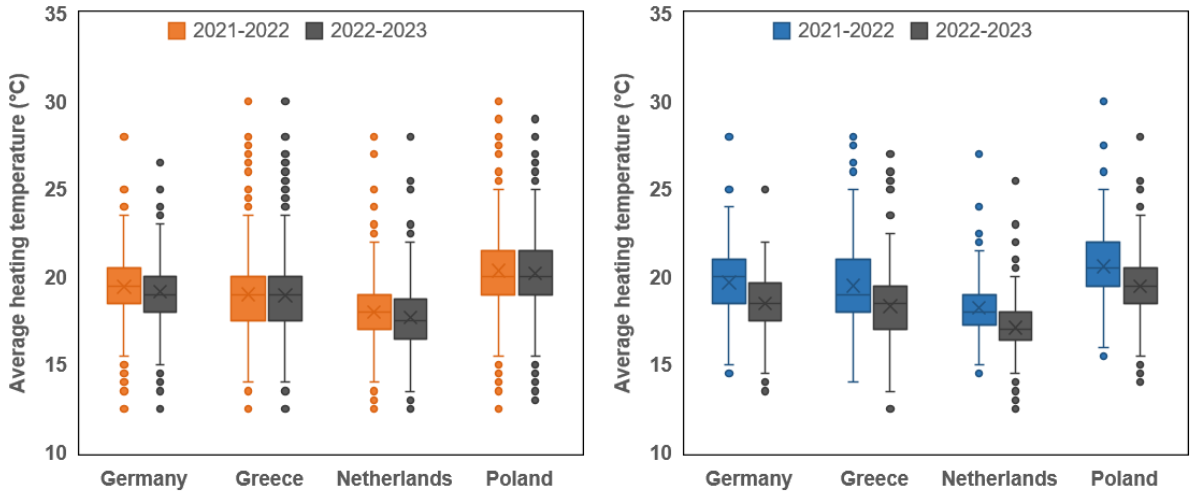

Figure 5.5: Distribution of the average heating temperature- left: all households, right: only households that reported a temperature reduction (in each diagram the box shows the middle 50% of the data, the line and the cross in each box indicate the median and mean, respectively).

These figures take into account all survey responses, those reporting a reduction in the heating temperature and those reporting either an increase or no change in average temperature between years. On average, slightly above 30% of respondents (DE: 33%, GR: 28%, NL: 34%,

PL: 30%) reported a reduction in their heating temperature compared to the previous year. If only this group is considered, the reduction in heating temperature is much higher (around 1.6°C) than if all observations are taken into account (see Figure 5.5).

Energy saving measures

To get an overview of the (non-technical) approaches followed by households to save energy, and also to identify changes in behaviour in this respect, respondents were asked whether they had taken certain measures during the last and current heating periods. The list included measures for reducing heat demand (e.g. shortening the heating period and reducing the heating hours, not using one or more rooms), lowering energy losses (e.g. keeping doors, windows, shutters and blinds closed) and compensating for heat demand by other means (e.g. wearing more clothes and using a blanket or hot-water bottle).

The overall picture of adopted approaches varies between countries, however, in 2021-2022 (Figure 5.6) keeping windows and doors closed is the most chosen approach in all surveyed countries, followed by not heating unused rooms (DE, NL, PL) and closing shutters and wearing more clothes (GR). Between 11% (DE, NL) and 21% (PL) of respondents did not take any energy saving measures. The results of the survey show an average increase of 24% in the number of energy saving measures applied by each household in the heating period 2022-2023 compared to the previous year (Figure 5.7).

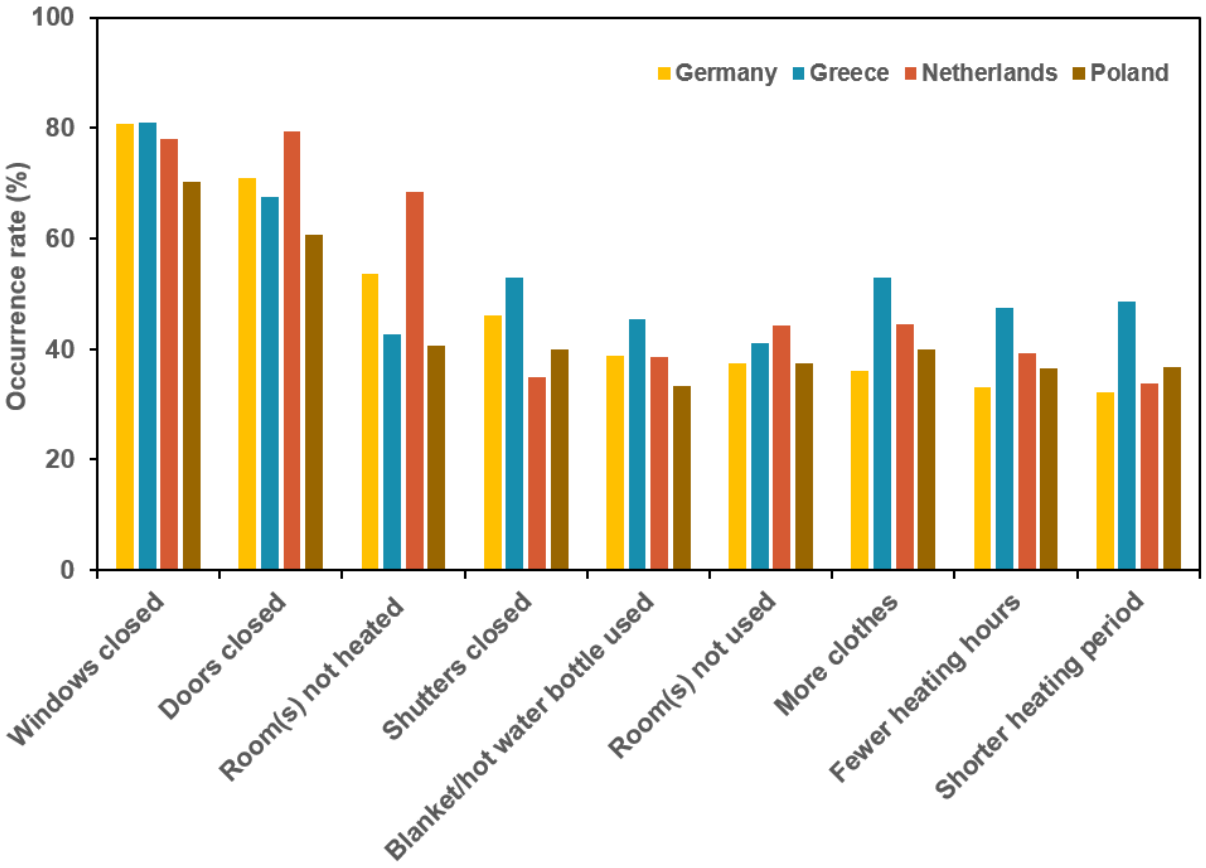

Figure 5.6: Overview of the stated adopted energy saving approaches in the heating period 2021-2022

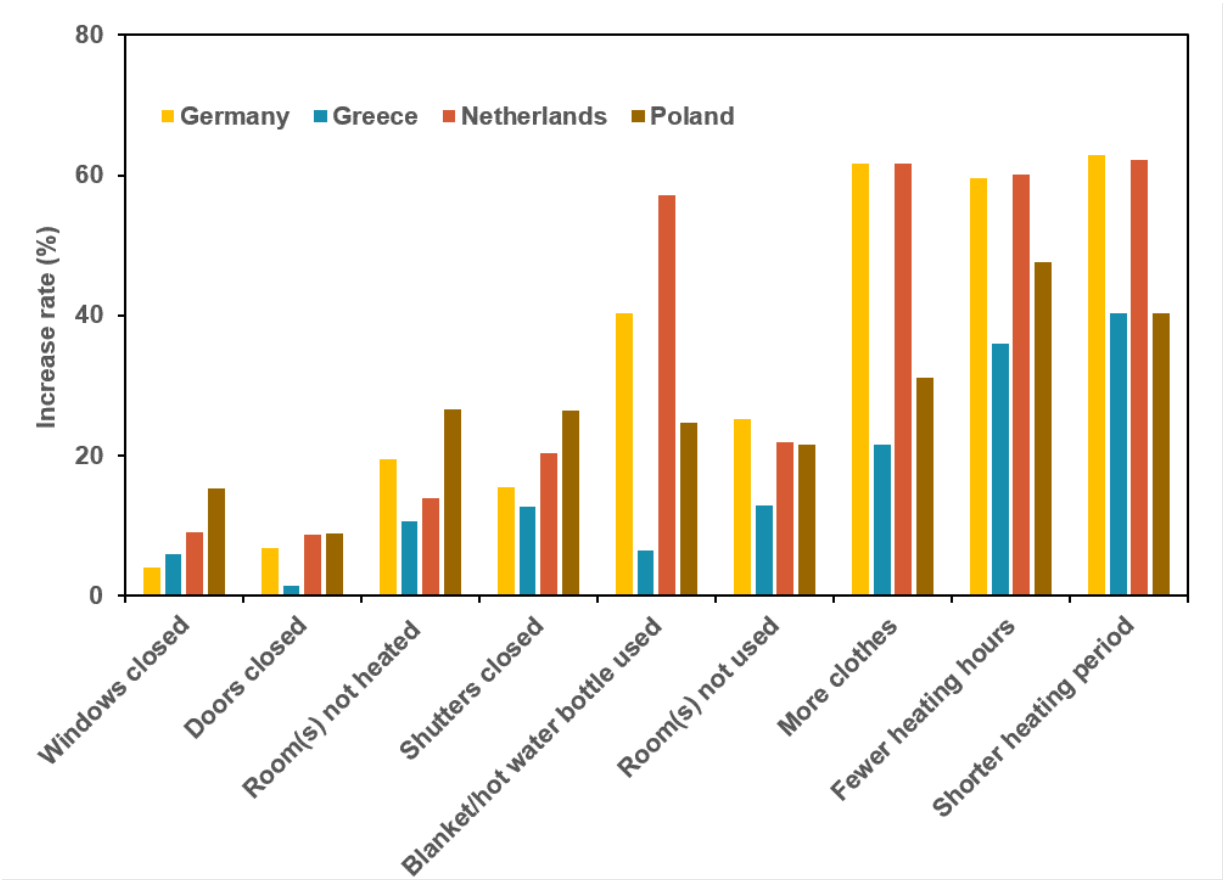

Figure 5.7: Increase in popularity of energy saving approaches in the heating period 2022-2023 compared to 2021-2022

Although the largest increase (around 30%) was reported in the Netherlands, certain measures received high attention in all countries in the current heating period compared to last year, namely: shortening the heating period, reducing the heating hours and wearing more clothes. In addition, the use of a blanket or hot-water bottle to save heating energy has increased between the years in Germany and the Netherlands.

In addition to these non-technical saving measures, the use of alternative (more efficient) heating systems was examined. This showed an average increase of 44% between years, with the lowest increase in Germany (35%) and the highest in Poland (58%).

Technical improvements

The technical ability to control the temperature of the heating system facilitates the implementation of the desired changes in heating temperature. For this reason, the survey asked respondents about the type of thermostat in their heating system and what improvements they had made between the two heating seasons, in terms of temperature control, e.g. switching from a manual thermostat to a programmable or smart thermostat. Figure 5.8 presents the results concerning the technical improvements in the surveyed countries.

Around a fifth of respondents (DE: 21%, GR: 18%, NL: 16%, PL: 22%) made a technical improvement e.g. by changing the thermostat before the 2022-2023 heating period. Of the remainder who did not make such a change, around two-thirds had no information about the possibility of such improvements - of these, on average 75% had not searched for information

and around 15% had not found any useful information despite searching - and a third had not made any improvements despite being aware of the possibilities. More than half of this group consider such changes to the controller to be either too expensive or not worth the potential energy savings. 10% do not have the time to consider such improvements. Among the other reasons given for not being informed about the possibilities for improvement or not implementing the changes despite being informed, the dominant one is that they are tenants and therefore have no influence on the decisions and actions, chosen by around 30% of respondents who selected this category.

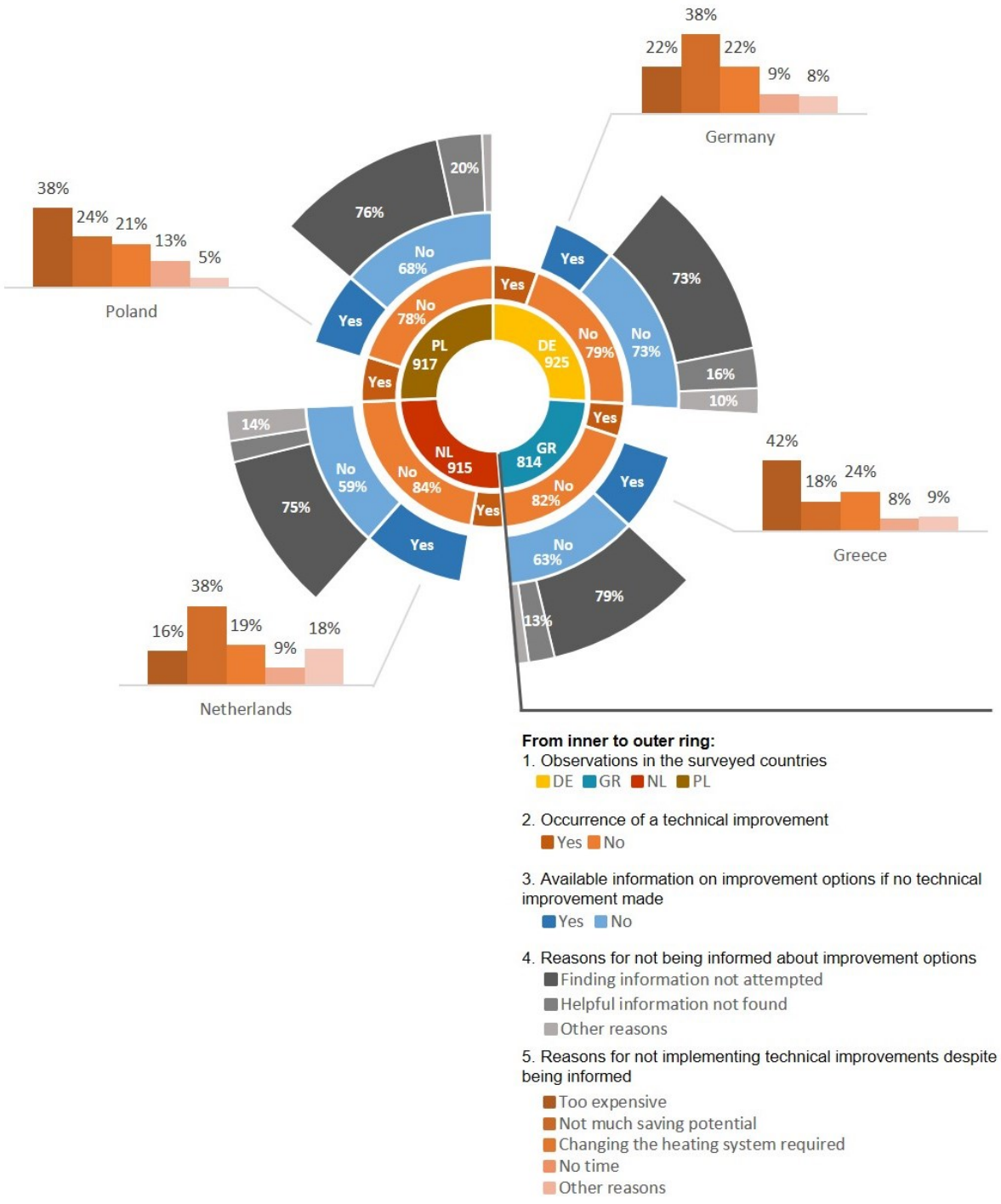

Figure 5.8: An overview of technical improvements in the studied countries between the two heating periods

5.4.2.3. Reasons for the adopted heating behaviour

Heating temperature

The type of energy carrier used by the household appears to have a statistically significant effect on the temperature reduction. In general, households using gas as an energy source reported a greater reduction in heating temperature than those using other energy sources. At country level, this trend seems to be general in at least three countries, Germany, Greece and the Netherlands, but not in Poland (Table 5.14). In addition, households in the countries with higher gas dependency (NL, DE) reported a higher reduction of the heating temperature compared to those with lower gas dependency (GR, PL) (Table 5.17). Looking at the ownership structure, the analysis shows that in all countries, a higher percentage of owners than tenants have reduced the heating temperature in the current heating period (Figure 5.9).

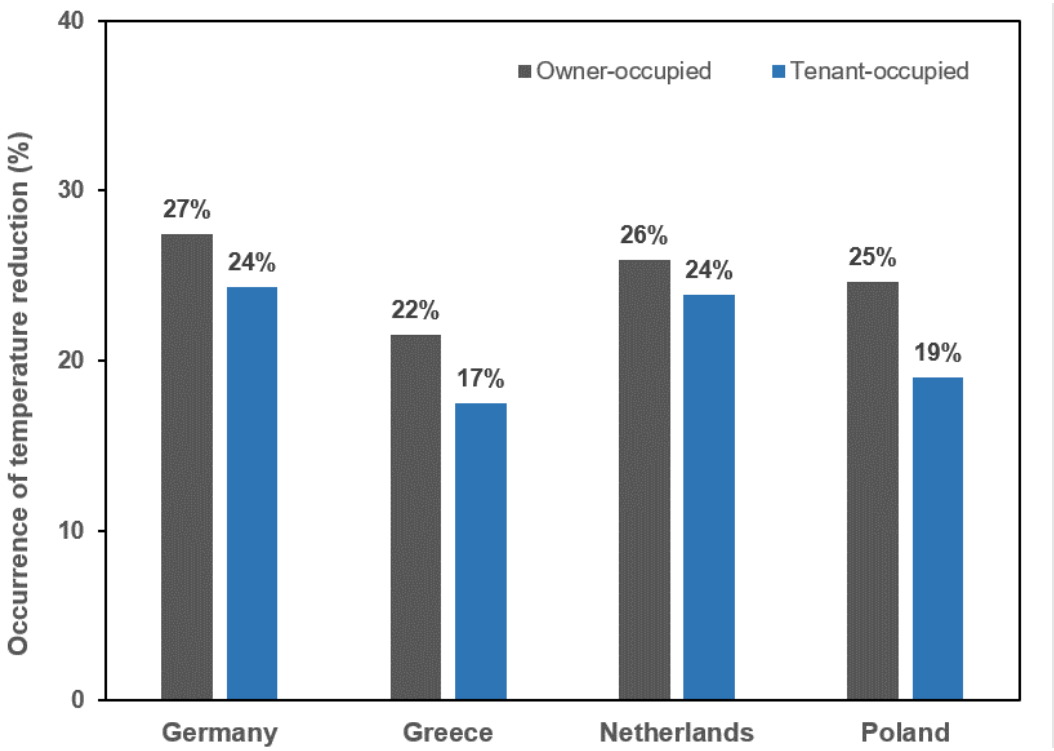

Figure 5.9: Occurrence of a heating temperature reduction by ownership structure

At the aggregated level, as well as at the country level, with the exception of Poland, tenant-occupied dwellings heat at a lower temperature on average and have reduced the heating temperature between years to a lesser extent than owner-occupied dwellings. Heating at a lower temperature is also reported in single-family dwellings in the whole sample and in the individual countries except for Germany (see Table 5.19 and Table 5.20). In both heating periods, the average heating temperature is directly related to the wealth of the household at the aggregated level (Figure 5.10). A similar trend can also be seen within individual countries, i.e. wealthier households tend to heat at a higher temperature. However, no relationship is observed between income level and temperature reduction (Table 5.16).

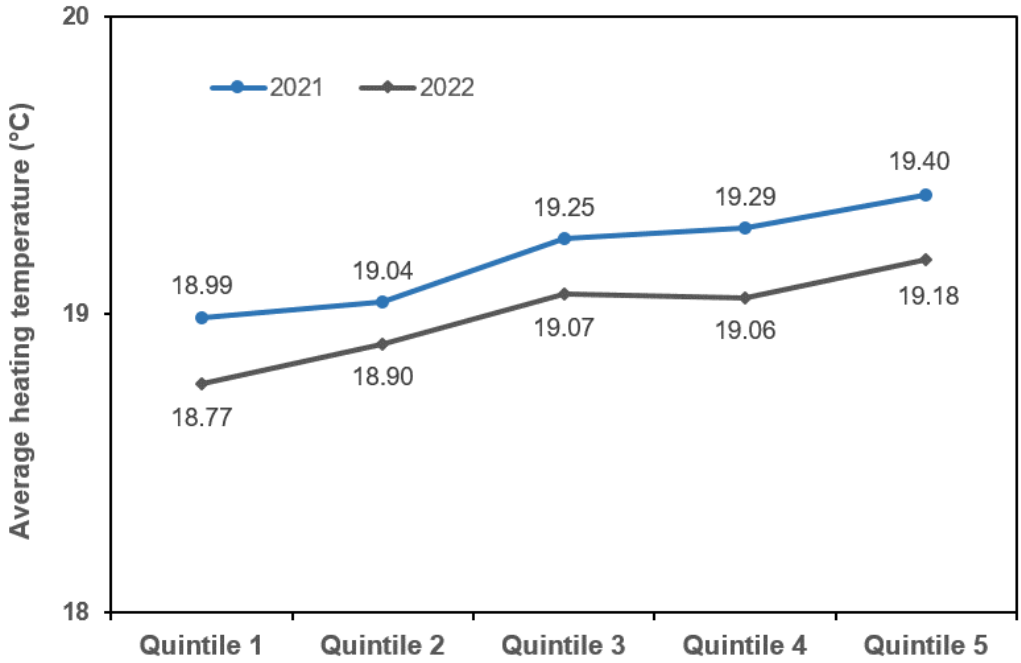

Figure 5.10: Average heating temperature by income level

Energy saving measures

The type of energy carrier does not seem to play a role in the absolute number of energy saving measures adopted by households in each heating period. However, even in this case, Germany and the Netherlands show a slightly larger increase in adopted energy saving measures in the heating period 2022-2023 compared to the previous year and compared to Greece and Poland (Figure 5.11). One possible explanation for this is the higher gas dependency of the first two countries, which could make consumer gas prices in these countries more vulnerable to external price shocks. In general, the overview of adopted energy saving measures in both heating periods shows that the occupants of single-family houses adopted slightly more of these measures. The same is true for rented dwellings (Table 5.3).

Table 5.3: Adopted energy saving measures by ownership structure and building type

Number of measures	Owner-occupied	Tenant-occupied	MFH	SFH
Average 2021-2022	4.34	4.48	4.23	4.54
Average 2022-2023	5.43	5.51	5.26	5.54
Added	1.09	1.03	1.03	1.00

However, no consistent trend could be observed at the country level with regard to building type and ownership. Looking at income level, low-income households (quintiles 1 and 2) already adopted a higher number of energy saving measures in the heating period 2021-2022 and had a lower increase in the number of adopted measures between the two heating periods compared to middle and high-income households (quintiles 3-5). Nevertheless, the trend is also observed in the current heating period at both the individual and aggregated levels, with the exception of Germany (Figure 5.12). It should be noted that the individual energy saving

measures are not directly comparable, especially in terms of costs and saving potentials, therefore a more detailed analysis of energy saving measures was not possible with the data collected for this paper.

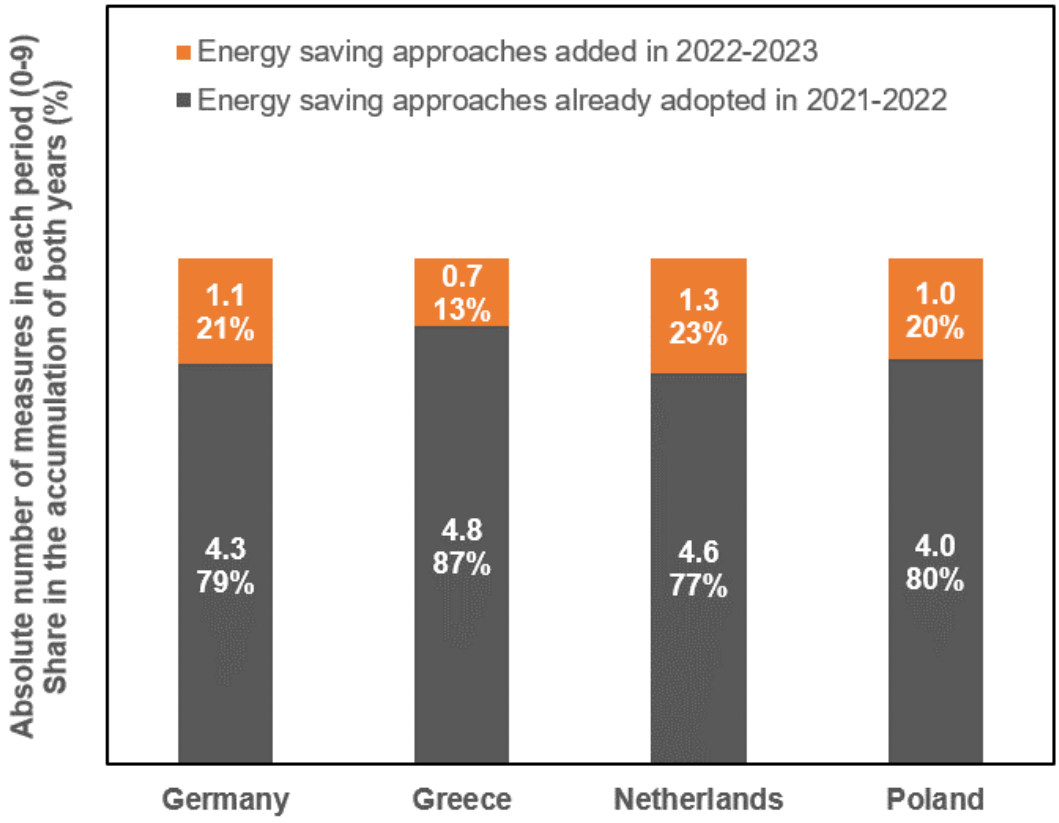

Figure 5.11: Overview of saving measures adopted (absolute values and relative increase between heating periods)

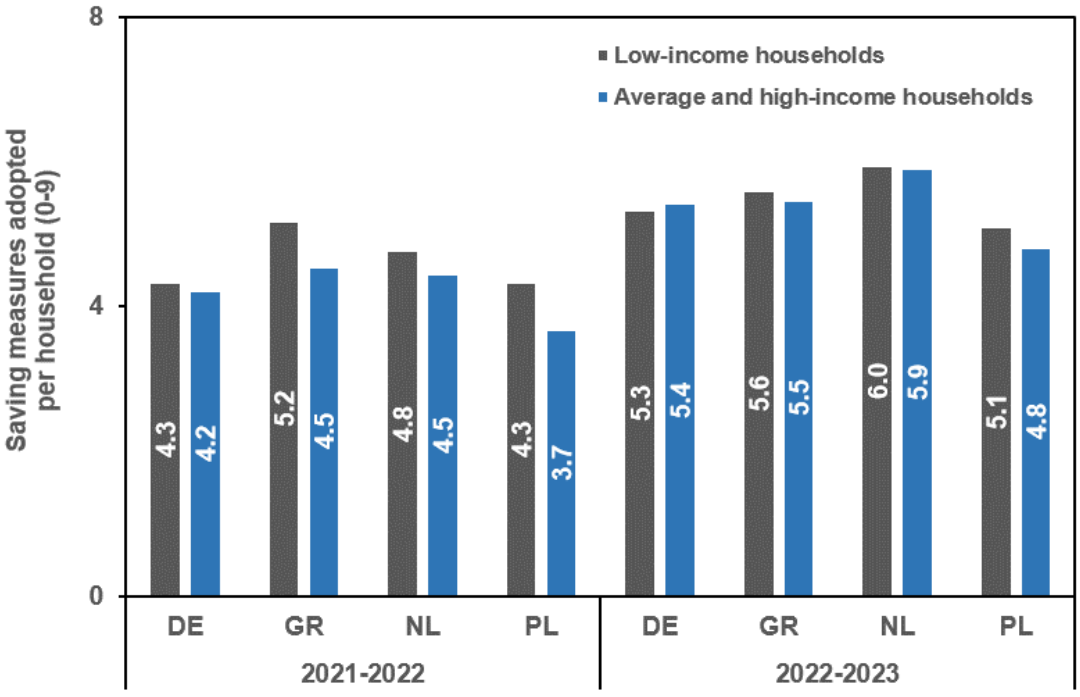

Figure 5.12: Overview of the adopted saving measures by income in each heating period

Technical improvements

According to the analysis, the type of energy carrier seems to have an influence on the occurrence of technical improvements. In all countries, dwellings heated by district heating are the least likely to have undergone technical improvements. In Germany, the Netherlands and Poland, wood is in second place. In these countries, households using electricity have (almost) the highest rate of technical improvements (Table 5.4). Focusing on gas, there is generally no statistically significant trend across countries when it comes to technical improvements undertaken by households using gas heating compared to the others (Table 5.24). Looking at countries individually, in Germany a higher proportion of households with gas heating made a technical improvement than households with other energy sources. Counterintuitively, the opposite trend was observed in the Netherlands. Within the total sample, technical improvements are more frequent in owner-occupied dwellings and also in single-family houses (Table 5.5). At country level, some of these associations were not statistically significant (Table 5.21 and Table 5.22). Regarding the financial situation, low-income households (quintiles 1 and 2) are less likely to invest in technical improvements than middle and high-income households (quintiles 3-5) in the whole sample. This trend is also observed in Germany and the Netherlands and is statistically significant (Table 5.23).

Table 5.4: Occurrence of technical improvements by energy carrier

Energy carrier	DE	GR	NL	PL
Coal				27%
District heating	10%	13%	3%	9%
Electricity	28%	15%	33%	46%
Gas	25%	21%	13%	25%
Gasoil		19%		
Heat pump	20%	22%	22%	35%
Solar			34%	
Oil	22%			
Wood/pellet	16%	19%	8%	19%

Table 5.5: Occurrence of technical improvements by ownership structure and building type (%)

	Owner-occupied	Tenant-occupied	MFH	SFH
Germany	24.5	18.1	19.2	24.0
Greece	20.1	14.0	16.9	20.5
Netherlands	17.7	10.9	14.5	16.0
Poland	22.3	17.6	14.2	28.4

5.4.3. Relationship between the studied factors and heating behaviour

Combining the results of the modelling (Chapter 5.4.1) and the survey (Chapter 5.4.2) for the countries studied, this Chapter summarises the relationships that could be identified between the studied factors and heating behaviour (Table 5.6). Statements on heating temperature and technical improvement have been made whenever the effect was statistically significant. The statement for energy prices comes from the modelling results, and for energy saving measures no statistical test was possible due to the nature of the data collected. Cells are blank where no clear relationship could be found. It should be noted that this table does not imply any causality between the studied factors (e.g. although larger temperature reductions are reported in the more gas-dependent countries (NL and DE), this does not mean that the reductions are only due to the choice of the energy carrier or its price, as other factors may influence the temperature reduction).

Table 5.6: Summary of the identified relationships between heating behaviour and selected factors (own illustration)

	Heating behaviour					
	Heating temperature		**Energy saving measures**		**Technical improvements**	
	Country level	**Aggregated**	**Country level**	**Aggregated**	**Country level**	**Aggregated**
Building type	-	SFH residents heat with a lower temperature compared to MFH residents (Table 5.19)	-	SFH residents slightly adopt more measures than MFH residents (Table 5.4)	-	SFH residents are more likely to invest in technical improvements than MFH residents (Table 5.22)
Energy carrier	Larger temperature reductions in gas using households in DE, GR, NL (Table 5.14); Larger temperature reductions in gas-dependent countries than in others (Table 5.17)	Larger temperature reduction reported in gas using households compared to the rest (Table 5.14)	Residents in countries with higher gas-dependency added relatively more energy saving measures between the years than the other countries (Figure 5.11)	-	Least technical improvements in district heating (Table 5.4); In DE more improvements are made by gas users, in NL the opposite trend is observed (Table 5.24)	-
Ownership structure	Only in DE tenants heat at a lower average temperature than owners (Table 5.20)	Tenants heat at a lower average temperature than owners (Table 5.20)	-	Tenants adopted slightly more saving measures than owners (Table 5.4)	Owner-occupied households in DE, GR, NL are more likely to invest in technical improvements compared to the tenant-occupied ones (Table 5.21)	Owner-occupied households are more likely to invest in technical improvements compared to the tenant-occupied ones (Table 5.21)

Income level	Wealthier households in DE, NL and PL tend to heat at a higher temperature than lower income households (Table 5.15)	Wealthier households tend to heat at a higher temperature than lower income households (Table 5.15)	Number of saving measures followed in each period is inversely related to income (except for DE in 2022) (Figure 5.12)	Number of saving measures followed in each period is inversely related to income (Figure 5.12)	In DE and NL, average to high-income households are more likely to invest in technical improvements than low-income households (Table 5.23)	-
Energy price	Higher increase in energy prices results in higher energy savings.					

5.5. Discussion

5.5.1. Comparative analysis of saving potentials: model vs. survey and policy targets

Combining the results of the survey with the saving potential calculated by the modelling exercise, it is possible to reflect on the achievability of the demand reduction targets set by the EU following the Russian invasion of Ukraine in early 2022. Around 30% of households in the sample report having reduced their average heating temperature in the heating period 2022-2023 compared to the previous year. The figure for Germany (33%) corresponds to the reported willingness to reduce the temperature before the start of the current heating period (Dena 2022). However, the average temperature reduction of around 0.3°C reported in Germany would only lead to a reduction in gas demand in the residential sector of around 2.5%. The same applies to the other countries (GR: 3.5%, NL: 2.8%, PL: 2.0%).

Nevertheless, the study points to a change in heating behaviour as a possible effect of the gas crisis following the war in Ukraine. At the micro level, it is observed that households using gas as an energy source report a higher temperature decrease than the others. Similarly, at the macro level, a larger temperature decrease is observed in the countries with higher gas dependency (DE and NL). Moreover, the increase in energy saving measures in the heating period 2022-2023, especially in the gas-dependent countries, may indicate a reaction to the energy crisis. Although the actual change in energy prices varied between countries, with the highest increase in the months immediately following the Russian invasion, similar changes in behaviour were observed in all the surveyed countries. Therefore, lowering the temperature and following the energy saving measures could be the result of both a real increase in the energy bill and the perception of higher gas prices conveyed by the media. In contrast to the experience before the energy crisis (Sovacool et al. 2021), the use of more clothes to save heating energy increased by more than 60% in gas-dependent countries compared to the last heating period. However, this may be a short-term measure, possibly influenced by fears of a possible gas shortage or the actual increased prices. Transforming such short-term behavioural changes into sustainable long-term practices is key to achieving demand reduction targets. This will require a range of policy instruments, for which further evidence from the survey may also be relevant.

The main reason given for not making technical improvements such as changing the thermostat is the financial burden. However, in the Southern and Eastern European countries surveyed (GR and PL), the direct and immediate costs of such a change have the greatest negative impact,

while in the Western European countries surveyed (DE and NL) the focus is on the saving potential and the payback period. Generally, Germany and the Netherlands show similar heating behaviour in terms of technical improvements and energy saving measures. The same applies to Greece and Poland. Taking this into account, experience from one country could be used for policy recommendations in the other.

Between 50-70% of the respondents (DE: 53%, GR: 50%, NL: 72%, PL: 58%) reported the measured heating temperature, in other cases the reported temperature was estimated. The ability to measure the temperature (e.g. using a thermometer or smart thermostat) could be associated with better control and possibly reduction of the temperature, however, there was no statistically significant difference between the reported reduction of the heating temperature for those who estimated and those who measured (Table 5.18). It is also not surprising that even before the energy crisis, low-income households had already adopted many energy saving measures and were less likely to invest in technical improvements than the other income groups, possibly due to lower disposable income. Considering that already in 2021 on average 6.5% of households in the studied countries were not able to keep their dwellings adequately warm (from 2.4% in NL to 17.5% in GR) (Eurostat 2023n), this income group already has a very low gas demand and therefore cannot be expected to make a large additional contribution to gas demand reduction by lowering the heating temperature.

Policy instruments to address rising energy prices were already provided by EU regulators in 2021, as wholesale electricity prices in the EU and many other regions increased by 200% to an annual basis, due to increased global demand (European Commission 2021a). Less than two weeks after the Russian invasion of Ukraine, the European Commission and the Council of the European Union initiated a series of interrelated communications, regulatory proposals, recommendations and regulations aimed at reducing dependence on Russian fossil fuels, reducing EU gas demand and protecting households and economy from excessively high gas prices (Table 5.7).

Table 5.7: EU-level policy instruments addressing the reduction of gas demand and prices in 2021-2022

Date	Reference	Policy instrument	Policy document type
13 October 2021	(European Commission 2021a)	"Tackling rising energy prices: a toolbox for action and support"	Communication
8 March 2022	(European Commission 2022c)	Outline of "REPowerEU: joint EU action for more affordable, secure, and sustainable energy"	Communication
23 March 2022	(European Commission 2022a)	Commission proposal to amend the Security of Gas Supply Regulation and a Communication: "Security of supply and affordable energy prices: Options for immediate measures for next winter"	Regulation proposal, Communication
18 May 2022	(European Commission 2022b)	The Commission REPowerEU Plan to rapidly reduce dependence on Russian fossil fuels	Communication, Regulation proposal, Recommendation

5 August 2022	(Council of the European Union 2022a)	Regulation (EU) 2022/1369 on coordinated demand-reduction measures for gas	Regulation
22 December 2022	(Council of the European Union 2022b)	Regulation (EU) 2022/2578 establishing a market correction mechanism to protect Union citizens and the economy against excessively high prices	Regulation

The data collected in the present study suggests that the behavioural changes of building occupants investigated in this study, such as lowering the indoor temperature, are unlikely to make a significant contribution to the EU policy target for gas savings through behavioural change, i.e. 13 bcm of natural gas saved (European Commission 2022b). We can speculate on the reasons for the gap between the energy saving targets set by policy and the weak energy savings observed in this paper and in the literature. One reason could be poor implementation of the proposed policies. Another possible reason for not meeting the targets could be poor design of the measures in the first place or an overestimation of the savings potential of measures designed to appeal to individual behaviour changes.

On the one hand, policy responses to the urgent need to reduce gas demand for space and water heating in the EU were not closely coordinated, as the EU-level regulation only provided a list of exemplary measures that could be implemented by Member States (Article 6 of Council Regulation 2022/1369). No clear targets, timetables and budgets were set for behaviour change campaigns (Council of the European Union 2022a, 2022b; European Commission 2022a, 2022b, 2021a, 2022c;). In Germany, the national energy saving campaign was not successful in achieving the national government's target of a 20% reduction in gas consumption (Kurmayer 2022; Sorge 2023). In Finland, the *Down a degree* programme, which aimed to reduce indoor temperatures also ran an awareness campaign (Astetta Alemmas Campaign 2022). In Sweden, households were encouraged to decrease their electricity consumption in order to reduce gas consumption in power plants (Energimyndigheten 2022).

On the other hand, Germany, the Netherlands, and Poland introduced retail price caps for gas consumption in the residential sector (Federal Ministry for Economic Affairs and Climate Action 2022; Sejm of the Republic of Poland 2022; Government of the Netherlands 2023). Greece introduced a subsidy per unit of gas consumed by households (Kathimerini 2022). While these policy instruments aimed to minimise increases in gas bills for the most vulnerable consumers, such measures blunted the price signals that play an important role in promoting behavioural changes towards reducing energy demand (van Dender et al. 2022).

5.5.2. Reflection on policy implications

According to the modelling results for the EU-27 countries, a 0.5°C reduction in indoor temperature leads to a 4% decrease in gas demand for residential space and water heating. A 1.0°C reduction lowers gas demand by about 8%. The impact is higher under warmer climatic conditions and depends on the mix of buildings and the uptake of the measure in different building types. It suggests that achieving the 15% gas demand reduction target by only lowering the indoor temperature would require heating with on average 2°C lower temperatures. Indoor temperature requirements for thermal comfort in winter vary between 15 and 21°C across the EU, with the lower and upper limits reported in only one country and most of the remaining

countries in the 19-20°C range (Brelih 2013). However, the average heating temperature in residential buildings in the EU is over 22°C (European Commission & International Energy Agency 2022), which is about 3°C higher than the average heating temperature recorded in the survey, which may indicate some social desirability bias in the survey responses. The 2°C reduction needed to meet the targets would require the surveyed households to heat at an average temperature of 17.2°C, which is around the minimum recommended room temperature in Germany (Lee et al. 2022; UBA 2022). Considering that the reported average temperature in the surveyed countries is already quite low compared to the EU average, further lowering the temperature may cause health issues as living in cold rooms can lead to various illnesses, sleep disorders or depression (World Health Organization 2018). Nevertheless, the survey found only an average temperature reduction of 0.3°C when comparing the heating period 2022-2023 with the previous year, which is much lower than the assumed reduction potential.

The observed decrease in EU gas consumption in the building sector in 2022 is partly due to the climatic conditions and the mild winter, leading to a decrease in the number of heating degree days compared to 2021 (IEA 2023b). Changes in heating behaviour as a result of the war in Ukraine might also have played a role. About 6% of the decrease in EU gas consumption between 2019 and 2022 and 7-11% of the gas savings in the German building sector in 2022 are attributed to changes in heating behaviour (Enerdata 2023; Expertenrat für Klimafragen 2023). However, this effect is expected to be temporary, stimulated or forced by the war in Ukraine and higher energy prices.

Improving thermostats could help achieve the goal of heating at a lower temperature by making it easier to control the temperature. A large proportion of respondents (around two-thirds) who had not improved the way they control the temperature between the heating periods report that they had no information about this option. Although this was partly (around 75%) because they had not looked for information, around 15% could not find any helpful information despite trying. Lack of time was also cited as a barrier to such changes. Technical improvements, such as upgrading thermostats, could be better promoted and facilitated by offering all-in-one packages that include consultation and information on the available options, installation of the chosen technology and after-sales service. This could be included in the annual inspection of the heating system and offered by the responsible companies.

High costs and long payback periods were compelling enough reasons for more than half of the survey respondents not to make technical improvements despite having the information. Therefore, measures involving financial support in various forms could be provided to overcome the financial barriers to the acquisition of technical improvements. The higher rate of technical improvements reported in the single-family and owner-occupied dwellings, as well as in the more affluent families, points to the role of socio-economic factors in setting the priority for investment in such technical changes, and may also indicate the existence of a landlord-tenant dilemma regarding investment in household infrastructure improvements. Tailored measures targeting specific groups such as tenants and low-income households, could therefore be useful to reach a larger population.

The reported higher temperature reduction and the greater increase in the number of adapted measures in Germany and the Netherlands, the two more gas-dependent countries, compared to the other surveyed countries, might indicate the (mental) impact of the energy crisis on heating behaviour and the need for information campaigns (as also studied by e.g. Corbos et al. 2023 and OECD 2023). Presumably, this is partly due to the sharp rise in energy prices and

the fear of not being able to pay heating bills in the coming winter (IEA 2023b), and partly due to the anticipation of gas shortages. In both cases, there is an incentive to change behaviour towards lower consumption (a pure price incentive in the first case and a longer-term incentive to save resources in the second). Hence, information campaigns could be an effective way of raising public awareness of the long-term scarcity of resources and the importance of reducing energy consumption, as well as the economic and environmental impact of reducing energy consumption. However, to achieve greater savings, such information policy instruments aimed at the general public could be complemented by detailed, tailor-made information, e.g. through direct feedback on energy consumption patterns (Ek et al. 2010; Ellegård et al. 2011). The resulting awareness of energy consumption seems to have a positive effect on changes in heating behaviour, i.e. lower heating temperatures and better control of heating (see Newman et al. 1975; Groot et al. 2006; Lindén et al. 2006) and to lead to energy savings of different ranges depending on the strategy used (Zangheri et al. 2019). The role of digitalisation in providing immediate and detailed feedback on energy consumption (e.g. installation of gas meters) could be promoted to support demand response efforts for the grid as well as to monitor consumer's own consumption.

Changes in heating behaviour in response to energy price increases are discussed in several studies (e.g. Wilhite et al. 1996; Day et al. 2009) and confirmed by the sensitivity analysis in this paper. Thus, well-designed fiscal measures could be another effective way to stimulate energy savings. As also suggested by Koasidis et al. (2022) in their study on monetising behaviour changes, lower consumption could be encouraged through financial incentives and rewarded with bonuses. An example of such incentives is the concept of feed-in tariff for energy savings (i.e., the users receive a financial incentive for each energy unit they save), whose potential characteristics and impact was already explored a decade ago (see Bertoldi et al. 2013 and Eyre 2013). On the other hand, high-consumers could be induced to reduce consumption through progressive prices and additional taxes, bearing in mind that only small tax increases may not lead to immediate responses in energy consumption (Ott et al. 2022). However the level of taxation should be carefully defined to achieve the desired demand reduction, while avoiding unintended energy poverty in the less affluent households (Bertoldi 2022). In the long-term, vulnerable consumers could be also protected through targeted policies (e.g. direct transfers) rather than price caps and consumption-based subsidies.

5.5.3. Limitations and future work

We have selected a set of countries based on the factors considered relevant for the scope of this paper (see Chapter 5.3.2). However, due to the diversity of countries and their energy systems within the EU, the study does not claim to cover a fully representative set of countries. Similar studies should be repeated in other countries, taking into account other aspects and dimensions, in order to get a complete picture of the situation in the EU.

The nature of the data collection method for the survey imposes some limitations on the conclusions that can be drawn from this study. The survey responses relate to self-reported behaviour rather than observed behaviour. In addition, as the survey asks for information on past behaviour, some social desirability bias cannot be excluded. Furthermore, gender perspective was not considered in this study, as the focus of the survey was primarily on household heating behaviour. Future research should consider gender as a variable of analysis to explore how the gender of the respondents may influence the results.

Due to the different underlying characteristics (such as climatic conditions, social, economic, and demographic characteristics) of the studied countries, a direct comparison of temperature differences between countries is not necessarily very enlightening. However, these temperature differences, can be interpreted within each country. Moreover, according to the analysis in this paper, the location of the respondents (country) has a greater effect on the results than socio-demographic factors (e.g. income, age). Therefore, a similar study with more observations in each country is recommended for a more detailed cross-country analysis.

The impact of building energy performance and dwelling size on the effective indoor temperature used in the modelling is derived from empirical data for Germany (see literature quoted in Chapter 5.3.3.1, Loga et al. 2003 and Loga et al. 2022). A detailed analysis of the extent to which the derived functions are valid for other countries within Europe could not be carried out within the scope of this paper and is left for further research.

Finally, a direct comparison between the modelling and survey results could be misleading without taking into account the limitations of the data used. The modelling results were calculated with climatic data for 2019 while the survey was conducted in the heating periods 2021-2022 and 2022-2023. However, while the heating degree days in 2022 were significantly lower than in 2021, they did not deviate much from the 2015-2019 average (Eurostat 2023b), allowing for at least some comparability. At EU-27 level, the number of heating degree days in 2022 was about 4% lower than the 2015-2019 average. This differed from country to country. For example, in Belgium, the Netherlands and Germany the number of heating degree days was 92% (Belgium) and 95% (Germany) of the average, while in Poland and the Baltic states the number of heating degree days was about 2 to 5% higher than the average. In terms of demographics and building characteristics, the survey data largely matches the input data used for modelling. As explained in Chapter 5.4.2.1, the survey sample is broadly representative of the population of the studied countries, at least in terms of building type, ownership and income. The input data used for modelling is also based on official statistics. As the survey refers to the year 2022-2023 and the model uses data from the base year, there may be some differences between the two datasets simply due to the evolution of the building stock and demographics, but we do not expect a major change within only a few years. Therefore, the fact that both datasets are representative of the countries allows for some comparability.

5.6. Conclusion

The present research is a case study to investigate the effectiveness of the measures recommended by the European Commission (e.g. REPowerEU) and the Council of the European Union (e.g. Council Regulation (EU) 2022/1369) in achieving the policy targets set by the EU or the Member States. The study focuses on gas demand and the EU target to reduce it by 15% in Member States between 1 August 2022 and 31 March 2023, compared to the average for the same period in the previous five years. Due to the high share of the residential sector in EU gas demand, this sector is expected to make a large contribution to energy savings. Using modelling and survey approaches in four selected European countries, the paper examines the energy savings in this sector resulting from changes in heating behaviour with a particular focus on reducing heating temperatures. The survey was conducted in Germany, Greece, the Netherlands and Poland and examined the changes in household heating behaviour between the 2021-2022 and 2022-2023 heating periods in three aspects: heating temperature reduction, energy saving measures (e.g. not heating unoccupied rooms) and technical improvements (e.g. replacing manual thermostats with programmable ones).

The observations of the whole sample (N=3571) showed an average temperature reduction of 0.2°C between years, from 19.2°C to 19.0°C. This corresponds to a 2-3.5% reduction in gas demand of the studied countries. Overall, around 30% of respondents reported a reduction in their heating temperature. The energy saving measures covered in the survey included the ones aimed at reducing heat demand, lowering energy losses and compensating for heat demand by other means. The most commonly reported measure in 2021-2022 was keeping doors and windows closed. There was an average increase of 24% between years, so that in 2022-2023 the most common practices were: shortening the heating period, reducing the heating hours and wearing more clothes. On average, 20% of respondents have made a technical improvement to better control the heating temperature. Two-thirds of the remainder had no information on the possibilities for such an improvement.

The study also looked at the impact of selected building characteristics and socio-economic factors on changes in heating behaviour. Households using gas as an energy source reported a greater reduction in heating temperature than those using other energy sources. Occupants of single-family houses heat at lower temperatures and are more likely to invest in technical improvements than occupants of multi-family houses. While tenants heat at a lower average temperature than owner-occupiers, they are less likely to invest in technical improvements. Wealthier households tend to heat at higher temperatures and take fewer measures to save energy. Analyses were carried out at the aggregate and country levels. Respondents in the gas-dependent countries (DE and NL) reported higher temperature reductions and added more energy saving measures compared to the other countries.

The paper recognises that individual measures may not be sufficient to achieve the EU targets. Furthermore, the observed behavioural changes leading to reduced energy consumptions may be a temporary effect of unexpected circumstances, such as high energy prices or geopolitical situations. Hence, to maximise the impact of such measures and to facilitate the transformation of these short-term responses into long-term behaviour, they need to be designed in conjunction with other measures and as part of a policy package. We therefore recommend a number of policy measures to encourage and facilitate reductions in heating energy consumption. These include (i) promoting technical improvements, such as the upgrading of thermostats, by providing financial and technical support (e.g. all-in-one packages providing consultation, installation and after-sales services), (ii) raising public awareness of the need to reduce consumption in the face of resource scarcity, while motivating energy savings through the provision of detailed and tailored information (e.g. direct feedback on consumption patterns) and (iii) using financial incentives in the form of bonus schemes to reward lower consumption or as progressive prices or additional taxes to penalise higher consumption.

5.7. Appendices

5.7.1. Appendix A: Summary tables

Table 5.8: Summary of the modelling results: Final energy demand in TWh for the EU-27 countries as well as the four surveyed countries Germany, Greece, Netherlands and Poland for all model scenarios. Total final energy demand is shown in the same row as the scenario names and additionally the final energy demand of some selected energy carriers (gas, district heating and electricity) is listed for each scenario.

	EU-27 [TWh]	Germany [TWh]	Greece [TWh]	Netherlands [TWh]	Poland [TWh]
Baseline	**2 511**	**558**	**39**	**96**	**224**
Gas	894	271	5	72	30
District heating	263	45	0	4	51
Electricity	239	24	2	10	16
Air exchange 1.0	**2 511**	**558**	**39**	**96**	**224**
Gas	894	271	5	72	30
District heating	263	45	0	4	51
Electricity	239	24	2	10	16
Thermal exchange 50%	**2 485**	**554**	**39**	**95**	**221**
Gas	884	269	5	71	30
District heating	260	45	0	4	50
Electricity	237	24	2	10	16
Secondary heating	**2 456**	**553**	**38**	**93**	**219**
Gas	862	268	5	70	29
District heating	238	44	0	3	49
Electricity	240	24	2	10	15
Ventilation rate 30%	**2 439**	**539**	**39**	**93**	**217**
Gas	868	261	5	69	29
District heating	252	43	0	4	48
Electricity	234	24	2	9	16
Hot water 30%	**2 389**	**534**	**37**	**90**	**215**
Gas	848	259	4	68	29
District heating	249	43	0	4	49
Electricity	209	22	2	8	14
Temperature minus 0.5°C	**2 409**	**537**	**37**	**91**	**216**
Gas	857	260	5	68	29
District heating	254	44	0	4	49
Electricity	232	24	2	9	15
Temperature minus 1.0°C	**2 312**	**516**	**34**	**87**	**209**
Gas	821	250	4	65	28
District heating	245	42	0	4	48
Electricity	225	23	2	9	15
Temperature minus 1.5°C	**2 220**	**496**	**32**	**83**	**202**

Gas	786	240	4	62	27
District heating	236	40	0	3	46
Electricity	219	22	2	9	15
Temperature minus 2.0°C	**2 132**	**477**	**30**	**79**	**196**
Gas	754	231	4	59	27
District heating	228	39	0	3	44
Electricity	213	22	2	8	14
Temperature minus 2.5°C	**2 051**	**459**	**29**	**76**	**190**
Gas	723	222	3	56	26
District heating	220	37	0	3	43
Electricity	208	21	2	8	14
Temperature minus 3.0°C	**1 976**	**443**	**27**	**72**	**185**
Gas	695	214	3	54	25
District heating	212	36	0	3	41
Electricity	203	20	2	8	14
Temperature minus 3.5°C	**1 907**	**428**	**26**	**69**	**180**
Gas	669	207	3	51	25
District heating	205	34	0	3	40
Electricity	198	20	2	8	13
Temperature minus 4.0°C	**1 845**	**415**	**25**	**67**	**176**
Gas	645	200	3	49	24
District heating	198	33	0	3	39
Electricity	194	20	2	7	13
Temperature minus 4.5°C	**1 791**	**403**	**23**	**65**	**172**
Gas	625	194	3	48	24
District heating	192	32	0	3	38
Electricity	191	19	2	7	13

Table 5.9: Comparison of survey data with Official statistics (the figures in the column official statistics are own calculations based on Eurostat 2023d for building type and Eurostat 2023e for ownership structure and income groups

		Official statistics				**Survey data**			
		DE	**GR**	**NL**	**PL**	**DE**	**GR**	**NL**	**PL**
Building type	SFH	41%	41%	75%	56%	43%	34%	75%	52%
	MFH	56%	59%	21%	44%	57%	66%	24%	48%
Ownership structure	Owner	51%	74%	69%	86%	51%	69%	70%	85%
	Tenant	49%	26%	31%	14%	49%	29%	30%	14%
Income groups	Quantile 1	20%	20%	20%	20%	19%	14%	20%	17%
	Quantile 2	20%	20%	20%	20%	19%	21%	21%	21%

	Quantile 3	20%	20%	20%	20%	20%	22%	20%	21%
	Quantile 4	20%	20%	20%	20%	21%	19%	21%	21%
	Quantile 5	20%	20%	20%	20%	20%	24%	19%	21%

Table 5.10: Summary of the survey sample: Occupant-related characteristics

		Germany	**Greece**	**Netherlands**	**Poland**
Observations		925	814	915	917
Age of respondents	18 - 25	3.9%	8.0%	3.2%	11.8%
	26 - 35	12.6%	20.5%	12.5%	30.0%
	36 - 45	21.0%	32.3%	15.3%	24.1%
	46 - 55	16.5%	2.8%	22.3%	6.2%
	56 - 65	21.9%	25.8%	20.1%	18.4%
	Above 65	24.0%	10.6%	26.7%	9.5%
Ownership structure	Owner	50.8%	69.2%	69.8%	84.6%
	Tenant	49.1%	28.9%	30.2%	14.3%
	Others	0.1%	2.0%	0.0%	1.1%
Income groups	Quantile 1	19.4%	13.9%	19.5%	17.1%
	Quantile 2	19.2%	21.3%	20.7%	20.6%
	Quantile 3	19.8%	22.4%	20.2%	20.6%
	Quantile 4	21.2%	18.9%	20.5%	20.6%
	Quantile 5	20.4%	23.6%	19.1%	21.0%
Household size	1	21.4%	11.4%	19.6%	12.6%
(Number of people living in the household)	2	42.5%	26.5%	45.4%	24.8%
	3	20.4%	29.7%	15.1%	30.3%
	4	12.0%	24.4%	15.0%	20.5%
	5	2.8%	6.1%	4.2%	8.2%
	6 or more	0.9%	1.7%	0.9%	3.6%

Table 5.11: Summary of the survey sample: Building-related characteristics

		Germany	Greece	Netherlands	Poland
Observations		925	814	915	917
Year of construction	< 1945	12.8%	1.5%	9.8%	9.7%
	1945 - 1969	21.4%	9.1%	15.2%	14.5%
	1970 - 1979	19.5%	20.8%	18.5%	18.5%
	1980 - 1989	14.8%	20.9%	19.1%	16.0%
	1990 - 1999	12.5%	16.5%	12.1%	11.8%
	2000 - 2010	9.7%	26.3%	13.9%	13.4%
	2010 - 2020	7.6%	4.8%	8.4%	13.7%
	> 2020	1.7%	0.2%	3.0%	2.3%
Building type	Single-family house	42.8%	34.2%	75.2%	51.8%
	Multi-family house	57.0%	65.5%	24.2%	47.8%
	Others	0.2%	0.4%	0.7%	0.4%
Heating type	Individual heating	22.6%	33.3%	16.8%	23.7%
	Central heating	62.5%	18.6%	63.0%	68.2%
	Single-story heating	9.0%	46.3%	18.8%	5.6%
	No info	5.9%	1.8%	1.4%	2.6%
Energy carrier	Coal	0.3%	0.2%	0.2%	19.8%
	District heating	16.1%	2.0%	6.7%	28.9%
	Electricity	4.2%	22.4%	9.2%	4.3%
	Gas	52.5%	23.2%	72.1%	27.6%
	Gasoil	0.5%	39.1%	0.1%	0.9%
	Heat pump	4.4%	2.2%	3.5%	3.7%
	Solar	0.2%	0.2%	3.5%	0.3%
	Oil	16.3%	0.9%	0.3%	0.8%
	Wood/pellet	3.5%	7.9%	2.6%	13.4%
	Others/ no info	1.8%	2.0%	1.7%	0.3%

5.7.2. Appendix B: Statistically tested statements

Table 5.12: Overview of the statistically tested statements

ID	Description	Test
H1	The average heating temperature in the heating period 2022-2023 is lower than that of 2021-2022	paired t-test
H2	Households using gas as an energy carrier, show a higher heating temperature reduction than households using other energy carriers	two-sample t-test with equal variances assumed
H3	Low-income households (quintiles 1 and 2) heat with a lower temperature compared to the average and high-income households (quintiles 3-5)	two-sample t-test with equal variances assumed
H4	Low-income households (quintiles 1 and 2) have reduced their heating temperature more than the average and high-income households (quintiles 3-5)	two-sample t-test with equal variances assumed
H5	Households in the countries with higher gas dependency (NL, DE) performed a higher heating temperature reduction compared to the ones with lower gas dependency (GR, PL)	two-sample t-test with equal variances assumed
H6	Households in which data was estimated have reported a higher temperature reduction than the households in which data was measured	two-sample t-test with equal variances assumed
H7	Households in SFH heat with a lower temperature compared to the households in MFH	two-sample t-test with equal variances assumed
H8	Owner-occupied households heat with a higher temperature compared to the tenant-occupied households	two-sample t-test with equal variances assumed
H9	Technical improvements occur more often in owner-occupied households	Chi-squared test
H10	Technical improvements occur more often in single-family houses	Chi-squared test
H11	High-income households (quintiles 3-5) are more likely to invest in the technical improvement than the low-income households (quantiles 1 and 2)	Chi-squared test
H12	Energy carrier has an influence on the occurrence of technical improvements (gas vs. other energy carriers)	Chi-squared test

5.7.3. Appendix C: Results of statistical hypothesis testing

Table 5.13: H1- The average heating temperature in the heating period 2022-2023 is lower than that of 2021-2022. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N	Mean heating temperature 2022-2023 (°C)	Mean heating temperature 2021-2022 (°C)	Difference (°C)	t	df	p
All countries	3571	19.00	19.21	0.20	12.77	3570	0.00
Germany	925	19.16	19.44	0.27	9.44	924	0.00
Greece	814	18.96	19.02	0.06	1.55	813	0.12
Netherlands	915	17.70	18.00	0.30	10.52	914	0.00
Poland	917	20.20	20.37	0.16	5.26	916	0.00

Table 5.14: H2 - Households using gas as an energy carrier, show a higher heating temperature reduction than households using other energy carriers. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_gas	N_other	Mean heating temperature reduction (gas heating households) (°C)	Mean heating temperature reduction (households using other heating) (°C)	Difference (°C)	t	df	p
All countries	1588	1983	0.34	0.12	-0.21	-5.65	3569	0.00
Germany	486	439	0.32	0.14	-0.18	-2.73	923	0.01
Greece	189	625	0.29	0.01	-0.29	-2.63	812	0.01
Netherlands	660	255	0.45	0.24	-0.21	-2.60	913	0.00
Poland	253	664	0.12	0.17	0.05	0.68	915	0.49

Table 5.15: H3 - Low-income households (quintiles 1 and 2) heat with a lower temperature compared to the average and high-income households (quintiles 3-5). "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_ Q1,Q2	N_ Q3-Q5	Mean heating temperature, Q1,Q2 (°C)	Mean heating temperature, Q3-Q5 (°C)	Difference (°C)	t	df	p
2021-2022								
All countries	1356	2215	19.01	19.34	0.33	4.31	3569	0.00
Germany	357	568	19.27	19.54	0.27	2.21	923	0.01
Greece	286	528	18.97	19.04	0.08	0.42	812	0.34
Netherlands	367	548	17.73	18.18	0.45	4.00	913	0.00
Poland	346	571	20.13	20.51	0.38	2.67	915	0.00
2022-2023								
All countries	1356	2215	18.82	19.12	0.30	3.85	3569	0.00
Germany	357	568	19.00	19.27	0.27	2.17	923	0.02
Greece	286	528	18.90	18.99	0.08	0.46	812	0.32
Netherlands	367	548	17.48	17.85	0.37	3.17	913	0.00
Poland	346	571	20.01	20.32	0.31	2.16	915	0.02

Table 5.16: H4 - Low-income households (quintile 1 and 2) have reduced their heating temperature more than the average and high-income households (quintile 3-5). "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" associated p-score.

	N_Q1,Q2	N_Q3-Q5	Mean heating temperature reduction, Q1,Q2 (°C)	Mean heating temperature reduction, Q3-Q5 (°C)	Difference (°C)	t	df	p
All countries	1356	2215	0.22	0.18	0.03	1.00	3569	0.31

Table 5.17: H5 - Households in the countries with higher gas dependency (NL, DE) performed a higher heating temperature reduction compared to the ones with lower gas dependency (GR, PL). "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_ DE,NL	N_ GR,PL	Mean heating temperature reduction, DE,NL (°C)	Mean heating temperature reduction, GR,PL (°C)	Difference (°C)	t	df	p
All countries	1840	1731	0.29	0.11	-0.17	-5.39	3569	0.00

Table 5.18: H6 - Households in which data was estimated have reported a higher temperature reduction than the households in which data was measured. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_ measured	N_ estimated	Mean heating temperature reduction (if temperature measured) (°C)	Mean heating temperature reduction (if temperature estimated) (°C)	Difference (°C)	t	df	p
All countries	1914	1294	0.20	0.17	0.31	0.94	3206	0.34

Table 5.19: H7 - Households in SFH heat with a lower temperature compared to the households in MFH. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_SFH	N_MFH	Mean heating temperature _SFH (°C)	Mean heating temperature _MFH (°C)	Difference (°C)	t	df	p
2022-2023								
All countries	1837	1719	18.83	19.20	0.37	4.93	3554	0.00
Germany	396	527	19.34	19.03	0.32	2.56	921	0.06
Greece	278	533	18.81	19.05	-0.23	-1.29	809	0.10
Netherlands	688	221	17.62	17.93	-0.32	-2.39	907	0.01
Poland	475	438	20.17	20.23	-0.06	-0.43	911	0.33
2021-2022								
All countries	1837	1719	19.05	19.39	0.34	4.55	3554	0.00
Germany	396	527	19.62	19.30	0.32	2.62	921	0.00
Greece	278	533	18.83	19.13	-0.30	-1.62	809	0.05
Netherlands	688	221	17.95	18.12	-0.17	-1.28	907	0.10
Poland	475	438	20.29	20.44	-0.15	-1.10	911	0.13

Table 5.20: H8 - Owner-occupied households heat with a higher temperature compared to the tenant-occupied households. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_owner	N_tenant	Mean heating temperature (owner) (°C)	Mean heating temperature (tenant) (°C)	Difference (°C)	t	df	p
2022-2023								
All countries	2448	1096	19.11	18.78	0.32	4.01	3552	0.00
Germany	470	454	19.36	18.95	0.42	3.42	922	0.00
Greece	563	235	19.00	18.86	0.14	0.73	796	0.23

Netherlands	639	276	17.72	17.65	0.08	0.63	913	0.26
Poland	776	131	20.16	20.46	-0.29	-0.43	905	0.33
2021-2022								
All countries	2448	1096	19.32	18.95	0.37	4.61	3542	0.00
Germany	470	454	19.65	19.21	0.43	3.62	922	0.00
Greece	563	235	19.10	18.83	0.28	1.42	796	0.08
Netherlands	639	276	18.03	17.93	0.10	0.81	913	0.21
Poland	776	131	20.36	20.45	-0.09	-0.47	905	0.32

Table 5.21: H9 - Technical improvements occur more often in owner-occupied households. “Chi2” denotes the Chi2 statistic of the hypothesis test, “df” the associated degrees of freedom, “p” the associated p-score.

	N	N_owner	N_tenant	Percentage of home-owners who made technical improvements	Percentage of tenants who made technical improvements	Chi2	df	p
All countries	3544	2448	1096	20.99	15.33	15.65	1	0.00
Germany	924	470	454	24.46	18.06	5.65	1	0.02
Greece	798	563	235	20.07	14.04	4.03	1	0.05
Netherlands	915	639	276	17.68	10.87	6.78	1	0.01
Poland	907	776	131	22.30	17.56	1.49	1	0.22

Table 5.22: H10 - Technical improvements occur more often in single-family houses. “Chi2” denotes the Chi2 statistic of the hypothesis test, “df” the associated degrees of freedom, “p” the associated p-score.

	N	N_MFH	N_SFH	Percentage of MFH residents who made technical improvements	Percentage of SFH residents who made technical improvements	Chi2	df	p
All countries	3556	1719	1837	16.57	21.61	14.50	1	0.00
Germany	923	527	396	19.16	23.98	3.15	1	0.07
Greece	811	533	278	16.88	20.50	1.61	1	0.20
Netherlands	909	221	688	14.48	15.98	0.29	1	0.59
Poland	913	438	475	14.15	28.42	27.41	1	0.00

Table 5.23: H11 - High-income households (quintiles 3-5) are more likely to invest in the technical improvement than the low-income households (quantiles 1 and 2). “Chi2” denotes the Chi2 statistic of the hypothesis test, “df” the associated degrees of freedom, “p” the associated p-score.

	N_	N_	Percentage of households in	Percentage of households in	Chi2	df	p

	Q1,Q2	Q3-Q5	Q1,Q2 who have invested in technical improvements	Q3-Q5 who have invested in technical improvements			
All countries	1356	2215	18.36	19.68	0.95	1	0.94
Germany	357	568	18.49	23.06	2.74	1	0.01
Greece	286	528	20.63	16.67	1.97	1	0.16
Netherlands	367	548	12.26	17.88	5.27	1	0.02
Poland	346	571	22.83	20.84	0.51	1	0.48

Table 5.24: H12 - Energy carrier has an influence on the occurrence of technical improvements (gas vs. other energy carriers). "Chi2" denotes the Chi2 statistic of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_gas heating	N_other heating	Percentage of households using gas heating that have invested in technical improvements	Percentage of households using other heating that have invested in technical improvements	Chi2	df	p
All countries	1588	1983	19.45	18.96	0.114	1	0.71
Germany	486	439	24.60	17.53	7.03	1	0.01
Greece	189	625	21.16	17.12	1.60	1	0.21
Netherlands	660	255	13.18	21.96	10.75	1	0.00
Poland	253	664	24.50	20.48	1.75	1	0.19

5.8. Supplementary material

Supplementary data to this chapter (survey questions and model parameters) can be found at: https://doi.org/10.1016/j.enbuild.2024.114257.

6. Implementing housing policies for a sufficient lifestyle[6]

Abstract: The German buildings sector is currently facing a double challenge: meeting emission reduction targets and providing affordable housing in rapidly growing cities. Living space per person has a major impact on the household energy consumption and has increased significantly in recent decades. On the one hand, new construction increases the demand for often energy-intensive building materials, and on the other hand, energy demand during the use phase of buildings is positively related to the size of the space. Optimising the allocation of living space therefore offers great potential for addressing both challenges. Sufficiency policies such as flat exchanges, moving bonus and moving advice aim to reduce the total floor area in the housing sector by using existing space more efficiently. However, the effectiveness of such measures is not yet fully understood. As the sufficiency approach relies heavily on the individual choices, residents' involvement, perception and acceptance are crucial for the success of such measures. An investigation in selected German housing companies shows that the potential of these measures is not fully exploited under the current political and social framework in Germany. Social acceptance and new norms and business models are needed for the effective use of these measures.

Policy relevance: How effective is the implementation of sufficiency measures for space utilisation in the German rental housing sector? The success factors and limiting barriers of the measures along with the acceptability and effectiveness of these measures are investigated by interviewing housing companies (some of them social housing providers) that have the potential to implement such policies in their housing stock. Improvements are needed in the social and technical infrastructure to increase the effectiveness of the measures. Raising awareness, rethinking communications and designing effective financial incentives are recommended to make the measures attractive to the public. Involving all stakeholders, keeping the issue on the political agenda and engaging in dialogue with policymakers are considered effective steps in the process of achieving space sufficiency in the housing sector.

[6] This chapter has been submitted to the Journal Buildings and Cities as Bagheri, Mahsa; Roth, Linda; Siebke, Leila; Rohde, Clemens; Linke, Hans-Joachim (2024): Implementing housing policies for a sufficient lifestyle. In: Buildings and Cities, 5(1), DOI: https://doi.org/10.5334/bc.435.

CRediT authorship contribution statement: Mahsa Bagheri: Conceptualisation, Methodology, Data collection, Data analysis, Writing – Original Draft; Linda Roth: Data collection, Data analysis; Leila Siebke: Resources, Writing – Original Draft; Clemens Rohde: Methodology, Writing - Review & Editing; Hans-Joachim Linke: Methodology, Writing - Review & Editing

6.1. Introduction

Human well-being is already threatened by climate change and will be increasingly so in the future (Gough 2020). Achieving the goal of keeping global warming well below 2°C, as part of the legally binding Paris Agreement, requires rapid and deep cuts in greenhouse gas (GHG) emissions. The latest report of the Intergovernmental Panel on Climate Change (IPCC) states that much additional effort will be needed to achieve the climate goals (IPCC 2022b). The main drivers of climate change are increasing total and per capita consumption of energy, land and other resources, which pose concrete challenges to global and local environmental sustainability. This trend is the result of global urban development, characterised in its structure, institutions and household behaviour and trends such as sprawl, spread, expansion of large technical systems and growing populations (Jin 2017). Previous studies have linked energy consumption to human well-being (Burke 2020). For instance, a recent meta-analysis investigated the threshold of rising energy consumption beyond which it no longer correlates with increasing human well-being. Overall, the results suggest that European energy consumption has reached such a threshold where increased consumption no longer implies increased well-being (Gynther 2021).

The German buildings sector fails to meet its environmental targets (Umweltbundesamt 2020). It is responsible for high resource consumption, typically accounting for 30% of the country's final energy demand (Dena 2019) and 14% of total energy-related emissions (Sach et al. 2021). To achieve climate neutrality in the buildings sector by 2045, a goal set by the German government (Federal Climate Change Act 2021), CO_2 equivalent emissions must be reduced by 8.57 million tonnes annually from 2022 (Breidenbach et al. 2021). Energy use in the buildings sector includes the energy required to construct and operate buildings, which depends on factors such as the need for new buildings, room temperatures or the size of the heated space. Ellsworth-Krebs (2020) argues that the size of houses is the most important determinant of household energy consumption, and hence the global increase in per capita floor space is a problematic trend. Bierwirth et al. (2019) estimate that the available savings from reducing the current per capita living space in Germany from 46.6 to 35 to 30 m^2 would result in a theoretical saving potential of 378 547 to 541 361 TJ, representing a reduction in space heating energy of 24.9-35.7%.

Over time, many techno-economic measures have been implemented to improve energy efficiency, such as the thermal building regulation, resulting in increased energy efficiency and reduced energy consumption of buildings. However, measures that address the human desire to consume more are scarce and summarised under sufficiency policies. Sufficiency policies are ‘a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human well-being for all within planetary boundaries’ (IPCC 2022b, p. 31). The concept of sufficiency is based on the idea that there is a point of enough consumption where human needs are met and that this point should not be exceeded (Princen 2005). Sufficiency in the buildings sector not only decreases emissions, but also positively influences many dimensions of well-being and sustainable development such as health, social cohesion, and economic sustainability (Wronski 2023; Hayden et al. 2022).

In addition to the long-known environmental impacts, there are several social issues in the housing sector related to the availability of adequate living space and energy costs. First, there is a mismatch in the housing market, with people living in dwellings that they perceive as too large (Gavrilis 2019), while young families urgently seek larger dwellings (Breidenbach et al.

2021). In 2018, only 47.4% of households in German metropolitan areas had access to suitable large and affordable housing and 34.5% of this shortage could be solved by an optimal distribution of existing housing (Holm et al. 2021). Second, rising gas prices, which are a burden on households (BDEW 2022), make it even more urgent to reduce the use of gas, which, accounts for 44.3% of space heating in Germany based on 2019 data (statista 2021). While 8.1% of the German population was unable to heat their homes adequately due to energy poverty in 2023 (Eurostat 2023m), this figure is expected to rise with energy prices, putting an increasing number of German households at risk of being affected by rising energy prices. This underlines the importance of reducing household energy consumption (Breidenbach et al. 2021).

While Germany has set a target of less than 30 ha of new soil sealing per day (Deutscher Bundestag 2021), 400 000 new homes are to be built each year to meet the need for affordable housing in many German cities. Currently, the sealed area for housing and transport is the fastest growing land use in Germany, increasing by 18.1% (7964 additional km^2) between 2000 and 2022 (Umweltbundesamt 2024b). This is associated with negative impacts such as loss of agricultural land, fragmentation of wildlife habitats, material and energy consumption for construction and maintenance of additional buildings and infrastructure, increased traffic with higher fuel consumption, and increased pollutants and noise (Umweltbundesamt 2024a). Intensifying the use of existing buildings and sealed land in built-up areas is one way to meet the demand for new housing in growing regions while reducing pressure on currently undeveloped areas. This can be achieved by making better use of existing densification potential in urban areas (Breidenbach et al. 2021).

Increasing urbanisation is leading to regional imbalances in the availability of living space. Specifically, some regions have a structural housing shortage, while others have many vacant dwellings. In Germany, the average living space per person has increased from 14 m^2 in 1950 (Friedrich-Ebert-Stiftung 1997) and 34.8 m^2 in 1990 (iwd 2020) to 47.7 m^2 in 2021 (Umweltbundesamt 2023b). If this trend continues, living space per person will reach 52 m^2 by 2030 (iwd 2020). There are many reasons for this development, such as the increasing number of one- and two-person households, the lack of small dwellings (Friedrich-Ebert-Stiftung 1997) and the remanence effect. In 2022, around three-fourths of German households consisted of only one person (41%) or two persons (34%) (Umweltbundesamt 2023a). One and two-person households have a higher per capita living space than larger households (Umweltbundesamt 2023b). The figures for 2018 are 68 m^2 for one-person households, 49 m^2 for two-person households and 33 m^2 for households with three or more persons. While there were around 17 million one-person households in Germany in 2022, only 2.5 million dwellings were smaller than 40 m^2 (Destatis 2024). In 2021, the average size of newly built dwellings was around 74 m^2 in multi-family houses and 145 m^2 in single-family houses (Destatis 2021). The remanence effect describes the tendency of shrinking families to remain in their large dwellings (Umweltbundesamt 2023b). This means that older people often live alone in (possibly non-accessible) oversized flats, which can lead to problems in the housing market, especially in dense residential areas (Fischer et al. 2016). A total of 20-50% of older people with a per capita living space of over 80 m^2 feel that their living space is too large (Kenkmann et al. 2019). However, the cost of moving (Kenkmann et al. 2019) and rising rents may make it financially attractive for them to stay in their large homes (Gavrilis 2019).

The great potential and importance of well-designed energy sufficiency policies for achieving climate and sustainability goals has been recognised by the IPCC (2022b), Faber et al. (2012)

and (Samadi et al. 2017). However, they are rarely considered as an option for achieving climate goals of the EU Member States (Zell-Ziegler et al. 2021b). Sufficiency is often perceived as complex (Zell-Ziegler et al. 2018), especially compared with technical emission-reduction options such as efficiency and renewable energy policies. Furthermore, the impacts, feasibility, and acceptability of sufficiency policies have not been fully explored. In particular, as they rely directly on individual choices, the social perspective plays an important role. Thus, policymakers and citizens still lack guidance to make informed choices for sufficiency policies, despite a growing scientific base (Akenji et al. 2019; Creutzig et al. 2022; Vita et al. 2019b).

Against this background, the paper investigates the effectiveness of such policies in optimising the use of living space (Figure 6.1). It focuses on selected policies from the Sufficiency Policy Database (Best et al. 2022) that directly address residential space use, and examines their perceptions and acceptability, as well as their limiting barriers and success factors, through qualitative analysis of semi-structured interviews with selected German housing companies. The study explores the lessons that can be learnt for better policy design in the housing sector.

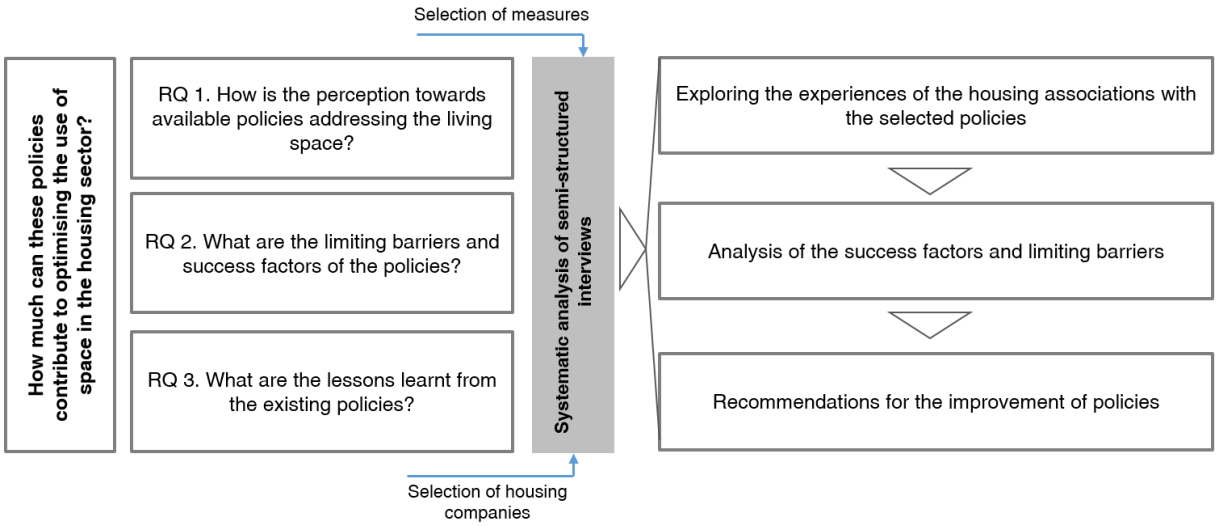

Figure 6.1: Research design of the study on examining sufficiency policies

6.2. Methods

6.2.1. Context of the study

More than half of German households live in rented accommodation (Eurostat 2021) and more than a third of rental housing is owned and managed by professional owners, including private housing companies, public authorities, housing cooperatives and non-profit organisations (Savills 2019). With access to a large number of rental dwellings, housing companies have the technical capacity to implement innovative approaches and plans to help balance the availability of living spaces and reduce the housing shortage. Therefore, they are considered to be important stakeholders in promoting such sufficiency policies and were selected as interviewees for this study.

6.2.2. Selected housing companies

In order to select the potential housing companies for the interviews, a list of all companies in the field of Real estate leasing and rentals (N=10 971) was first extracted from a company

database provided by Dun & Bradstreet-Corporation. From these, only those companies in Germany with more than one employee and dealing with private dwellings whose contact details were available in the database were filtered out (N=718). In the next step, the location of the company and the number of rental apartments owned or managed by it were used as two criteria to narrow down the list further. This was done in two parallel steps. The number of apartments available in the companies' stock was considered to be an important factor in the degree of flexibility of the companies to implement different measures. Therefore, the database was extended to include data on this indicator, extracted from the companies' websites. This data was publicly available for 148 companies. For the second criterion (location), two indicators were considered, namely: Growth potential and Housing shortage. In shrinking cities, the population moves out of the city and gradually more housing becomes available for rent, whereas in growing cities the demand for housing is constantly increasing. Therefore, growing cities are considered relevant for this study. On the other hand, cities with a housing shortage are considered to benefit most from the successful implementation of the measures studied in this paper.

According to a report by HBS (2019), of all German cities and municipalities, 80 are classified as large cities, the rest as medium-sized (N=633) and small towns (N=2 018) or municipalities (N=1 614). Of these, 2466 are (above average) growing, 1 309 are (above average) shrinking and the remaining 659 do not show any significant direction. The BBSR (2020) examines the housing shortage in 77 large German cities as the ratio of the required flats in the city to the current building stock. This ranges from 6% in Wolfsburg to 31.4% in Heidelberg.

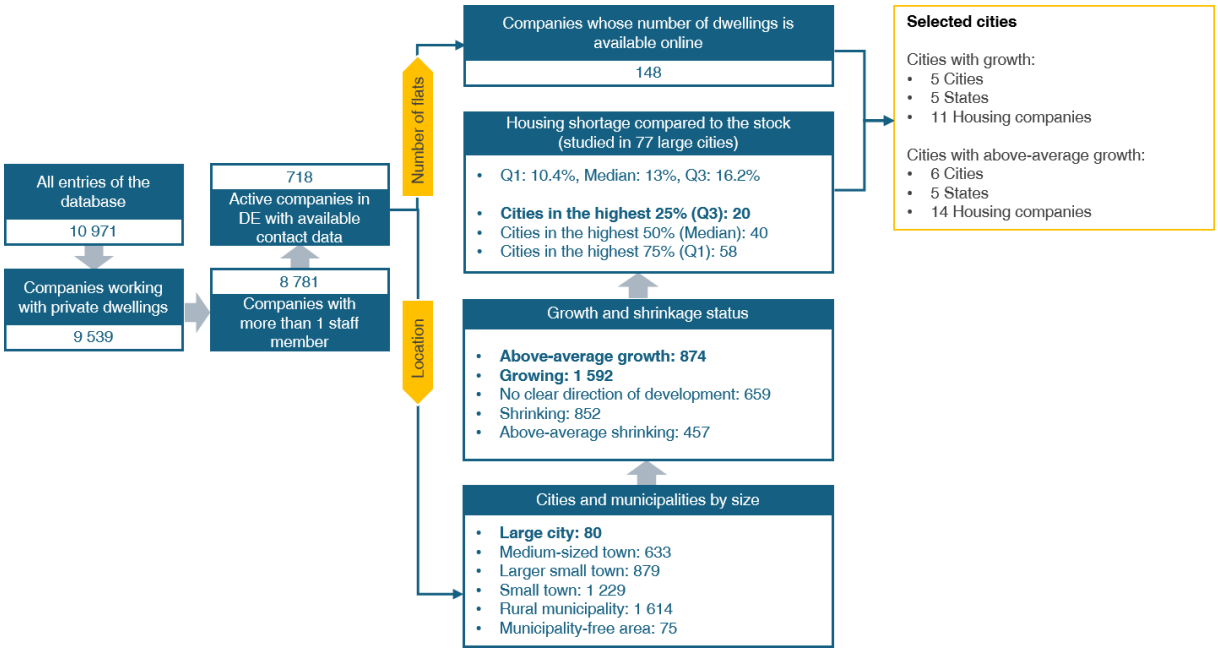

Figure 6.2: Selection process for the housing companies

For reasons of data availability, only the large cities for which data on housing shortages was available were considered. A threshold for the housing shortage was defined and all cities with a housing shortage above this threshold were kept in the list. All cities in this list for which at least one company with available data on the number of rental dwellings was listed were considered as potential interview partners. Figure 6.2 summarises the selection process. The 25

companies selected are located in 11 cities and nine states (regional distribution) and have different characteristics (commercial, non-profit, from the church or municipality).

6.2.3. Selected measures

Over 300 policies are listed in the Energy Sufficiency Policy Database[7], 53 of which are related to the buildings sector (as of March 2024). These include a variety of sufficiency strategies, among those reducing living space, which is the focus of this paper. This strategy triggers different actions, including building modifications, supporting ownership structures, new construction and oriented moving and living. The aim of this paper is to focus on the low-hanging fruit, i.e. measures that require only organisational effort which involve both the supply side (housing companies) and the demand side (private households). Therefore, the category of oriented moving and living is relevant, which in turn covers policy instruments related to sharing, alternative housing and moving. The first two are excluded from this study as they are either mostly relevant to homeowners or not feasible within the housing company building stock. Under moving, which is the focus of this study, the following policy instruments are listed: exchange of flats; moving bonus and moving advice (Figure 6.3).

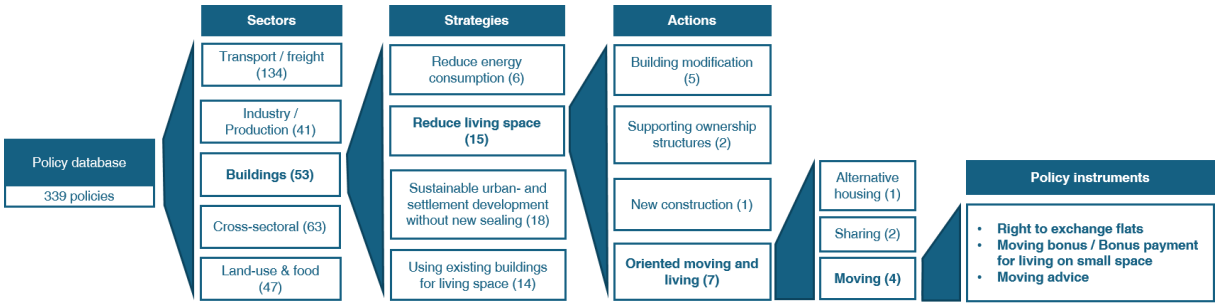

Figure 6.3: Process for selecting measures

6.2.4. Data collection and analysis

Data for this study was collected through guideline-based semi-structured interviews conducted virtually using Microsoft Teams in March 2024. The interviews were conducted in German and translated for this paper. A translated version of interview questions is available in the supplementary material in Chapter 6.5. The systematic analysis of the interviews was carried out in MAXQDA software and followed the six-step approach introduced by Rädiker et al. (2020). After systematically entering, preparing and organising the interview transcripts in the software, a first set of categories was developed based on the research questions and the interview guide (see supplementary material in Chapter 6.5). These categories were used for the basic coding of the transcripts. In order to ensure high-quality coding, the first interview was coded by two team members and the results were compared and discussed. Where necessary, the coding was corrected. In the next round, the subcategories were developed, the text passages were coded accordingly, and the main content of the coded segments was noted. Next, the appropriate analysis for the coded data was selected and carried out. Finally, the analysis result was documented.

[7] See https://energysufficiency.de/policy-database/.

6.2.5. Interview guide

The interview guide contains questions in two main categories: the interviewed housing company and the studied measures. In the first category, the characteristics of the company (e.g. location, structure and form, number of flats) and the mechanism for allocating dwellings are examined. The second part, on the policies, includes the description of the policy, documentation on its implementation and impact, failure and success factors. The final questions deal with suggestions for improving these policies.

6.3. Results

Of the 25 contacted housing companies, 13 responded to the request for an interview, three of which were unable to give an interview despite their interest in the topic. In one case, the main focus of the company had changed, making it unsuitable for the study. With the remaining nine companies, an interview was scheduled but one was cancelled, resulting in eight complete interviews. The eight interviews covered five cities and four states. Both cooperative and privatised housing companies as well as those owned by municipalities or churches, were represented. The respondents have different financial, legal and ownership forms and the size of their housing stock ranges from 2 000 to 200 000 dwellings. Figure 6.4 provides more details on the characteristics of the respondents. The interviewees were the chief executive officers of the companies (the majority) or their deputies, chief operating officers, chairmen of the board or managing directors. Half of the companies interviewed allocate part of their stock to social and subsidised housing. All companies take into account household income and household size (i.e. number of people in the household) when allocating their dwellings. This information is only gathered at the time of allocation and is not updated. Other aspects such as age of children, non-discriminatory selection, social mix in the neighbourhood, and special situation of a household (e.g. violence, disability) are among the soft factors considered when allocating flats.

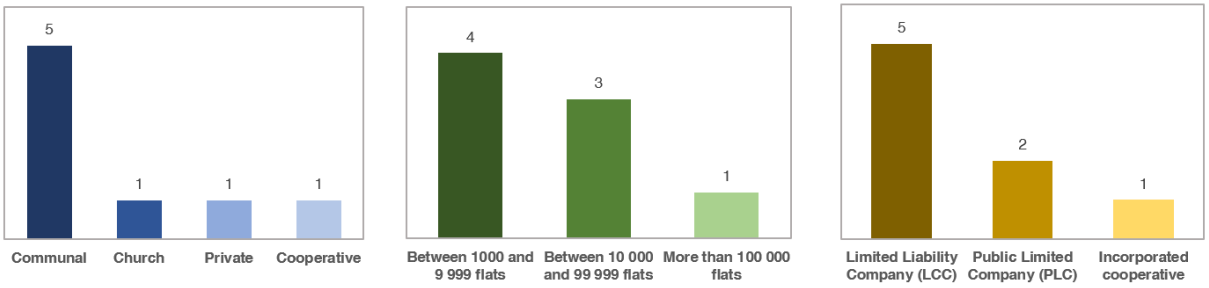

Figure 6.4: Characteristics of the interviewed companies: (left) Owner; (middle) stock size; and (right) legal form

6.3.1. Experience with the studied measures

This section summarises the experience of the interviewed companies with the studied measures, whether or not they offer the measure, and how they communicate the measure.

6.3.1.1. Flat exchange

This measure is implemented by companies in two different ways: *flat change,* where a household moves from its current dwelling to another, and *flat swap*, where two households exchange dwellings, i.e. the first household moves into the dwelling of the second household and vice versa. Both options are offered, but the flat changes are more common. Four of the

interviewed companies offer a flat change, one offers only a change from a larger to a smaller dwelling, and for two a change is generally possible but is not explicitly offered. On the other hand, flat swap is only offered by two companies, in two it is part of a larger swap programme (with other companies or within the municipality) and in one it is possible but not explicitly offered. In the companies that offer a flat swap, either a new rental contract is signed with new conditions (i.e. market price, but considering the price caps, the smaller flats will usually have lower rents) or the basic rent per square meter remains unchanged, which means that the tenants have a financial advantage by moving to a smaller flat.

In three companies the tenant receives a new contract with new conditions after a flat change. Although it is assumed that in case of a move to a smaller flat the new rent will not be higher than the old one, there is no guarantee that this will actually happen. Some companies have considered the financial incentive. One company offers the new flat at a lower m^2 price than the normal price when moving to a smaller flat. One of the companies keeps the m^2 rent the same and the other one pays attention to the point that a change should not lead to a financial burden. Usually, the tenants are temporarily relocated when the building is being renovated. In this context, companies usually offer a permanent flat change, as this also reduces the financial and organisational costs compared with the time when the household has to return to the original flat. Another reason for offering this instrument is to free up space in the larger dwellings and to have the possibility to increase the occupancy rate.

6.3.1.2. Moving bonus

Three companies offer financial support as a general rule: in one company tenants receive a bonus when they move, even if they move out of the company; in another, the moving costs are covered; in the third, a subsidy is paid when tenants move from a larger to a smaller flat, and the amount of subsidy depends on the m^2 reduction of the new flat compared with the old one. In three other companies, financial support is offered only in exceptional cases, i.e. when the move is due to, or in connection with renovation work, or when the company recognises that the household is in financial difficulty. Two companies offer organisational assistance with the move, which is particularly helpful for older tenants. The legal form of the company was mentioned by two companies as a reason for not offering a moving bonus.

6.3.1.3. Moving advice

In two companies, consultation is offered and regularly communicated, but not exclusively on relocation. Two companies offer moving advice only when a new building is planned or in the framework of a flat change. In both cases, the high administrative costs and low output of the consultations is the reason for not offering them regularly. Four interviewees mentioned that tenants are aware that the organisation is there when they need it.

Table 6.1 summarises these offers in the interviewed companies. All these offers are communicated in different ways: sending an email, tenant meetings, verbal conversations, information events, word of mouth, personal visits to the site (in the case of new construction), website, tenant newspaper, social media, flyers, and information stands in the housing areas. The documentation of the implementation and acceptance of the offers varies between the companies. While two companies comprehensively document and evaluate the measure, most have no specific documentation of cases. In a few companies the data is recorded but not evaluated. Only successful cases of flat swaps and flat changes are documented. Moving

bonuses and moving advice are always coupled with flat exchanges. In the remainder of this section, only flat swaps and flat changes are discussed, regardless of the incentives that led to them.

Table 6.1: Overview of the studied measures in the interviewed companies

Flat change	Flat swap	Moving bonus	Moving advice
Four offer a flat change One offers a change only from large to small Two have no specific programme but a change is possible	Two offer a flat swap Two offer it in cooperation with larger programmes One has the possibility but does not offer it exclusively	Three offer financial support Three offer financial support in exceptional cases Two offer organisational support	Two offer general consultation not only for moving One only when new construction is planned One offers only within the flat change Four tenants know they can contact them

6.3.2. Acceptance and effectiveness

Three companies reported very little success with the flat swap measure, three others reported that the measure is not (or no longer) offered because they do not expect (or have not observed) much success and therefore the effort is not worthwhile. Even if successful, it creates more administrative work for the company, which is a reason why one of the companies does not advertise it, although it is generally possible to do so. On the contrary, another company offers the measure because it wants to avoid the higher future costs of an unstable neighbourhood.

Although flat changes are more common than flat swaps, companies report very low success rates for this measure, despite advertising the offer through various communication channels. Some companies even contacted all tenants who might be eligible for a flat change, but this not only failed to achieve much success, but in some cases led to negative feedback from tenants who felt they were being evicted.

Looking at some figures, one company estimates the success rate of flat swaps (i.e. the proportion of successful flat swaps from initial enquiries) at 4%. Approximately half of the swap requests are initiated for the purpose of enlarging the dwelling. In another company, around three-fourths of the flat changes in 2023 were due to lack of space in the old home, resulting in a 41% increase in living space. None of the changes involved moving to a smaller flat. As a positive example, one of the companies interviewed had an annual average of around 17 changes from large to smaller dwellings between 2011 and 2022, resulting in an average reduction of 22% in living space. In general, the companies reported a wide range of one to 80 cases of flat swaps and changes in their housing stock in recent years.

6.3.3. Success factors and limiting barriers

Experience with swaps shows that location plays a role in the success rate. Changes within the neighbourhood and those that bring the tenants closer to the city centre are more successful. Similarly, if the amount of space remains the same and only the location changes through a swap, there is a higher chance of success. When it comes to flat changes, tenants who really

want to move will do so without any advertising. Nevertheless, communication plays a very important role, because there is a very fine line between counselling and harassment, and by crossing that line, companies can invade tenants' privacy. Too much advertising can have a negative effect, as tenants may think that the companies are making a huge profit from each flat change, when in fact each change costs the companies a lot due to renovation and maintenance measures. There is sometimes mistrust between tenants and the housing company, as the companies are biased as landlords and contractual partners and the advice comes from the party that could benefit from it. For this reason, it makes more sense that the municipalities or non-profit organisations take over the communication. In general, accessibility for wheelchairs and walking aids, lifts (especially to the underground car park), affordable rents and lower operating and energy costs, and proximity to the previous flat and therefore to social contacts are the factors that increase the chances of a successful flat change.

Interviewees also gave several reasons for the very low rate of swaps. From a financial point of view, the rent is usually very low and therefore there is no financial pressure for households to reduce the rent. On the other hand, after a flat swap, one has to sign a new contract usually with a rent which is much higher than the old one. Therefore, there is no financial incentive to move out of larger dwellings as households may end up paying the same or even more for less space. In addition, the financial transaction costs of moving (e.g. new furniture, new kitchen) are high.

In addition to the financial aspects, there are also high social transition costs. After a move, the household and especially the children have a new environment. Although the means are available, there is little willingness on the part of tenants in large flats to reduce their space, which leads to a mismatch between offers from people in small flats looking for a larger flat and people in large flats willing to move. Furthermore, both parties want to improve or at least maintain their current living situation and therefore have high and sometimes unrealistic expectations. This makes the likelihood of finding a match very low. The swap is often not successful because of details such as the orientation of the flats, the direction of the living room, and the lack of an ideal parking space. As far as flat changes are concerned, there is a very low vacancy rate in the housing stock and tenants rarely move out, so it is not technically feasible for companies to offer a flat change to every tenant. There is a strong emotional attachment to the flat, especially after a long period of living there. Tenants have usually built their social structures around their current flat, they have their friends, neighbours, even a family doctor. Moving to a new flat means a new start, a new neighbourhood and new neighbours, which is not easy, especially for older people. On the other hand, the old contract with a really low rent leads to a lock-in effect, as there is usually no financial advantage in moving. In addition, financial incentives are usually not important. In some cases, decisions are not made rationally (from an outsider's point of view), e.g. in the extreme case that an elderly tenant in need of care, living on the third floor of a building without a lift is unwilling to move to the ground floor of the same building. The tenants have high expectations of their future flat: well-located, barrier-free, cheap, and it is not possible to meet all these expectations.

6.3.4. Suggested improvements

After discussing the measures and their factors of success and failure, interviewees were asked for their views on various instruments that could encourage more people to move out of under-occupied dwellings. According to Eurostat (2011) under-occupied dwellings are those in which the number of rooms is excessive in relation to the number of people living in the household).

The suggestions are grouped under the categories of information and communication, financial, and regulation, and are described below.

Information and communication

The issue of high per capita living space and its environmental impacts should be kept alive in discussions, just like the discussions on the impact of meat consumption and flights. Public campaigns, financially supported by government, should aim to raise awareness and create a narrative on the issue that brings about positive dynamic in society. Communication should also be improved at various levels. First, there should be an exchange between housing companies to learn from each other, as some are more open about the topic than others. Second, it should be the responsibility of the municipalities and non-profit organisations to provide information and advice on (moving) options. Lastly, the issue should be communicated positively by all parties involved, i.e. tenants' companies, public administration, non-profit organisations and politicians. It should be openly communicated that new housing cannot be built for every generation, but the existing buildings should be used efficiently.

Financial

The public sector (state and national authorities) should encourage freeing up under-occupied dwellings by providing financial incentives to both tenants and housing companies. By subsidising the costs of moving, especially to smaller dwellings where there are no direct cost benefits, the financial burden will no longer be a barrier to action. The provision of bonuses and subsidies to housing companies also plays an important role in incentivising them to promote such measures, given the high renovation and maintenance costs that housing companies might incur after each flat change, as highlighted in the interviews. These costs depend, however, on the condition of the flat and the extent of renovation work already carried out. The very high costs addressed by the interviewees are probably due to the current renovation requirements in the building sector and the fact that the flat changes often occur after a very long stay, meaning that the flat is typically not in a good condition.

Other sufficiency measures, such as the promotion of flat-sharing, should also be encouraged through high financial incentives. Providing an empty flat through this measure would be more cost-effective (considering high construction costs) and time-efficient (considering the lengthy process required for new construction) than acquiring a flat through new construction. Based on an example given in one of the interviews, offering two households a relatively high hypothetical moving bonus of €10 000 each to incentivise them to share a flat and thereby freeing up the other flat would still be at least 10 times cheaper and faster for the housing company than building a new flat.

Regulation

Some interviewees felt that 'home' was a sensitive issue and that individual choices about their homes should be respected. They did not believe that tenants could or should be forced to leave their homes by regulation, as being too restrictive would not only be undemocratic but also unlikely to be very successful. However, some possible regulations and models were suggested. The first suggestion is to set a per capita rule for social housing (following the Swiss example). In this model, the occupancy rate (i.e. the number of people living in the flat) is defined and if the household size becomes smaller than required over time, the household has to vacate the flat, with the possibility of moving to one of the flats offered by the housing company. The

second suggestion goes in the same direction as the first and is a prerequisite for it. Almost all interviewees mentioned the misallocation tax (in German: *Fehlbelegungsabgabe*), as an effective measure that existed in Germany for publicly subsidised housing and was gradually abolished over time. Under this model, tenants had to continuously report their income to prove that they still met the criteria for social housing, otherwise they had to pay a tax to the municipality. A similar measure where tenants either have to comply with the rules (e.g. occupancy rate) or to pay taxes, was considered effective in motivating tenants of under-occupied flats to move to smaller dwellings. Another suggestion is to increase all rents up to a certain amount and set a transition period for the occupants of the under-occupied flats to move to a smaller flat. If they do not move out by the end of the transition period, their tenancy will be renewed at the higher rent. The fourth proposal is a model in which the rent is capped for a certain amount of floor space per person (e.g. 30 m^2). The rent will be differentiated for new and old buildings. Any floor space above this threshold would have to be rented at the market price. For example, if a household wants extra space for a home office, the space will be rented at the market price for office space. Finally, one interviewee suggested the right to swap flats as an option, while believing that this measure would not increase the number of swaps already occurring.

In addition to the instruments mentioned above, the improvement of the social and technical infrastructure was considered essential. From a technical point of view, standardised processes and universal digital platforms are suggested as a solution to better organise flat swaps and flat changes. A universal platform could provide a comprehensive overview of all available offers. This will lead to better communication of prices and also reduce the perception of housing shortage, which leads to some unrealistic housing requests. In order to achieve a better distribution of available flats, the restrictive data protection rules, which oblige companies to regularly delete applications and result in applicants having to regularly renew their application, should be relaxed. On the social side, current social norms in the area of housing (e.g. a three-room apartment as standard even for one-person households), should be reconsidered and redefined. On the other hand, social acceptance of the new concepts and rules should be increased.

6.4. Discussion and Conclusions

In response to the much-discussed housing shortage in Germany and the need for new construction, Hunziker (2024) considers a redistribution of space as an alternative to provide the missing living space. He argues that this could be achieved if each individual gave up just 2% of their current 47.4 m^2 living space. Given that this current per capita space is about 36% more than that of 1990, the present study investigates the success of selected sufficiency measures in reducing the average per capita floor area in German rental housing managed by housing companies. Eight housing companies in five cities and four states were interviewed through guideline-based semi-structured interviews to explore their experiences with the following measures: flat exchange (including flat swaps and flat changes), moving bonus and moving advice. What Hunziker suggests for such spatial redistribution is theoretically true, but as the author also acknowledges, it is challenging or even impossible under the current German political and social framework. While sufficiency relies greatly on individual choices, it should not be seen solely as an individual lifestyle change, as these individual choices are strongly shaped by available offers, existing infrastructure and the legal framework. To be successful, sufficiency must be regarded as a ‘collective challenge’ (SRU 2024) and the many small-scale initiatives observed at the municipal level need to be scaled up to the national level. Therefore, this section discusses the different instruments proposed by the housing companies in terms of

their potential role in changing the social and political framework in Germany, which is essential for the full exploitation of sufficiency.

Moving advice is an important first instrument that can trigger further measures such as flat swaps and changes. However, the fact that it is the responsibility of the housing companies does not seem to be optimal. Given the sense of attachment, especially for older tenants (in terms of both age and time spent in a flat), housing is a sensitive issue that needs to be handled carefully. As housing companies are usually seen as contractors, communication on this issue is challenging for them and not very successful. Giving the municipalities, as neutral stakeholders, the responsibility, can build trust and lead to more success. The city of Tubingen already offers such a programme, informing residents who have too much living space about options such as downsizing or alternative living forms (Tübingen Universitätsstadt 2019). An evaluation of the consultations conducted under this programme between late 2020 and December 2021, reported by Bierwirth et al. (2022) shows a high level of satisfaction with the offer and information provided. The consultations are reported to have given participants relatively positive encouragement for their plans. Participants were also largely confident that they would implement their plan. The restrictions imposed by COVID 19 affected the quantity and quality of the consultations carried out during this period, and the relocations and flat swaps were rarely reasons for taking up the consultation offer. Therefore, the results presented in this report are not directly comparable with the success rates reported by housing companies. However, the lessons learned in Tubingen may still be helpful in designing the programme in other municipalities.

The moving bonus by itself does not seem to have an impact on the initiation of relocation, especially in cases where there is no direct financial benefit from moving to a smaller dwelling (when there is no price guarantee after a move). However, once the barrier of moving costs has been removed, it can be an effective instrument in combination with other financial incentives. Public authorities should therefore support this instrument by providing financial incentives to tenants and housing companies. The city of Frankfurt am Main offers such bonuses when tenants move from a social housing flat to one that is at least 15 m^2 smaller (Stadt Frankfurt am Main 2024). Similarly, in Dusseldorf, landlords can receive a bonus if the move is due to a flat swap (Tauschwohnung 2024). Such a subsidy could also be given to housing companies, so that they receive a bonus for each successful flat change. Such investments contribute positively to the multiple objectives of the buildings sector: providing affordable housing, preventing soil sealing and reducing emissions.

Flat swaps and flat changes can be effective in freeing up under-occupied dwellings for use by larger households. However, in most cases they do not provide an incentive for residents to move. A combination of different financial incentives that reward downsizing (such as the package offered by ProPotsdam 2023, which includes a living space bonus, a bonus for a shared flat and a moving bonus) could make such instruments attractive. Furthermore, other instruments are needed as catalysts to make the most of these potentially effective instruments. The need for a universal platform has been raised as a technical prerequisite to facilitate flat swaps. An example of such a platform already exists on a small scale in Berlin[8] with the participation of six housing companies. Another example is the French *Echanger Habiter*, a platform for social housing with the participation of around 40 housing companies. Since its

[8] See https://inberlinwohnen.de/.

launch in 2018, around 3 000 flat swaps have taken place, with a success rate of 4%, not higher than the success rate already communicated in the interviews. This confirms the need to improve the social infrastructure to complement this technical infrastructure, also suggested by the interviewees. Information campaigns should promote sufficiency as a social practice in all sectors. However, the sense of attachment, as one of the notions of well-being and mentioned in many interviews as a reason for the failure of the studied measures has to be considered as a key factor when promoting sufficiency. This is crucial not only for increasing the success of these measures, but also to prevent the unwanted social and psychological implications of forcing such measures, intensively discussed by scholars in the context of forced relocations, un-homing and displacement (e.g. Westin 2021; Elliott-Cooper et al. 2020). The multiple benefits of sufficiency measures for the climate (e.g. lower energy and material consumption) and individual well-being (e.g. stronger community ties, increased sense of equity) should be communicated, so that people voluntarily follow the measures on the basis of the information they have.

This could be done, for example, by importing already practiced and accepted social norms from other European countries. The Swiss minimum occupancy rate (Stadt Zürich 2024), repeatedly mentioned in the interviews, is one such example. Tenants of social housings in Zurich have to meet the requirements of household size and income level in order to continue living in their flats. This is similar to the misallocation tax that used to exist in Germany, which was abolished for two reasons, first, it required a lot of administration and, second, it led to less social heterogeneity in neighbourhoods, as higher-income tenants had to move out. Adapting and reactivating this old law will make it possible to identify under-occupied dwellings that could potentially be occupied by larger families. Merely enforcing a tax on high-income households will not improve the situation, as they will simply pay and continue to live in their under-occupied dwellings. Therefore, the focus of this measure should be on household size, so that the high-income households can still stay in the neighbourhood and contribute to its heterogeneity. The high administrative costs of regular data collection can be overcome by improvements in digitalisation. Finally, residents seem to react only to significant price increases. According to one interviewee, tenants saved a lot of energy following the 2022 energy crisis and the resulting sharp increase in energy prices. However, this behaviour changed when price caps were introduced. This low price elasticity, although typical for essential goods such as energy, indicates that users are not easily willing to leave their comfort zone and alter their habits towards low consumption behaviour (e.g. putting on extra clothes instead of turning on the heating). The rent cap has not proved to be an effective instrument. Defining an essential amount of space per person at the capped price (fulfilling the ‘needs’) and offering additional spaces at market price (fulfilling the ‘wants’) has two advantages: first, the financial pressure might incentivise freeing up the under-occupied flats; and second, it can contribute to the use of shared spaces such as shared office spaces, communal spaces for hobbies and guest accommodations. This would be similar to the already established concept of car sharing in Germany, which saves the occasional car drivers the annual high maintenance and insurance costs. In the case of such a model with a defined essential living space, besides the indicator of floor area per capita, new indicators of floor area per household size and floor area per household composition should be used when discussing the occupancy rate of the flats.

Proper documentation of successful cases can identify opportunities for improvement. Documenting and evaluating implementation cases is not a priority for many companies, mainly due to capacity and the lack of incentives and a defined target. Even where documentation is

carried out, only successful swaps and changes are documented, making it impossible to understand the real reasons why tenants do not want to move. Therefore, incentivising companies to document the reasons for failure from the tenants' point of view (or perhaps even requiring them to do so, while compensating the extra cost and effort) would provide a good overview of the failure factors and identify opportunities for improvement. This point was also discussed in one of the interviews and, as a result, the authors provided a set of questions to be included in an online flat swap portal, where tenants who have initiated a flat swap, will have to enter the reason when terminating the process of a failed swap.

Although this study focuses only on rental properties managed by housing companies, this presumably niche market still accommodates around 17% of German households. The suggested instruments and the lessons learned from this part of the housing sector can also be applied to privately rented dwellings, which together account for more than half of German dwellings. Moreover, motivating households to reconsider their spatial needs could be effectively transferred to homeowners. Given this transferability, any success in this niche sector in empowering and motivating occupants of under-occupied dwellings to downsize will ultimately play a significant role in optimising space use, reducing per capita and total space demand and decreasing the high residential energy consumption.

While space heating is considered the main driver of high residential energy consumption in Germany and most parts of Europe, the need for space cooling is steadily increasing due to climate change and global warming. Most measures that reduce the energy demand for space heating equally contribute to improving the energy demand for space cooling. In addition to the savings achieved by reducing the need for new construction, space optimisation offers significant savings potential by decreasing the energy required to operate buildings, benefiting both occupants and the environment. Despite the small sample size, considered a limitation of the study, the findings from the interviews with the housing companies provide a valuable contribution to effective policy design that enables such space optimisation while still meeting the occupants' needs. These companies are in direct contact with the target groups, mostly highly committed to the issue and in dialogue with policymakers at various levels. As the phenomenon of significant increases in space consumption and high residential energy demand is not limited to Germany, the policy lessons may be widely applicable in other societies. Nevertheless, the study sample does not allow for an exploration of the influence of the characteristics of the housing companies (e.g. legal form, business model) on their interest in adopting sufficiency and the number or type of measures they offer.

Furthermore, while the study offers insights into the factors affecting the success and failure of the studied measures, the analysis of the interviews could only provide a partial picture of the various cultural, social and economic factors that influence individual decision-making, which contributes to the under-occupation of dwellings. Further research, including the views of tenants living in these dwellings, is needed to develop a more holistic understanding of the underlying factors. Additionally, a potential analysis of the studied and proposed measures in this paper could assist policymakers in the strategic allocation of resources, ensuring a balanced ratio between effort and outcome and effectively reaching each target group with the most appropriate measures.

Finally, at a time when the buildings sector, and housing companies in particular, are faced with the challenge of becoming carbon-neutral and also meeting the ever-increasing demand for housing, it is more important than ever to explore and invest in measures such as those

discussed in this paper. Given the drastically increased construction costs and the high emissions associated with emission-intensive building materials, it may be ecologically and economically beneficial to redistribute and use more efficiently the existing space through such measures. This last point could and should be further explored.

6.5. Supplementary material

Supplementary data to this chapter (interview questions and developed categories for the qualitative analysis) can be found at: https://doi.org/10.5334/bc.435.s1.

7. Synthesis

7.1. Contribution and key results

This thesis aimed to provide strategies to optimise the impact of policies which address residential energy consumption and target its reduction. In order to do so, an understanding of user behaviour and the decision-making around housing was outlined using different quantitative and qualitative methods. In order to capture various perspectives, different stakeholders were approached in this thesis. With its three core components - user, housing consumption and policies - this thesis focused on the social aspects of residential energy consumption by considering the role of users, their perception and acceptance, in the effectiveness of policies in reducing consumption. Figure 7.1 presents a simplified overview of the different steps to reach the aim of this thesis, presenting the core component addressed in each step.

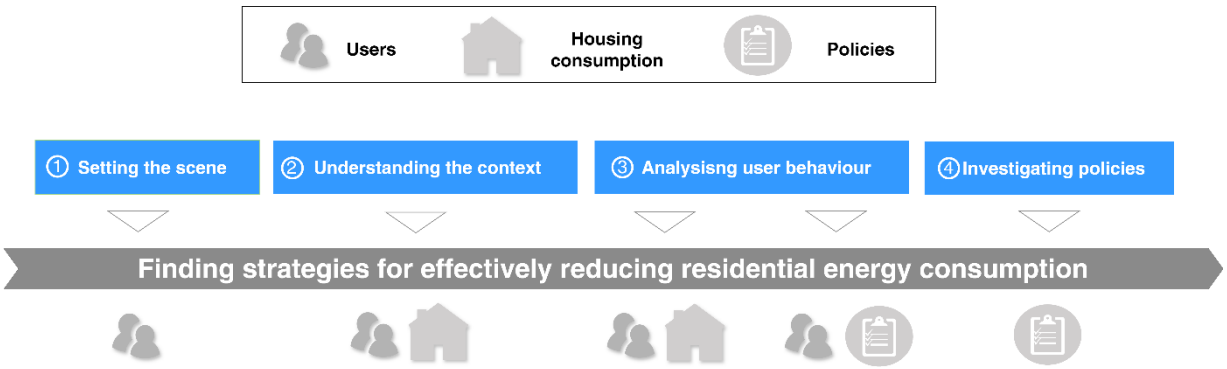

Figure 7.1: Overview of the working steps in the thesis

First, to set the scene, a study on social sustainability was conducted in an exemplary urban settlement, the Garden City of Karlsruhe. This case study was selected due to the similarities between the objectives of the Garden City concept and the definitions of a sustainable community (as one of the indicators of urban social sustainability), focussing on human needs and quality of life. The survey in Garden City showed a high satisfaction rate among the residents with their neighbourhoods and living conditions; however, it also pointed out a dissatisfaction resulting from a lack of communication between the Garden City Cooperative and the residents. It also recognises the need to adapt to the changing needs of the inhabitants.

Then, to further understand the context, the patterns of residential space use among EU households and their underlying factors were explored. The existing and emerging trends, and how they impact the household structure and consequently the household consumption were examined. This study recognises the changes in household consumption occurring as a result of changes in the surroundings and highlights the need for flexibility and adaptability in the buildings sector to be able to accommodate these changes within the existing space, instead of expanding constantly. It also identifies the social and technical changing potentials that facilitate behavioural changes towards lower consumption. Among those solutions are promoting non-materialistic narratives and offering alternative and innovative solutions to satisfy people's spatial needs.

After providing the first overview of what influences user behaviour and shapes consumption patterns, the households' space use and heating behaviour in selected EU Member States were captured through two online surveys. The first survey on the space use pattern examined the

behaviour of the residents of households in Germany, Sweden, Poland, and Portugal and explored the potential for changes in their space use behaviour. The households reported an average floor area per capita ranging from 39.0 m^2 in Poland to 60.5 m^2 in Portugal. A cluster analysis of the survey data divided the households into four categories, two of which were identified as having a high potential to change their space use behaviour. The residents in the Space-oriented cluster have a high average per capita floor area of 108 m^2 and perceive their dwellings as too large. The individuals in the second cluster, the Satisfaction-seekers, live on average on 33 m^2 per capita and feel their dwellings are too small. For these two clusters, the study further analysed the willingness to change the space use behaviour and the support rate of certain policies. Learning from the willingness to change and policy support of these two identified clusters and considering that the distribution of floor area is not equal across different demographical groups and household compositions, the study recommended some strategies to trigger changes in space use behaviour and achieve more efficient use of the available space. These strategies include promoting space sharing, supporting structural changes in the dwellings and providing incentives to residents of under-occupied dwellings to move to rightsized dwellings. Each of these strategies is to be targeted to the right group, considering their characteristics, potential and capacity for change.

The second online survey was conducted in Germany, the Netherlands, Poland and Greece and examined the changes in the heating behaviour between the heating periods 2021-2022 and 2022-2023. The survey focused on heating temperature, energy-saving measures (e.g. not heating unoccupied rooms), and technical improvements in controlling the heating temperature (e.g. replacing manual thermostats with programmable ones). The households in the studied countries reported an average temperature reduction ranging from 0.06 °C in Greece to 0.3 °C in the Netherlands. Using a building stock model, the savings potential achieved through these changes in the heating temperature was calculated, which was around 2-3.5%. This study suggests promoting technical improvements by providing technical and financial support, raising public awareness of the need to reduce consumption, and using financial incentives in different forms (bonuses or progressive prices).

Finally, with a focus on specific policies - namely moving advice, moving bonus and flat exchange - and to study their effectiveness, selected German housing companies were interviewed to share what they learned from these sufficiency measures in their housing stock. These policies mainly target a reduction in the per capita space use by encouraging the residents of under-occupied dwellings to free up the space for larger families. Through a qualitative analysis of these semi-structured interviews, the status quo of the implementation of these policies, as well as their success and failure factors, were investigated. The study showed that whether and how these policies are offered varies from one company to another. However, regardless of this, most companies reported a very low success rate for these measures. No financial incentive to move, along with high social and financial transition costs, a mismatch between the offers (people wanting to move from large flats to small ones and vice versa) and emotional attachment to the dwellings are among the reasons for this low success rate. The results show that, by using some financial, regulatory and communicational solutions, the acceptability and effectiveness of these policies could increase. Learning from the existing good examples in Germany and other EU countries could help achieve more success.

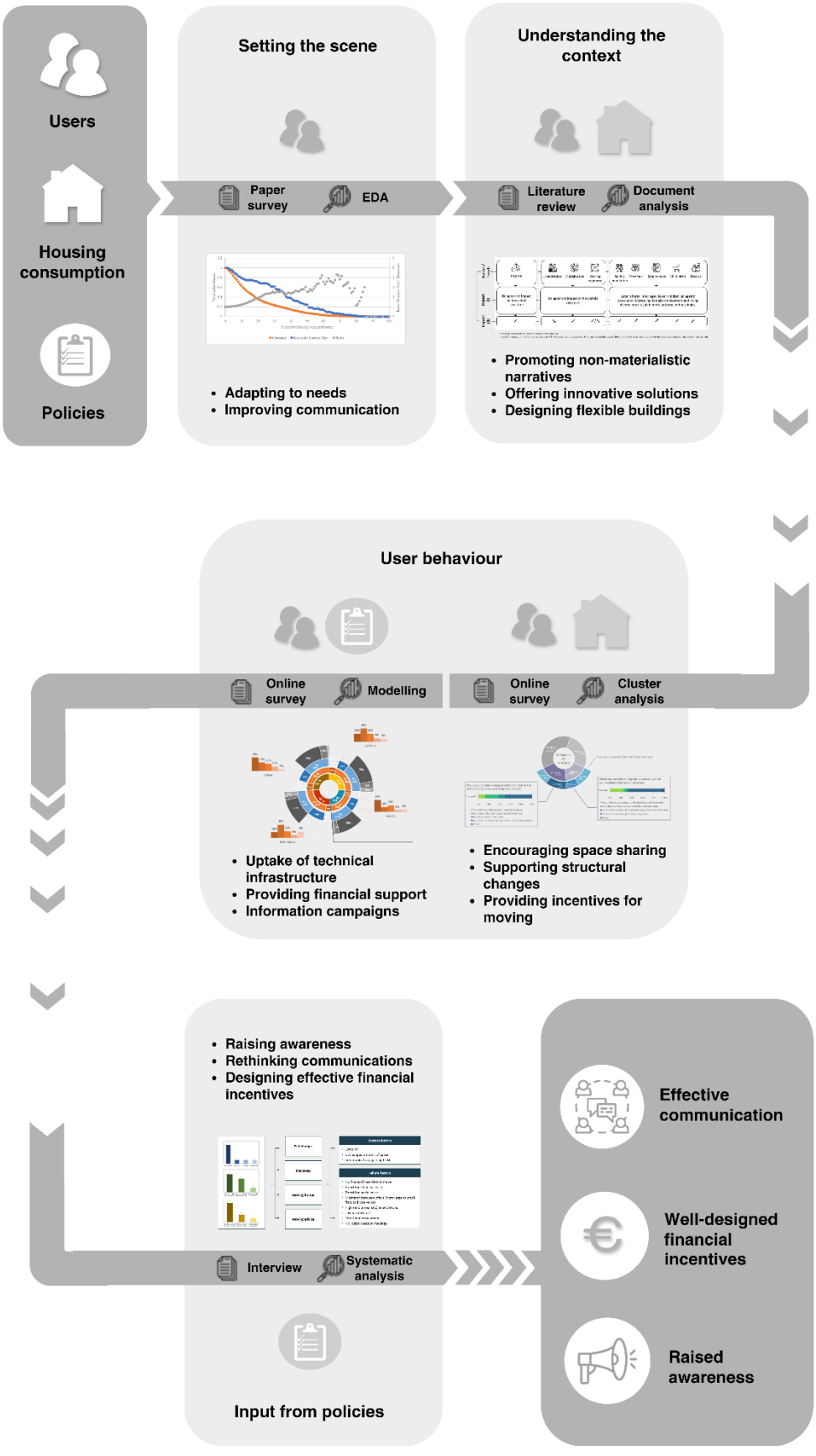

Figure 7.2: Summary of the methods, results and conclusions of thesis

Figure 7.2, a detailed expansion of Figure 7.1, underscores the research trajectory that this thesis has followed to achieve its objective. This figure also summarises the component(s), applied methods and main results of each step along the path.

By utilising the outcomes and results of each explained step, this thesis contributes to a comprehensive understanding of user behaviour in the field of housing and closes the gap in effectively addressing "living space" as a major potential for policies, a point previously highlighted by Fischer et al. (2019). From a practical standpoint, the thesis offers recommendations based on empirical data, which can be instrumental in developing strategies and policies that enhance space efficiency and target the reduction of energy consumption. From a methodological perspective, the datasets collected in this thesis through multi-country surveys, provide a rich insight into heating and space behaviour, thereby filling the data gap on empirical data about user (space use) behaviour. This invaluable data has the potential to be used by policy makers to make informed decisions or by other scholars for further research. Using these datasets in the commonly used modelling exercises as model input or to build and validate assumptions can help in generating more reliable results. The integration of different quantitative and quantitative methods in this thesis not only enhances the depth of the findings but also provides multiple perspectives on the topic. This can serve as a model in future research designs, leading to more robust results and a more comprehensive understanding of the studied topic.

7.2. Discussion and outlook

To answer the research questions and achieve the aim of this thesis, data was collected with several perspectives and scopes and analysed using different methods. A detailed explanation of the applied methods is provided in Chapters 2-6. This section reflects on them by discussing the methods, their limitations and alternatives and, where applicable, making suggestions for future studies.

Most of the data in this thesis was collected through online and paper surveys. Although a large number of respondents could be reached through this data collection method, it comes with some limitations, which may vary depending on the survey design and distribution method. An example of these limitations is the potential over- or under-representation of a specific group. In the paper survey from Chapter 2, possibly more pensioners participated; therefore, the respondents over 65 were presumably over-represented. On the other hand, in the online survey of Chapter 4, this group was not easy to reach, possibly due to the technical nature of an online survey, leading to an under-representation of this group in Portugal.

The interview method, also applied in this thesis, enables a profound exploration of the topic under study. However, due to its time-consuming nature, the number of interviews conducted is typically limited. As a result, unlike survey results, interview results cannot be generalised through scaling-up and statistical analysis of these results is not feasible. For the data collection in Chapter 6, an alternative approach could have been to use surveys to collect data from housing companies, which would have provided a larger sample size. However, this method would have only provided superficial data on the implementation of the studied policies. While a larger sample would have made it possible to explore interesting aspects, such as whether the legal form of the housing companies influences the number or type of measures they offer, it would not have allowed for the in-depth discussions achieved through interviews, which were crucial for this thesis.

Chapter 4 used cluster analysis to group the surveyed households and to identify those with the highest potential for change. While this could have also been done using classification methods, the clustering approach was considered more appropriate for the purpose of the chapter. In classification methods (supervised learning), the expected output is defined and the data points are assigned to predefined classes. In clustering (unsupervised learning), the data points are grouped according to their similarities without predefined labels. This chapter aimed to explore the space use pattern of the surveyed household without making any assumptions about their behaviour. Therefore, the clustering approach was chosen for pattern identification. The clustering was done using the k-means algorithm and Euclidean as distance metrics and using specific variables (space use and space perception) as explained in Chapter 4.3.3.3. The clustering could also be done with other sets of variables and different algorithms or distance metrics. In Chapter 4, hierarchical clustering was implemented in addition to k-means clustering, and similar results were obtained. For future research, statistical methods such as regression analysis could be used to further explore the relationships between the studied factors and variables. However, this was beyond the scope of this chapter.

Low data availability, a familiar challenge to many scholars, was also an issue in some stages of this thesis and therefore one of its limitations. First, data availability was one of the selection criteria for selecting the countries to be surveyed, and some potential countries were filtered out as they were known to have less data available compared to the others. Second, due to the lack of data, it was not always possible to validate the collected data through literature and had sometimes to be done using expert assumptions. On the other hand, the quantification of the influencing factors presented in Chapter 3 would give the opportunity of better dealing with these factors. However, the lack of available data would be one limitation of such a study and should be addressed in future research.

This thesis focuses mainly on space use as a significant driver of residential energy consumption and studies selected activities within the dwelling that can impact space use. Other behavioural categories that occur outside the home and can significantly influence space use and activities in other sectors with an impact on residential energy and space consumption should be considered in future studies. The surveys conducted in this thesis provide rich datasets beyond the scope of this thesis, which can cover some of these topics. Part of this dataset from Chapter 4 has already been used in a study evaluating the impact of teleworking on energy consumption of residential, transport and tertiary sectors. This study looks at, among others, the impact of household decisions on moving to a larger dwelling due to the need for an in-home office.

Among the end uses in residential buildings, this thesis focused on space heating, as it currently accounts for a high share of residential energy consumption in most European Countries. However, the heat waves experienced in recent years, the reported rise in temperature and the increase in the use of cooling appliances point towards the increasing need for space cooling and the importance of considering it in future studies on residential energy consumption. However, many strategies to reduce the energy need for space heating discussed in this thesis (e.g. adjusting the temperature and using other means for satisfying the heating needs) could also apply to space cooling.

The strategies explored in Chapters 3 and 5 - moving, sharing, rearranging - are not only low-hanging fruit but also novel approaches that could significantly enhance the efficiency of space use in the residential sector with minimal effort. To build a comprehensive understanding of the acceptability, feasibility, and effectiveness of all types of strategies, similar studies should

be replicated, focusing on other types of strategies. This will provide an even more robust basis for policymakers to make informed decisions in the future.

The empirical data collected in this thesis provides a valuable basis for policymaking. However, it focuses mainly on the social aspect of user behaviour and could be further complemented by studies on the economic aspects that should be considered in decision-making regarding these strategies. An example of such a study is a cost comparison between two scenarios: (i) providing a dwelling through new construction, or (ii) freeing an already existing dwelling through sufficiency measures, as discussed in Chapter 6. Such a study should consider all stakeholders and their costs and benefits.

The countries studied in Chapters 4 to 6 were selected on the basis of factors considered relevant to the scope of each chapter. Although, similar studies should be repeated in other countries to get a complete picture of the situation in the different European countries with their characteristics, the findings of this thesis are transferable to other countries for the following reasons. Firstly, the topic of high residential energy consumption addressed in this thesis is relevant to almost the whole of Europe. Therefore, some general conclusions could be drawn for all countries regardless of their characteristics. Secondly, Chapter 5 showed that although the country factor seems to have a more significant influence on heating behaviour than socio-demographic factors, similar patterns of heating behaviour could be observed in Germany and the Netherlands. The same was true for Greece and Poland. Therefore, lessons from one country could be applied to other countries with a similar policy mix and energy prices. Thirdly, concerning the space use pattern, the study on space use behaviour (Chapter 4) showed that the country's effects on behaviour are not as significant as socio-demographics. Therefore, despite the focus on specific countries, the results of this thesis are transferable to other countries with careful consideration of the local context and specificities, suggesting that the findings may have broader applicability under certain circumstances.

The extensive literature on high energy consumption in the residential sector, coupled with the awareness among all interviewed housing companies of the sufficiency concept and its crucial role in reducing residential space use, underscores the significance of the topic addressed in this thesis. However, greater emphasis should be placed on integrating the "user" perspective. This thesis provides a solid foundation for incorporating this aspect, highlighting its potential to enhance the effectiveness of the policies addressing this topic.

7.3. Concluding remarks and recommendations

The main aim of this thesis was to provide strategies for optimising the impact of policies that address residential energy consumption and target its reduction.

As discussed in Chapters 4 and 6, many existing tools and policies could potentially lead to reductions in energy and space use in the residential sector. However, in order to realise the full potential of these tools, improvements in the technical and social infrastructure are needed. On the technical side, this includes increasing digitalisation and using new platforms and technologies, and on the social side, increasing social acceptance and redefining social norms. Learning from the best examples of other countries and documenting the successes and failures of existing strategies could also help to plan such improvements effectively.

Furthermore, as discussed in Chapter 3, it is essential to bear in mind that various external factors shape individual behaviour and influence choices, which in turn are reflected directly

and indirectly in household consumption. To have efficient and effective policies, these different backgrounds and their influence on policy acceptance and compliance should be recognised and taken into account when designing policies and strategies. While the Space-oriented cluster identified in Chapter 4 can be encouraged to follow policies by receiving organisational support, for the Satisfaction-seekers, more financial support would do the job. Tailored policies should also consider the different capabilities of their target groups. Chapters 4 and 5 identify the tenant-owner dilemma as an obstacle to making positive changes to reduce energy and space consumption, as tenants usually do not have the power to make these decisions.

Financial aspects play a crucial role in the decision-making of all stakeholders about implementing or pursuing strategies to reduce consumption. The housing companies interviewed in Chapter 6 mention financial costs as one of the barriers to implementing sufficiency measures. Similarly, the households surveyed in Chapters 4 and 5 considered financial burden as a reason for not taking measures to reduce the consumption in their dwellings. Therefore, designing policies with a financial component seems to effectively trigger positive changes towards lower consumption. However, the type and scope of these policies should be carefully chosen to avoid undesirable side effects, such as encouraging even more consumption or pushing households into energy poverty.

Finally, the results of Chapters 2 and 6 show that communication is crucial for the success of policies, as a lack of communication can lead to mistrust and dissatisfaction, thus reducing the chances of a successful policy. Finding the best means of communication, transparent communication and giving responsibility to the right stakeholders are key to involving households and building trust. One aspect that should also be considered in communication is to focus on the multiple benefits of reducing consumption, not only for the environment but also for the individual.

Appendices

Appendix A: Original published version of Paper 1

European Journal of Sustainable Development (2020), **9**, 4, 250-260 ISSN: 2239-5938
Doi: 10.14207/ejsd.2020.v9n4p250

Traces of Social Sustainability in Garden Cities- Karlsruhe as a Case Study

By Mahsa Bagheri[1]

Abstract
Discussions about sustainable communities as a significant measure in social sustainability began in the 2000s. Sustainable communities are defined as places in which existing and future generations would like to work and live. They contribute to the well-being and quality of life and offer equal opportunities to their residents. The definitions are similar to the objectives of one of the most influential movements in the history of urban planning: the Garden City. The principles of the Garden City are applicable to new and existing towns and its concept has been adopted in different contexts until today. Therefore, many lessons can be learnt regarding sustainable urbanism by studying social sustainability in this type of urban settlement. As a first step towards this aim, this paper studies the experience of living in the Garden City of Karlsruhe today. A survey was conducted among the current inhabitants. The study shows a high level of satisfaction and the tendency for a long residency in the Garden City because of the reasons like ample greenery, central location, and quietness of the settlement. The results will be used as the first dataset for developing a framework for urban social sustainability in the Garden Cities.

Keywords: sustainable urbanism, social sustainability, sustainable communities, user satisfaction, Garden Cities

1. Introduction

Since introducing the concept of sustainability in the 80s, several scholars have tried to define and interpret it. The concept of sustainable development was soon spread all around the world, covering the discussions at different levels, ranging from local to global. Its flexibility resulted in several attempts in redefining and reinterpreting the concept, in order to make it compatible with the discussed issues. The topic has been addressed by scholars from different disciplines including urban studies. Making the cities and communities more sustainable is one of the 17 sustainable development goals (SDG 11) set by the United Nations General Assembly (United Nations, 2015). Among the three pillars of sustainability, the social dimension, especially in relation to the built environment (Dempsey et al., 2011) has received the least attention compared to the environmental and economic dimensions. However, the recent discussions in sustainability are not limited to the environmental dimension only, instead they include economic and social aspects. Including the social dimension in sustainability discussion increased around the beginning of the 21st century (Colantonio, 2007). As a context related concept (Dempsey et al., 2011) social sustainability has been discussed at different urban levels: from small-scale urban units (e.g. Ghahramanpouri et al., 2015) and neighborhoods (e.g. Bramley et al., 2009) to large-scale cities (e.g. Panda, Chakraborty, and Misra, 2016) and regions (Spangenberg and Omann 2006). Having considered

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community as one of the three key components of the urban social sustainability by scholars like (Yiftachel and Hedgcock 1993) shows the importance of sustainable communities in enhancing social sustainability. Bristol Accord (ODPM 2005) defines sustainable communities as "places where people want to live and work, now and in the future. They meet the diverse needs of existing and future residents, are sensitive to their environment, and contribute to a high quality of life. They are safe and inclusive, well planned, built and run, and offer equality of opportunity and good services for all" (ODPM 2005). Dempsey et al. (2011) describe the community stability as one of the measures in community sustainability and Silburn (1999) indicates that a sustainable community requires long term residents.

In today's societies career paths have become more mobile and consequently people relocate more often compared to the past (Sennett, 1999). This frequent spatial mobility and its effects on social attachment and stability of the society has been previously addressed by some scholars (see Toffler, 1970; Packard, 1972; Long, Boertlein, and United States. Bureau of the Census, 1976 and Long and DeAre, 1981). According to the world pictured by these authors, one would assume that the concepts like place attachment and sense of belonging, which are among the measuring factors of social sustainability, have no meaning in contemporary societies. However, most of the debates about the increased rate of mobility and its consequences in the society concern the United States. According to Schneider, Stahl, and Struyk (2013), the residential mobility in West Germany is much lower than in the US, nevertheless German residents still have a higher mobility rate compared to the average in the EU (European Union, 2015).

2. Notion of Social Sustainability in the Garden City

The *Garden City* movement, one of the most influential movements in the history of urban planning, targets the uncontrolled growth of the cities and its consequences. In 1898, Ebenezer Howard introduced the Garden City concept as a response to overcrowded and deteriorated cities like London and as a solution to improve the quality of life of the residents. Howard provided some ground rules for the concept but left the room open for the Garden City to be designed based on the site characteristics and the social and cultural backgrounds of the society. The aim of the Garden City was to improve the quality of life, to provide each family with a house and a piece of garden, to accommodate people of different social classes and to provide working opportunities at different levels all through building a well-planned city. Some of the concerned are to be found also in the definition of sustainable communities: high quality of life, opportunity and services for all and well-planned communities.

The Garden City movement originated in the UK but was soon translated and interpreted in other countries. Germany was one of the pioneers to adopt the idea of the Garden City and to initiate realizing the concept by planning and building Garden Cities. Among the German Garden Cities Karlsruhe was the first one to be founded and is considered as an important example in Germany. The flexibility in designing the Garden City makes the concept adoptable and transferable to different contexts and its principles applicable to new settlements as well as the existing ones (Unwin 2014). Considering that the characteristics of the neighborhood play an essential role in residents' decisions to

leave (or stay in) the neighborhood (Feijten and van Ham, 2009), it is necessary to analyze how the characteristics of a settlement, like the Garden City, influence the residents' behavior, including residential mobility. Therefore, the current paper takes one of the most important German Garden Cities as the case study and analyses the perception of the residents, of living today in the Garden City.

3. Case Study

The Garden City Cooperative in Karlsruhe was founded in 1907 with the aim of building the first German Garden City. However, the construction started first in 1911 and Karlsruhe Garden City was built, as the second German example, in an area called Rüppurr, located in the south part of Karlsruhe in southwestern Germany. According to an agreement between the Garden City Cooperative and the city of Karlsruhe, a large part of the Garden City was registered as historical monument and therefore under conservation (Figure 1). Its architectural and socio-historical significance, the artistic elements and exemplary values were the reasons for this decision (DSchG BW, 1983).

Figure 1: Houses considered as historical monuments in the Garden City of Karlsruhe (source: City of Karlsruhe)

The area under conservation includes 641 single family houses (single buildings, row houses and double houses) and 70 apartment buildings; out of which 646 are classified as historical monument and considered in this paper. All single family houses in the Garden City are provided with a garden and have a similar spatial division which follows the clear zoning; the kitchen and the living room on the ground floor; bedrooms on the upper floor and service area in the basement. They are categorized into different types according to their characteristics including the entrance (side or central), position of the staircase, number of the rooms as well as their arrangement and position (street side vs. garden side). The Garden City is run by community ownership and the inhabitants are the members of the cooperative. The Garden City Cooperative is in charge of the administrations and renting out the houses, meaning that the inhabitants of the Garden City do now own the properties.

4. Methodology and Data Collection

Data for this research was gathered through a survey carried out by the author. The survey was meant not to be anonymous as the end goal was to merge the data from the survey with the database of the Garden City Cooperative. To this aim the participants were requested to provide the address of their house. The survey covered questions regarding the building (architectural design, material, elements), inhabitants (demographic data, motivation for living in the Garden City, satisfaction with the neighborhood) and neighborhood (activities and facilities). These questions were in different forms; rating scale (5-point) questions where the respondent could choose a rate between 1 (lowest) and 5 (highest), "yes" or "no" questions, closed-ended questions, usually followed by a field where the respondents could add their answer if it was not one of the possible options, open-ended questions, multiple choice questions where the respondents could choose one or more answers.

In the first round the questionnaires were distributed (dropped in the mailbox) among all the houses in the Garden City which are considered as monuments. Two months later a reminder was sent to the households who had not participated in the survey or had not provided the full address. One month after the first reminder, 100 addresses were picked using the random function of Excel, and the chosen addresses were contacted in person and were requested to fill in the questionnaire. After consultation with the Garden City Cooperative, respondents were asked to return the filled-in questionnaires to one of the former representatives of the Cooperatives who lives in the area. In order to potentially increase the response rate, and before carrying out the survey, the inhabitants of the Garden City became aware of the ongoing research with the help of the Garden City Cooperative and through an announcement in the regular magazine (*Freude am Wohnen,* 2017) published by the Cooperative.

Out of 646 households, 138 questionnaires were filled in and returned which gives us a response rate of 21.4%, with a confidence level of 95% and a 7% error margin based on the Cochran's formula (Cochran 1963). After receiving the surveys, the data was inserted into an Excel database, it was then analyzed and when possible compared with the overall trend in Germany (using the data from SOEP and Eurostat). The survey was carried out in 2017 and therefore the results were compared with the available data from 2017.

5. Results

The relevant results of the survey are discussed here in two different categories, inhabitants and their relationships and interactions in the Garden City. In each part the respective question from the questionnaire is mentioned:

5.1 Demographic data

On average 2.2 people live in each household in the Garden City, higher than the average household size in Germany (2.0). The highest share corresponds the households with two people (47.9%) and 24.8% accommodate only one person. These values are respectively 33.8% and 41.4% for Germany. The responding households

include inhabitants between the age of 1 and 96 years old, with a mean and median value of 49.5 and 54 years, respectively. The mean age in Germany is 45.9 years (Eurostat 2020b). Figure 1 and Figure 2 compare the values in the Garden City and Germany. At least 28.6% of the participants in the survey have a university degree, 22.6% have done a vocational training and 17.3% have a high school diploma. The rest have either a secondary education or no certificates. More than half of the participants in the survey must travel to work and the average distance from home to the place of work is around 23.3 km.

5.2 What was the initial reason for you to live in the Garden City?

The inhabitants were asked about the motivation for living in the Garden City. 61.0% of the inhabitants made their own decision to live in the Garden City, out of which 5.6% have inherited the house where they live in. It is to be noted that in the Garden City of Karlsruhe the rental contract can be inherited to the tenants' children. After own-decision, birth (20.6%) is the second common reason for living there, followed by marriage (11.8%) and moved in with the parents (6.6%).

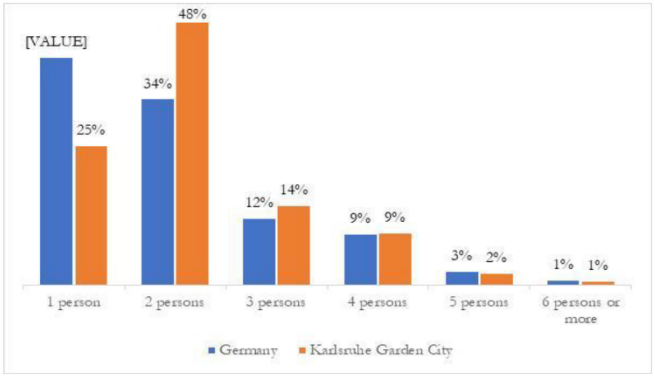

Figure 2: Household size Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and Eurostat 2020a)

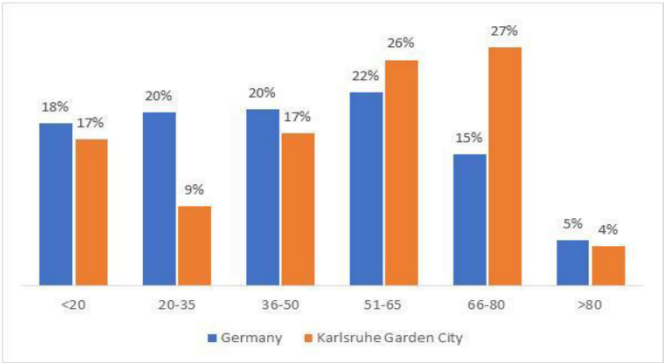

Figure 3: Age of the inhabitants Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and Eurostat 2020c)

5.3 How long have you lived in the Garden City?

A comparison between the collected data from the Garden City and the available data for Germany (SOEP) shows a noticeable difference between the ongoing trends (Figure 4). The participants in the study have lived in their houses in the Garden City on average for 33.8 years. This figure is almost half (18.5 years) for Germany. In both cases the share of the inhabitants gradually decreases by increasing the period of living in the current home. However, in case of the Garden City the share is constantly higher up to the point of 70 years. Moreover, the trend shows more consistency between the years 13 and 26. The graph clearly shows a positive and increasing ratio between the values for the Garden City and the overall trend in Germany, indicating a more sustainable trend in the Garden City. In total 50% of the participants have resided in the Garden City for more than 35 years and 25% have lived there for almost 50 years or more. These figures are respectively 14 and 28 years for Germany (Table 1).

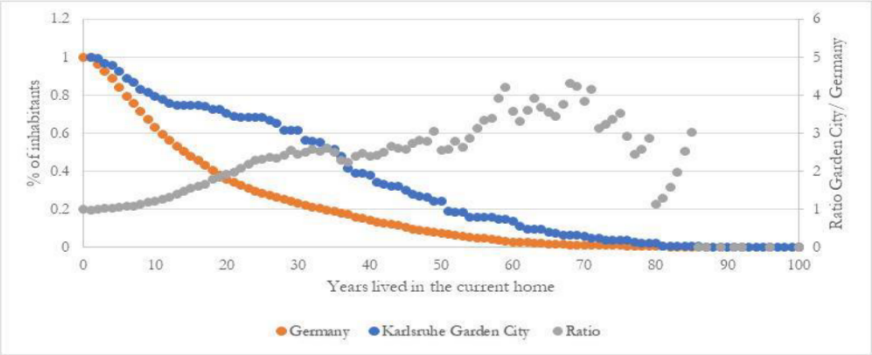

Figure 4: Duration of living in the current home- Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and SOEP)

Table 1: Mean relative duration of living in the current home (source: own calculation based on collected data and SOEP)

	Quartile 1	Median	Quartile 3
Germany	7	14	28
Karlsruhe Garden City	11	35	49.5

5.4 Would you recommend others to live in the Garden City?

A 5-point Likert scale was used to define the extent to which the inhabitants of the Garden City recommend living in this area. More than half of the residents absolutely recommend it to other people to live in the Garden City. One fifth of the inhabitants would still recommend it however with a lower certainty. This means 75% of the inhabitants highly recommend moving to the Garden City. Only 7.5% of the participants do not make such a recommendation.

5.5 Are there any interesting activities organized in the Garden City?

The Garden City Cooperative offers some activities in the neighborhood and residents were asked about their impression of those activities. Moreover, they were

requested to name the interesting offers by the Garden City. Among all 138 participants, 47 have provided a valid answer to this question. Neighborhood Breakfast was the most mentioned activity with 64%. After that offered excursions are the second most interesting, mentioned by 34% of the participants. 15% of the inhabitants had mentioned that they do not participate in the events and 6% were not aware of the available options.

5.6 How is your relationship with the neighbors?

A 5-point Likert scale was also used for this question. Roughly two thirds of the residents have a (very) close relationship with their neighbors (scales 4 and 5); among those 42.1% are in very close contacts with the neighbors. The data for Germany shows a much lower figure; only 8.4% have a very close relationship with their neighbors (Figure 5). Around half of the people in Germany have a moderate contact with the neighbors, in contrast to 18% in the Garden City. On the other hand, only around 15% of the residents do not have a lot of interactions with the neighbors (scales 1 and 2).

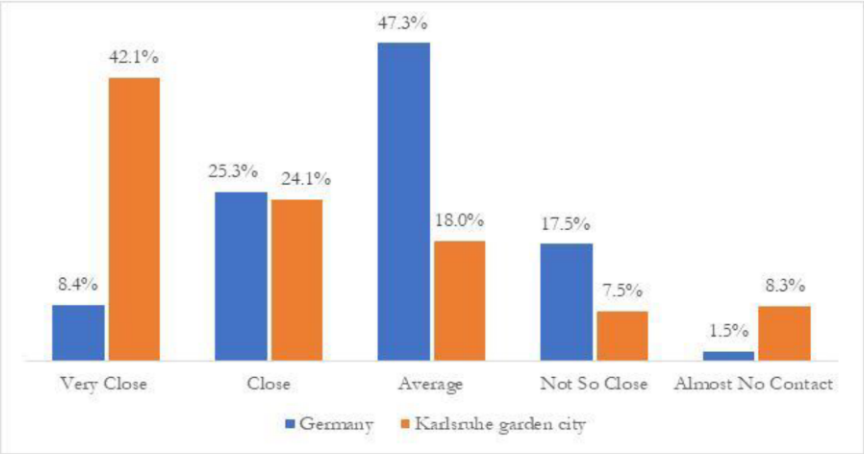

Figure 5: Relationship with the neighbors- Germany vs. Karlsruhe Garden City (source: own illustration based on collected data and SOEP)

5.7 What do you like in the Garden City?

This was an open question and the participants could write what they liked in the Garden City. In total 126 participant have provided an answer to this question. As expected, the highest share relates to the greenery in the Garden City (54.8%). Among those, 36.2% of the inhabitants have specifically mentioned "living in green" as one of their favorite characteristics. It is however not usual that only 54.8% of the participants have considered the green areas as a favorable element of the Garden City. The next favored characteristics are the central location (34.9%) and having a peaceful and quiet environment (23.8%). Having own share of the garden is what 19.8% of the residents like about living in the Garden City. Other interesting figures in this list are reasonable rent (13.5%), social mixture (7.9%), village feeling (7.1%), dismissal protection (7.1%) and community living (5.6%).

5.8 What do you not like in the Garden City?

The parking situation in the Garden City (too many cars and narrow streets) is what bothers the inhabitants the most; mentioned by almost half of the 98 participants who have answered this question. 15% are unhappy with the way the problems are dealt with by the Cooperative. In addition to that 10% of the residents consider their current rent expensive and they complain about increases of the rent the reason for which is not always clear and traceable. Some of the older tenants have expressed their willingness to move into a smaller flat as their family size has shrunk and their current dwelling has more living space than their needs. What they mention as the obstacle on the way is the higher rent that they will pay if they start a new contract even if they will be living in a smaller flat.

6. Discussion

Bramley and Morgan (2003) believe that the sense of belonging to the surroundings is stronger in the homeowners compared to the renters. Similarly, research on geographic mobility in the EU (European Union, 2015) shows that there is a lower likelihood for the homeowners to move home than the renters. The same study reveals that people living in the cities are more likely to change places than the ones in rural areas. Kemper (2008) analyzes the type of destination dwellings to which the inhabitants move. The results show that the highest share in West Germany corresponds the residential buildings with 5-8 apartments and the least favorable is the terraced house. According to the results of this study, the most observed destination quarters are the ones with mostly new buildings; with a slight difference comes the quarter with mostly old buildings (built prior to the second world war) in the second place. The points mentioned here do not match the characteristics of the case study of this paper, as the Garden City of Karlsruhe is run by community ownership in which none of the inhabitants of the settlement owns their property. It consists of mostly old buildings and terraced houses.

Sustainable communities are defined as the places where existing and future generations would like to live and work. This paper analyzed the Garden City which was developed following the idea of sustainable living long before the idea of sustainability became prominent in order to find out if it is still able to keep up with these promises. The presented survey provides strong support for this assumption. First of all, it has shown the willingness of the residents to not only live for a long time in the Garden City but also recommend living in the Garden City to others. About two-thirds of all 138 participants in the survey have lived in the Garden City for more than 25 years. Among all the participants 60.1% have freely decided to live or to continue living in the Garden City. Several factors could be the possible reasons behind these observations, e.g. community ownership, architectural and urban features, the history behind the Garden City. It could be argued that although the inhabitants do not own the properties, they have the feeling of homeowners due to the special circumstances in the Garden City, namely membership in the Cooperative and the long waiting times for receiving a house. On the other hand, the street structure and the design of the houses might encourage the residents to have a closer relationship with the neighbors, what was referred to as the

"village feeling" by some of the respondents.
Like all empirical work, the study design also has some limitations. The most important one is probably that it is likely that the survey sample is biased towards more engaged renters as participation in surveys in voluntary. Second as participants were asked to provide their names this may have increased social desirability as well as the fact that the survey was handed in via a former representative of the cooperative. However, this design was chosen after weighing different alternatives. The aim of this paper was then to share those observations and to raise the interest for further research about the underlying reasons. Socially enhancing the situation in the communities and settlements like Garden Cities would count as a crucial step toward social sustainability and it is hence essential to identify the relevant indicators of social sustainability in the Garden Cities. The results of this study will be used as the first dataset to develop a framework specifically suitable for the Garden Cities.
Although the Cooperative publishes the news and updates about the Garden City regularly, it seems that some of the problems and dislikes mentioned by the inhabitants are indeed due to the lack of communication about the ongoing projects and policies within the Garden City Cooperative. Hence it would be essential to communicate the observations of this survey with the Garden City Cooperative and to tackle these issues from the Cooperative's point of view. Although the satisfaction rate is already high in the Garden City, it is assumed that making people more involved and improving the ways of communication, would improve their satisfaction level even more. Therefore, this paper has tried to investigate the ongoing concerns and impressions of the inhabitants and will communicate them with the Garden City Cooperative.

Conclusion

This paper focuses on sustainable communities as one of the indicators of urban social sustainability. Considering the similarities between the definition of a sustainable community and the objectives of the Garden City movement, e.g. the concerns about higher quality of life and providing opportunities and services for all , the study tries to find the traces of social sustainability in one of the first examples of the Garden City in Germany. Building on the results of this paper, the next step would be to study other indicators of the social sustainability in this type of settlement. The results of the survey will then serve as the initial dataset for developing a framework for studying social sustainability in the Garden Cities. The findings of this study will be made available to the Garden City Cooperative.

Acknowledgment

The author would like to thank the residents of Karlsruhe Garden City for participating in the survey and providing the input for this research, and the staff of the Garden City Cooperative, especially Wolfgang Gerstberger, the former deputy chairman of the cooperative, for their support during the data collection phase. Special thanks go to Dr. Elisabeth Dütschke for her valuable feedback and comments on the paper.

References

Bramley, Glen, Nicola Dempsey, Sinead Power, Caroline Brown, and David Watkins. 2009. Social Sustainability and Urban Form: Evidence from Five British Cities. *Environment and Planning A: Economy and Space* 41, no. 9: 2125–42. 10.1068/a4184.

Bramley, Glen, and James Morgan. 2003. Building Competitiveness and Cohesion: The Role of New Housebuilding in Central Scotland's Cities. *Housing Studies* 18, no. 4: 447–71. 10.1080/02673030304245.

Cochran, William G. 1963. *Sampling techniques. 2nd ed.* New York: John Wiley and Sons.

Colantonio, Andrea. 2007. Social Sustainability: An Exploratory Analysis of its Definition, Assessment Methods, Metrics and Tools: Best Practice from Urban Renewal in the EU. *2007/01: EIBURS Working Paper Series.*

Dempsey, Nicola, Glen Bramley, Sinéad Power, and Caroline Brown. 2011. The social dimension of sustainable development: Defining urban social sustainability. *Sustainable Development* 19, no. 5: 289–300. 10.1002/sd.417.

European Union. 2015. *People in the EU: Who are we and how do we live? : 2015 edition.* 2015 edition. *Statistical books.* Luxembourg: Publications Office.

Eurostat. 2020a. Household composition statistics - Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php/Household_composition_statistics (accessed April 22, 2020).

———. 2020b. Population structure and ageing - Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing (accessed April 22, 2020).

———. 2020c. Population: Structure indicators by NUTS 2 region - Eurostat. https://ec.europa.eu/eurostat/web/products-datasets/product?code=demo_r_pjanind2 (accessed April 22, 2020).

Freude am Wohnen. 2017. Umfrage für Doktorarbeit, October 2017, 5.

Gesetz zum Schutz der Kulturdenkmale (Denkmalschutzgesetz - DSchG) in der Fassung vom 6. Dezember 1983. 1983. http://www.landesrecht-bw.de/jportal/?quelle=jlink&query=DSchG+BW&psml=bsbawueprod.psml&max=true&aiz=true (accessed April 30, 2020).

Ghahramanpouri, Amir, Ahmad S. Abdullah, Sepideh Sedaghatnia, and Hasanuddin Lamit. 2015. Urban Social Sustainability Contributing Factors in Kuala Lumpur Streets. *Procedia - Social and Behavioral Sciences* 201: 368–76. 10.1016/j.sbspro.2015.08.188.

Kemper, Franz-Josef. 2008. Residential mobility in East and West Germany: mobility rates, mobility reasons, reurbanization. *Zeitschrift für Bevölkerungswissenschaft* 33, no. 3: 293–314. 10.1007/s12523-009-0018-1.

Liebig, Stefan, Jürgen Schupp, Jan Goebel, David Richter, Carsten Schröder, Charlotte Bartels, Alexandra Fedorets, Andreas Franken, Marco Giesselmann, Markus Grabka, Jannes Jacobsen, Selin Kara, Peter Krause, Hannes Kröger, Martin Kroh, Maria Metzing, Jana Nebelin, Diana Schacht, Paul Schmelzer, Christian Schmitt, Daniel Schnitzlein, Rainer Siegers, Knut Wenzig, Stefan Zimmermann, and Deutsches Institut Für Wirtschaftsforschung. 2019. *Socio-Economic Panel (SOEP), data for years 1984-2017*, 2019.

Long, L. H., C. G. Boertlein, and United States. Bureau of the Census. 1976. *The geographical mobility of Americans: an international comparison. Current population reports: Special studies*: U.S. Dept. of Commerce, Bureau of the Census : for sale by the Supt. of Docs., U.S. Govt. Print. Off. https://books.google.de/books?id=-77Jy9TRsfkC.

Long, L. H., and D. DeAre. 1981. *Population Redistribution: 1960-1980.* Washington, D.C.: U.S. Bureau of the Census, Government Printing Office.

ODPM. 2005. Sustainable Communities: People, Places and Prosperity.

Packard, V. 1972. *A nation of strangers. A Nation of Strangers*: McKay. https://books.google.de/books?id=Cxe7AAAAIAAJ.

Panda, Sudha, Manjari Chakraborty, and S. K. Misra. 2016. Assessment of social sustainable development in urban India by a composite index. *International Journal of Sustainable Built Environment* 5, no. 2: 435–50. 10.1016/j.ijsbe.2016.08.001.

Schneider, Wolfgang, Konrad Stahl, and Raymond J. Struyk. 2013. "Residential Mobility in the United States and the Federal Republic of Germany." In *U.S. and West German Housing Markets: Comparative Economic Analyses*, ed. K. Stahl and R. J. Struyk, 23–54. Berlin: Springer Berlin.

Sennett, Richard. 1999. *The corrosion of character: The personal consequences of work in the new capitalism.* New York, London: W. W. Norton.

Silburn, Richard. 1999. *Neighbourhood images in Nottingham: Social cohesion and neighbourhood change*. York: YPS.
Spangenberg, Joachim, and Ines Omann. 2006. Assessing social sustainability: Social sustainability and its multicriteria assessment in a sustainability scenario for Germany. *Int. J. Innovation & Sustainable Development* 1: 318–48. 10.1504/IJISD.2006.013734.
Toffler, Alvin. 1970. *Future shock*. New York: Random House.
United Nations. 2015. General Assembly Resolution A/RES/70/1: Transforming Our World, the 2030 Agenda for Sustainable Development. https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (accessed April 22, 2020).
Unwin, Raymond. 2014. *Nothing gained by overcrowding: With an introduction by Dr Mervyn Miller*. *Studies in international planning history*. London, New York: Routledge.
Yiftachel, Oren, and David Hedgcock. 1993. Urban social sustainability. *Cities* 10, no. 2: 139–57. 10.1016/0264-2751(93)90045-K.

Published by ECSDEV, Via dei Fiori, 34, 00172, Rome, Italy http://ecsdev.org

Appendix B: Original published version of Paper 2

Consumption and Society • vol XX • no XX • 1–23 • © Authors 2024
Online ISSN 2752-8499 • https://doi.org/10.1332/27528499Y2024D000000025
Accepted for publication 08 July 2024 • First published online 21 August 2024

RESEARCH ARTICLE

Investigating the influence of current trends and behaviours on household structures and housing consumption patterns

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As a major contributor to overall carbon emissions and energy consumption, the housing sector has great potential to reduce energy consumption, whether by reducing the number of appliances, heating temperature or floor space. Consumption patterns encompass how people choose and consume products that satisfy their needs and wants. However, wants, and to some extent needs, are influenced by various factors and existing material and non-material (infra) structures, especially in the housing sector. Focusing on the floor area, this article aims to identify potentials towards lower consumption lifestyles by applying the Avoid-Shift-Improve framework in the residential sector. Through a conceptual review, the article explores what shapes current patterns of space use and outlines potential future pathways. Starting from the macro level, the article examines existing and emerging (societal) trends with (potential) impacts on housing consumption. It then looks at the structural development of households affected by the studied trends. At the micro level, the article provides an overview of the potential impact of individual behaviour on space use patterns within different categories of housing behaviour. The article identifies the potential for social and technical change in the housing sector and concludes that promoting non-materialistic narratives (avoid), offering alternative and innovative solutions to satisfy people's spatial needs (shift) and designing flexible buildings (improve) appear to be effective ways for fostering behavioural change towards more efficient use of space.

Keywords housing sector • energy consumption • lifestyle • consumption pattern • behavioural changes

Key messages

- The study identifies potentials to reduce space use in the housing sector.
- The Avoid-Shift-Improve framework was used as the analytical framework.
- Identified trends can prevent downsizing by influencing household structure and consumption.
- Non-materialist narrative, social and technical innovation can drive change towards space reduction.

To cite this article: Bagheri, M., Tröger, J. and Freudenberg, C. (2024) Investigating the influence of current trends and behaviours on household structures and housing consumption patterns, *Consumption and Society*, XX(XX): 1–23, DOI: 10.1332/27528499Y2024D000000025

Introduction

The housing sector is a major contributor to CO_2 emissions. In 2020 all phases of construction, use and operation accounted for at least 37 per cent of global CO_2 emissions, and heating and cooling, cooking, and the use of appliances are responsible for at least 28 per cent of these emissions (United Nations, Human Rights Council, 2022). The increase in the amount of living space per capita, which has been observed worldwide in recent decades, results in, on the one hand, the need for more building materials and, on the other hand, an increase in energy consumption during the use phase of the dwelling. Reducing the floor area therefore not only reduces the energy demand in the use phase of the building but also has the largest potential for reducing the emissions from materials in the building sector (Zhong et al, 2021). This type of demand reduction is therefore the most effective approach to reducing the carbon footprint of the housing sector.

A household is defined as a social unit consisting of a person living alone or a group of people living together in the same dwelling (Eurostat, 2017; Merriam-Webster, 2023). Household structure, which refers to household demography, living arrangements and household economics (Sociology, 2019), varies across cultures and countries and evolves over time, influenced by dynamic socioeconomic trends. Housing satisfies the need for shelter, one of the basic needs to which every individual is entitled (Doyal and Gough, 1984). However, in addition to satisfying this basic need, the form of housing and housing-related behaviours play a role in the self-expression and sense of belonging of individuals, making a house a symbol of self (Newmark and Thompson, 1977).

The link between consumption patterns and lifestyle has been discussed in several studies in recent decades (for example, Reusswig et al, 2003; Gram-Hanssen, 2012; Oliveira et al, 2020). Gram-Hanssen (2012) argues that an individual's values and attitudes shape their lifestyle and can be observed through their different types of consumption in all areas, from food to housing to clothing. Similarly, Bosserman (1983) defines lifestyle as a pattern of consumption that reflects values, tastes and preferences. Many studies have addressed this link in different sectors such as energy, food, housing and transport (Reusswig et al, 2003; Hubacek et al, 2007; Gram-Hanssen, 2012; Saleem and Ali, 2019). Moreover, the ever-increasing environmental impacts of Western lifestyles and consumption patterns, especially in the housing sector, have already been addressed (Bjørn et al, 2018; Saleem and Ali, 2019).

The way we consume and how these patterns relate to our needs has also been addressed in the literature. Coelho et al (2020: 21) define consumption patterns as '[t]he process by which people search, purchase and consume products in a way to meet all their needs or desires'. Consumption patterns are directly defined by how and which needs and desires we want to satisfy, which in turn should be an indicator of a growing quality of life. While classical economic theories predict a linear correlation

between our consumption growth and quality of life, recent empirical evidence suggests a weak link between the two, showing no or even a negative contribution of consumption to quality of life (Jackson, 2005; Vita et al, 2019). Moreover, at the macro level, after a certain threshold, the satisfaction of human needs increasingly depends on non-material factors (Sen, 1988; Vita et al, 2019), such as social ties and psychological well-being (Sirgy, 2002).

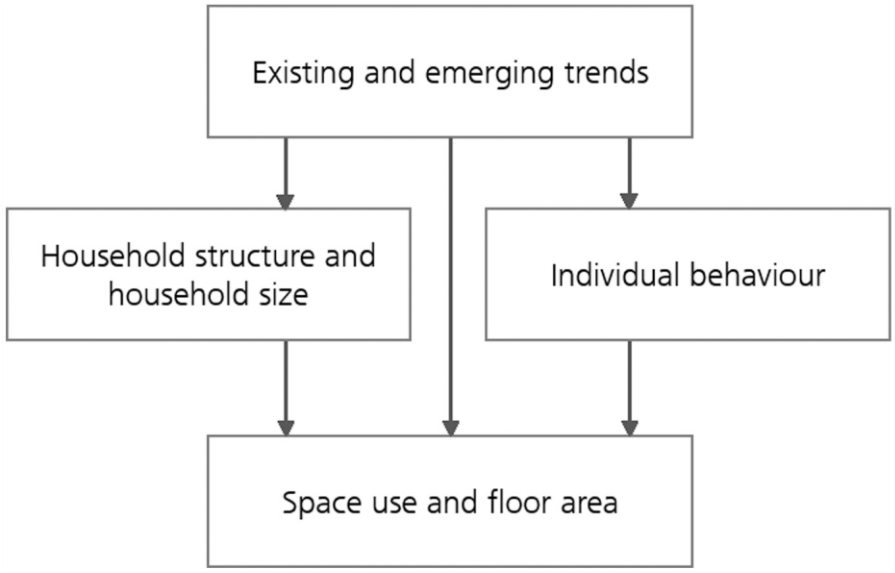
Considering the fluidity and changeability of lifestyles, theories recognise that people are not determined by static parameters at a personal or situational level but by dynamic and interactive ones (Walters, 2006). Studies show that housing needs and preferences are influenced by factors such as societal norms, working styles and income levels (see, for example, Højrup, 2003; Benedikter, 2012). Social structures, on the other hand, are shaped by individuals' 'habitus', as they continuously find new solutions and solve problems based on their intuition and past social experiences (Bourdieu, 1987). Meadows (1999) refers to 'leverage points' as the places in a complex system where small interventions can lead to large changes. The author lists several 'places to intervene' in the systems to evoke transformative changes, for example, changes in parameters, information flow and the system's goal. Tröger et al (2022) support this framework and argue that changes in situations, such as infrastructure and available options, as well as changes in people's mindsets, can lead to fundamental changes in behavioural patterns.

Investigating the trade-offs of selected actions and their possible effects on energy consumption in residential buildings, Pérez-Sánchez et al (2022) emphasise the significance of incorporating both social (concerning the household) and technical (concerning the dwelling) changes to address environmental challenges in the building sector. This article builds upon their findings and delves deeper into identifying the potential for these social and technical changes in the EU housing sector, aiming to achieve reduced energy consumption. To accomplish this, the paper:

- explores the potential and important routes of influences between different factors in the housing sector that affect the amount of space used in dwellings (Figure 1); and
- applying the Avoid-Shift-Improve (ASI) framework, identifies the social and technical solutions that can potentially orient the impact of those factors towards such positive changes.

With its origins in the early 1990s in Germany, the ASI framework introduces an approach to structure the policy measures to reduce energy consumption and greenhouse gas emissions in line with the 1.5°C Paris Agreement goal (Dalkmann and Brannigan, 2007). With a focus on the demand side, the framework consists of three pillars: 'avoid' refers to reducing the need for services (for example, the need for motorised travel); 'shift' addresses changing to more energy-efficient and environmentally friendly means (for example, modal shift from private cars to buses or trains); and 'improve' focuses on increasing the efficiency of the service provider (for example, fuel and vehicle efficiency). Initially the framework targeted the transport sector. However, it has been taken up in some other domains as well. For instance, Creutzig et al (2018) and IPCC (2022) use the ASI approach in the discussions for mitigating climate change and illustrate service-oriented solutions in sectors and services such as clothing, appliances, goods and nutrition. Even within the transport

Figure 1: Potential routes of influence between different factors in the housing sector (only one-way relationships are considered)



sector, the framework is used with different foci (for example, a conceptual framework for transport in response to COVID-19 in TUMI [2020]; and telecommunications in Corral Naveda [2022]).

In line with the ASI framework, the present work reflects on the impact of selected factors on space use and proposes recommendations for improving the social and technical infrastructure to achieve space use reductions as a contribution to reach the Paris climate targets and increase societal well-being. We apply a conceptual review of qualitative and quantitative literature at multiple levels to identify the affecting factors. Figure 2 illustrates the research design and highlights the steps of analysis. The methods and data sources used for the analysis are explained throughout the article in each section.

Existing and emerging trends

This chapter examines the selected trends that may have an impact on the use of space in the housing sector, either directly or indirectly through changes in household structure that in turn affect the space use. To select these trends, a rapid literature review was conducted using various combinations of the following keywords in search engines such as Google Scholar and Scopus: *trends/factors, effects, residential space use, household structure/composition*. The titles and abstracts of approximately 150 studies were scanned, of which 25 were considered potentially relevant. The main text of these studies was analysed with the aim of extracting factors that were considered to have an impact on space use or household structure. Nine studies discussing such factors and the list of trends and factors mentioned in these studies are presented in Table 1. The listed trends and factors were harmonised (for example, wage rates,

Figure 2: Research design

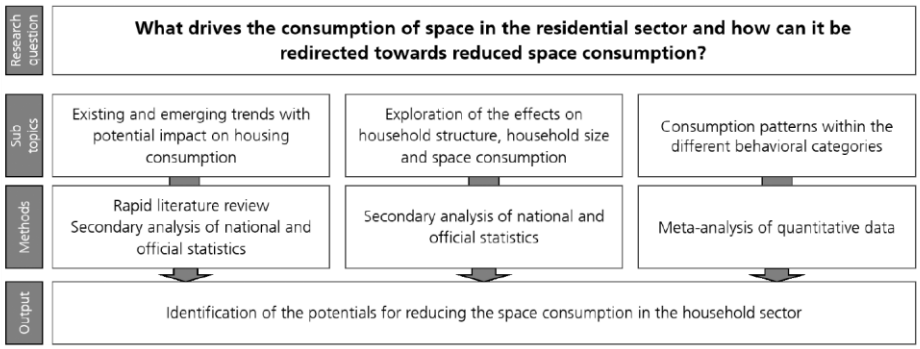


Table 1: Selected literature on factors influencing space use or household structure

Source	Mentioned factors/trends
Blau and van der Klaauw (2013)	wage rates, tax and transfer incentives, legal environment, state of the marriage market
Mason (2023)	economic well-being
Greenwood et al (2017)	fertility,women, employment, marriage, divorce, assortative mating, children living with a single mother, shift in social norms
Wulff et al (2004)	ageing population, birth rates, divorce and marriage rate
OECD (2021)	teleworking, digitalisation, ageing population, climate change
OECD (2022)	COVID-19 pandemic, digital sharing platforms, e-commerce effects, rapid population ageing, urbanisation
Williams (2009)	ageing population, couple forming later in life, divorce rates, income, house prices and availability, employment opportunities, social provision for children and the elderly, the age at which young people move into their own homes
Xie et al (2020)	urbanisation
Stewart (2006)	birth rates, longevity, family disintegration, life expectancy, childhood mortality rate, income, ageing population, employment rate, homeownership
Pérez-Sánchez et al (2022)	shareability and economies of scale, flexibility of time and level of services

economic well-being and income are all collapsed into income) and the recurring trends (that is, mentioned more than once) were examined. The resulting factors are ageing population, income, employment, marriage, divorce, births, digitalisation, urbanisation and sharing economy. Additionally, the historical development of these trends was studied through secondary analyses of official national and EU statistics from reputable sources such as the Statistical Office of the European Union (Eurostat) and the Federal Statistical Office of Germany (Destatis).

Ageing population

Rising life expectancy and low birth rates mean that the proportion of older people in Europe's total population is increasing. The median age in the EU-27 is projected

to increase by 4.5 years between 2019 and 2050, reaching 48.2 by the end of this period (European Parliament, 2021). The proportion of the EU population aged 80 and over is projected to increase two and a half times between 2021 and 2100, from 6.0 per cent to 14.6 per cent. The over-65s will account for 31.3 per cent of the EU population by the end of the century. In 2021, their share was only 20.9 per cent, which was already 17 per cent more than a decade earlier (Eurostat, 2023i). In contrast, the population group aged 15 to 65 will shrink by about 10 percentage points over the same period (Eurostat, 2023h). An increase in the median age in Europe has also been observed in recent decades: from 38.4 years in 2001 to 43.7 years in 2019 (European Parliament, 2021).

Income

Economic conditions, including income trends, vary across European countries due to factors such as economic policies, global economic dynamics and regional circumstances. According to recent data from Eurostat (2023f), the EU countries with the highest median disposable incomes in 2022 were Luxembourg, the Netherlands, Austria, Belgium, Denmark and Germany. In contrast, Bulgaria, Slovakia, Romania, Hungary and Greece reported the lowest values. This indicates, that income varies considerably across Europe with the Nordic countries having higher per capita income than the Southeastern and the Baltic states. Furthermore, the Gini coefficient was 29.6 in 2022. In tendency, the Gini coefficient slightly declined over the last ten years across Europe (Eurostat, 2023f). However, many studies highlight a widening gap between rich and poor in many European countries and outline increasing inequality over recent decades (for example, Eurostat, 2010; Blanchet et al, 2019; Hung, 2021). This gap may be influenced by factors such as changes in labour markets, technological advancements, globalisation and policy decisions. Furthermore, growing income disparities in the EU have led to economic consequences, including migration from poorer to wealthier countries and shifts in industrial production, which has also fuelled discontent and support for populist movements, posing a threat to cohesion and democracy within the EU.

Employment

In 2020, 72.3 per cent of the EU population aged between 20 and 64 were employed, 10 per cent more than the rate in 2000. In the same period, with the exception of Greece and Denmark, in all EU countries the employment rate has increased. The absolute employment rates in 2020 separated for males and females of the same age group follow almost the same pattern in the member states with an average EU level of 78.0 per cent for men and 66.5 per cent for women. However, the relative rates compared to the year 2000 differ significantly for men and women. The rate of female employment has risen in all the EU countries except for Romania and the highest jump is observed in Malta where the female employment rate in 2020 is double that of 2000, followed by Bulgaria and Spain with an increase of around 35 per cent in the number of employed women. The change in the male employment rate in the same period ranges between -10.3 per cent in Greece and 29.2 per cent in Bulgaria. The EU average has risen by 3.7 per

cent for the male population compared to the major increase of 19 per cent for the female population (Eurostat, 2023c).

Marriage, divorce, childbirth

While the crude marriage rate, that is, the number of marriages during the year per 1,000 persons, in the EU has fallen from 5.2 in 2000 to 3.9 in 2021 (Eurostat, 2023g), the crude divorce rate has fluctuated over the same period, peaking in 2006 and then falling slightly. In 2022, an average of 1.7 divorces per 1,000 persons were reported, showing almost one divorce for every two marriages. Between 2000 and 2017, the average age at first marriage increased in EU member states with available data for both men and women between around 2.1 and 5.5 years. The average age of women at the birth of their first child has also increased over the last two decades in all EU countries between 1.3 and 4.6 years, reaching an average of 29.5 years in 2021. In that year, women in more than a third of EU member states gave birth to their first child at an average age of 30 or more.

Digitalisation

One of the most influential trends of recent decades has been increasing digitalisation. The term refers to the widespread transformation of formerly analogue processes, assets, goods and services into digital ones, enabled by underlying innovations in information and communication technologies (ICT). Across different sectors of the economy and society, the increasing integration of digital technologies is shaping the way businesses and public administrations operate and the way individuals interact with each other and the world around them.

The trend shapes the way people carry out everyday tasks, gather information or communicate in a globalised world. Digital technologies have also helped to reduce transaction costs, increase process efficiency, productivity and competitiveness in various economic sectors and support the creation of entirely new digital goods and services of the so-called 'digital economy' (Kravchenko et al, 2019). Disruptive machine learning and artificial intelligence technologies support breaking new scientific ground and creating new industries and markets, ultimately affecting the organisation of societies around the world. As such the digitalisation trend is not only changing technology landscape but is also fundamentally driving socioeconomic transformation processes.

Sharing economy

In traditional markets, consumers buy products and acquire ownership (Dervojeda et al, 2013). However, the sharing of goods and services has become increasingly important in Europe in recent years (Hamari et al, 2016) and the demand for sharing models is expected to grow in the future. While the emergence of new technological capabilities is accelerating the growth of the sharing economy, the literature identifies key motivations for consumers to prefer the sharing economy. In contrast to ownership, which often involves a high financial burden for purchase and maintenance reasons, the sharing economy is financially profitable for consumers, who only have to pay for what they actually use. Owners of shared items have also the opportunity to generate income

by sharing them. Motivation in terms of norms such as environmental sustainability is seen as an important predictor of participation in sharing economy business models (Hamari et al, 2016) as sharing economy models are generally expected to be highly sustainable (Prothero et al, 2011). The use of the sharing economy can involve a significant level of personal interaction and community experience, particularly when products are offered by individuals rather than 'faceless' companies. There is a growing demand for this type of consumption, leading businesses to shift from transaction-based (that is, primarily focusing on completing a transaction or exchanging goods or services) to experience-based services (that is, the focus is on creating a positive experience for and a sense of connection with customers) that rely on trust (PwC, 2015). Another important consumer trend influencing the development of the sharing economy is the change in what is seen as a status symbol. While property used to be a kind of status symbol, there is a trend away from this understanding, especially among young people (PwC, 2015). In contrast to owning property, users of access driven business models are far less tied down and enjoy the ability to switch products and services at any time.

Urbanisation

Urbanisation has been identified by the European Commission as one of the most influential megatrends for some time. At a global level, the population living in cities, defined as high-density places of at least 50,000 inhabitants, has more than doubled in the last 40 years, from 1.5 billion in 1975 to 3.5 billion in 2015. It is projected to reach 5 billion by 2055, almost 55 per cent of the world's population. In Europe too, the trend towards urbanisation has intensified in recent decades, with more and more people moving to urban areas (European Commission, 2023). By 2021, more than 70 per cent of Europe's population already lived in urban areas (World Bank, 2022), and Europe's urbanisation rate is expected to increase to around 83.7 per cent by 2050 (United Nations, 2018). However, this process is uneven across the continent. While urbanisation rates are already high in Western and Northern Europe, there is still a significant level of rural–urban migration in Eastern Europe and certain rural areas (World Bank, 2022).

There are many reasons for urbanisation in Europe. One the one hand, cities offer a wider choice of jobs and career opportunities in different sectors, especially in services, technology and creative industries. Proximity to businesses, universities and research institutions fosters innovation and economic growth. In addition, urban areas offer a wide range of educational, health and cultural opportunities. High-quality schools and universities, medical facilities, museums, theatres, restaurants and shopping opportunities attract people who value the urban lifestyle and want to benefit from the diverse opportunities (European Commission, 2023).

Impact of trends on household structure and consumption

Household structure

Traditional family structures have changed in many European countries. There is an increase in non-marital partnerships, single-parent families, patchwork families and same-sex partnerships. These changes have implications for social support

systems, childcare, housing and legal recognition of partnerships. The nuclear family, with the traditional concept of partners committing to live together and share their lives, remains the dominant family type across Europe but is losing ground in terms of numbers. With the higher number of non-marital cohabiting couples, the proportion of children born out of wedlock is also increasing (Kapella and Rille-Pfeiffer, 2010).

The trend towards starting a family later is noticeable throughout Europe. This is particularly evident in a higher age at first childbirth among women as well as in later first marriages. In 2022, 5.5 per cent of adult women aged 25–54 years in the EU were single parents with children, against 1.1 per cent of adult men (Eurostat, 2023e). In many European countries, the number of childless households is also increasing. The number of single-person households without children in the EU increased by 30.7 per cent from 2009 to 2022 (Eurostat, 2023e). This is the result of various factors such as demographic changes, occupational challenges, higher female participation in education, changing lifestyles and individual preferences.

The share of adults aged 18–24 who still live with their parents increased from 2007 to 2020 and started dropping afterwards. In 2021 an average of 80 per cent was reported in the EU-27. The similar trend is observed for the wider age range of 18–34, however in this age group the figures fluctuate more extremely among the countries, ranging from 16.0 to 76.5 per cent (Eurostat, 2023f). In most EU countries the figures have only changed slightly between 2007 and 2021. Among the few exceptions are Ireland and Portugal, where children stay between three and five years longer with their parents, and Lithuania and Estonia where they leave the parental home around three years earlier than before (Eurostat, 2023d).

Household size

The average size of households in the EU has been shrinking in recent decades, going from an average of 2.4 persons per household in 2007 to 2.2 in 2022 (Eurostat, 2023e). The share of the households occupied by only one or two residents has increased, reaching at least 60 per cent of all EU households in 2022. While the EU average share of single-person households was 26 per cent in 2007, the figure had already risen to 36.2 per cent by 2022, covering more than one-third of the EU households. In the same period the share of two-person households inhabited by childless couples increased by around 5 per cent, reaching almost a quarter of all EU households (Eurostat, 2023e).

The trend towards smaller households can be explained on the one hand by the decline in marriages and births and the spread of partnerships with separate living arrangements. On the other hand, the progressive demographic ageing and the improvement of the health condition of older people ensure that more and more senior citizens lead an independent household alone or in pairs. In addition to these sociodemographic factors, the high occupational mobility of workers has also promoted the trend towards smaller households (Destatis, 2023).

Floor area and room per capita

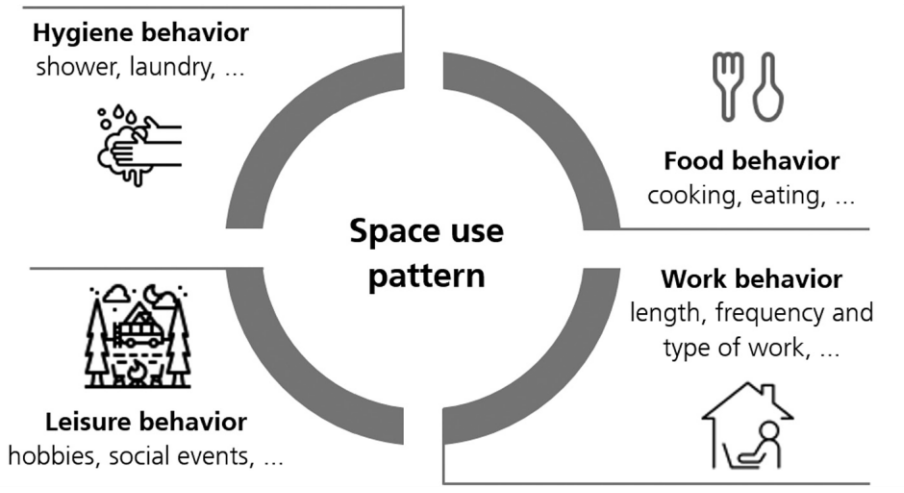
While the EU population increased by only about 1.6 per cent between 2009 and 2021, the number of households rose by 8 per cent in this period. The per

capita floor area has also increased in recent decades, reaching 48.7m^2 in 2021 compared to 41.4m^2 in 2009 and 35m^2 in 1990 (ODYSSEE-MURE, 2023) and the number of rooms per person has increased from 1.5 in 2009 to 1.6 in 2021. However, this increase in space is not evenly spread across age groups, household types and income groups. In 2021, the lowest overcrowding[1] rate in the EU was observed among those aged 65 and over, at 7 per cent compared with an average of 17 per cent, while the younger generation lived mostly in overcrowded dwellings (for example, 28.4 per cent of 12–17-year-olds and 25.7 per cent of 20–29-year-olds) (Eurostat, 2023f). The same trend is observed for the number of rooms per person. On the other hand, almost half of the oldest age group have too many rooms in their dwelling, compared with only 25 per cent of the under-18s. Single and double households in which all or one member is aged over 65 occupy the largest number of rooms per person. A comparison of household composition shows that childless single or double adult households occupy the highest number of rooms per person. Any increase in the number of adults or children reduces the share of rooms per person. The overcrowding rate is also negatively related to the income level, with the lowest income households (quintiles 1 and 2) above the average.

Areas of lifestyles affecting the space use patterns

This chapter explores how certain behaviours and individual habits affect the space use in the housing sector. We built categories and argue how they have a direct effect on floor space (Figure 3). A meta-analysis is conducted to synthesise quantitative data on consumption patterns across these different behaviour categories. Search terms such as *space requirements for remote working* and *frequency of home cooking among EU/German citizens* were used to identify relevant studies. Data was obtained from studies, scientific papers, existing databases, and official national and EU statistical portals.

Figure 3: Behaviour categories influencing residential space use pattern



Food-related behaviour

The frequency and style of dining can impact the space dedicated to the dining area. If individuals or households prefer formal dining, a separate dining room may be desired, while those who have casual or informal eating habits may use multipurpose spaces for dining or opt for smaller dining rooms. Food behaviour plays also a significant role in the kitchen design and layout. If individuals frequently engage in cooking meals from scratch, they may prefer ample counter space for food preparation and have additional food processing appliances such as a blender. In contrast, if the individuals rely more on ready-made or take-out meals, a smaller kitchen with less emphasis on cooking space may be preferred, however they might have larger freezers and appliances such as a microwave that also need space and energy. According to the German BMEL (2023) nutrition report, 45 per cent of Germans cook daily, 36 per cent 2–3 times a week and only 18 per cent once a week or less. When it comes to eating out, 15 per cent say they go out frequently, 72 per cent rarely and 13 per cent never (ifd Allensbach, 2022).

The complexity of cooking and the number of people eating the meals can also influence the need for specific or larger appliances. People who cook regularly, or for more household members, may need larger kitchens with larger ovens, freezers and storage. Especially big appliances like big refrigerators, standalone freezers, ovens and dishwashers require additional space and larger kitchens. Kitchen size in the UK, for example, tends to be relative stable, having gone up from 12.27m^2 for houses built in the 1930s to its peak of 15.37m^2 for houses built in the 1960s and back to 12.61m^2 for houses built in the 2010s (Thomas, 2019). Storing and preserving food uses space and energy, while cooling and refrigeration food is especially energy intensive (Eurostat, 2022a). Different types of diets or culinary interest may require specific storage areas for ingredients, spices and kitchen tools. The proximity of supermarkets or fresh food stores in urban areas can increase the number of shopping trips and reduce the need for food storage and refrigeration, resulting in less space usage and energy consumption for refrigeration.

Work behaviour

In 2022, around 75 per cent of the EU population aged between 20 and 64 was employed (Eurostat, 2023b), of which more than 10 per cent worked usually from home (Eurostat, 2023a). However, occurrence and intensity of working from home varies across countries. In a global survey conducted in 2021 and 2022, respondents from European countries worked weekly between 1.2 (Greece) to 1.8 days (Netherlands) in the home office. In Germany, the proportion of employees working at least partly in a home office fell from just under 30 per cent at the beginning of 2021 to around 25 per cent at the end of 2022 (ifo Konjunkturumfragen, 2022). Regarding the daily working time, more than one-third of Hungarians surveyed spent three to five hours a day working from home, 41 per cent spent six to eight hours and 13 per cent more than eight hours (statista, 2022).

Teleworking has become increasingly common in recent years, especially in the wake of the COVID-19 pandemic (Eurostat, 2022b), with individuals being sometimes forced to use different areas of their homes as offices. The change in the working pattern continued even after the pandemic with more employees willing to work from home and more employers offering this possibility. The arrangement

of working space can vary depending on personal preferences, spatial feasibility, occurrence and intensity of working from home as well as the type of work. It can range from using the kitchen table as a desk in the times that it is not used as a dining table, to dedicating a separate room with all office equipment to the home office.

Therefore, the impact of typical home office configurations on housing space consumption can vary widely depending on the setup. A teleworker who moves to a larger house to accommodate their home office can have a significant impact on the household space consumption. In households with several teleworkers, efficient use of existing space (such as a kitchen table) can lead to more energy-efficient home office configurations. Teleworkers use 6.5m^2 exclusively (or 4 per cent more than non-teleworkers) and 12.5m^2 generally for home offices. Forty-five per cent of telecommuters have a dedicated office, while the rest use shared space in their home (O'Brien and Yazdani Aliabadi, 2020). However, the need for a working space at home is not limited to the employees with teleworking possibility, but also self-employed people and employees who actually cannot work remotely but need to do some preparation for their work (for example, teachers preparing teaching materials).

Leisure behaviour

According to the OECD Time Use Database (2016), the EU population aged between 15 and 64 spends from 241 minutes per day in Portugal to 368 minutes a day in Norway on leisure. Leisure time includes indoor and outdoor activities such as recreation and entertainment that take place during free time. The type and intensity of hobbies people pursue can have an impact on space requirements. Indoor leisure activities may require specific spaces within the home, for example, people who enjoy playing musical instruments may require a designated music room or area with adequate space for their instruments and equipment. Similarly, those who pursue hobbies such as painting or crafting may need a dedicated workspace or studio. However, some other hobbies may not require a dedicated space and allow for multifunctional rooms, such as turning the living room into a gaming area. Outdoor activities require less living space than indoor activities, however some may be less flexible than others. Individuals who enjoy gardening and outdoor games may allocate space for a garden or patio, while people who enjoy outdoor hobbies such as hiking, skiing and surfing may need less space in their home for these activities, and more for storing the necessary equipment.

Some leisure activities allow for some flexibility and leave room for individual preferences in how they are carried out. For example, people who like to exercise may use multipurpose rooms in their homes to do their exercises, create a dedicated fitness area or choose to go to a gym. Leisure behaviour often involves entertainment activities such as watching movies, playing video games or hosting gatherings. This can influence the allocation of space, with the living room or media room being designated as an entertainment hub, equipped with comfortable seating, audiovisual equipment and storage for media. According to Destatis (2013) people in Germany use media (for example, TV, radio, smartphone) for an average of three hours in their leisure time. The impact of the organisation of leisure time on the living space has been a topic of interest in recent studies. The question of whether a separate living room is necessary for leisure activities or socialising has been raised. In the UK, the average living room size is reported to be 17.09m^2 (Thomas, 2019).

Hygiene behaviour

Hygiene behaviours include activities related to personal hygiene and household cleanliness, such as showering and laundry. How long and how often we shower or bathe, and how we wash and dry our clothes, can have an impact on space and energy use, particularly in the bathroom. For example, the average room size for newly built bathrooms in the UK is 5.55m^2 (Thomas, 2019). The size and layout of residential bathrooms can be influenced by the choice of bathtubs or shower, as the bathtubs tend to be larger than showers. Currently, for example, 35 per cent of all Dutch households have a bathtub (Statista, 2023). The availability and use of bathroom space can vary according to the showering patterns of household members, that is, how often and for how long they shower. In Germany, for example, people shower for 6–10 minutes on average, with 53 per cent of people saying they shower 2–4 times a week or less, 14 per cent showering 5–6 times and 27 per cent showering daily (Yougov, 2021). When multiple household members have similar showering routines, it is probable that they prefer having more than one bathroom.

The frequency of laundry may also have an impact on space use, with the vast majority of respondents (82 per cent) in Austria doing laundry at least once a week and 10 per cent doing so daily (Statista, 2018). This can impact the amount of laundry-related clutter in a home, and the space required for laundry equipment and supplies. As the convenience of frequent laundry appears to be important, washing machines are common household appliances in many European countries, with more than 90 per cent of households in Romania, Austria, Poland, Portugal, Italy, Spain, Germany, the UK and the Netherlands owning one (Statista Global Consumer Survey, 2022). This could lead to larger bathrooms or kitchens as personal washing machines take up more space than shared ones such as those in laundry rooms.

The way of drying clothes can affect the use of space in a home. Clotheslines and racks can take up significant amounts of space depending on their size and placement, while tumble dryers are typically installed in a specific location in the home and may require additional ventilation or plumbing. Although many households choose to use clotheslines or drying racks instead, the ownership rate of tumble dryers in Germany, for example, has increased from 32 per cent in 2000 to 43 per cent in 2021, remaining still much lower than the ownership rate of washing machines (Destatis, 2022).

Discussion and conclusion

The housing sector accounts for a large share of total final energy consumption, mainly driven by the amount of space in this sector and the energy required to heat it. This article examines the trends and factors influencing space use in the housing sector and, by analysing their (potential) impact, suggests social and technical solutions for facilitating the reduction in space use.

The trends examined in this article can have varying direct and indirect impacts on residential energy consumption and space use. For example, the growth of the sharing economy in the housing sector may lead to a reduction in the average size of dwellings per person due to reduced ownership of appliances and storage needs. However, it could also lead to an increase in floor area if certain parts of the dwellings are only rented out occasionally and are not used otherwise. Another example is the urbanisation and densification of urban areas, which often result in limited available living space. Rising rents and property prices in urban centres push people towards

smaller living spaces. This shift in consumption patterns is also accompanied by the adoption of sharing models, such as car-sharing and co-working spaces, which encourage sharing resources rather than individual ownership.

Potential changes in household structure resulting from such trends could also impact space use patterns. The growing number of households with only one or two adults and a high per capita area is a consequence of the increasing proportion of people over 65. Delayed childbearing and higher employment rates among women also play a role in forming childless households, which have an above-average per capita area. Higher divorce rates are another trend that increases the need for housing, as more dwellings are required for the same number of people. This situation is exacerbated when shared custody of children requires space in each parent's home.

In addition to the existing trends outlined in this article, other consumption or behavioural trends may emerge or accelerate due to, or facilitated by, unforeseen adverse events such as those observed in recent years, namely the COVID-19 pandemic and the Russian invasion of Ukraine. In response to these unexpected circumstances, individuals and companies showed signs of short- and long-term behavioural, lifestyle and strategic adjustments that could disrupt historical trends (for example, the increase in teleworking [Lund et al, 2021], digital health seeking [the use of technologies such as internet and communication tools to find and manage information and services related to health] [van Kessel et al, 2023] and online shopping [Said et al, 2023] following COVID-19 and the adoption of energy-saving behaviours [EEA, 2023] and changes in household expenditure trends [Menyhért, 2022] following the energy crisis as a result of the war in Ukraine).

On one hand, the household structure and the (space use) consumption patterns in the residential sector are influenced by external trends and factors; on the other hand, household needs and behaviours are dynamic and constantly evolving, influenced by these factors. Therefore, solutions for reducing consumption in the housing sector should consider these constant changes and their underlying reasons.

Some of the trends analysed in this article (that is, the ones regarding the ageing population, employment, marriage, divorce and childbirth) have an impact on the household structure, which in turn changes the spatial needs of households. Therefore, more flexibility is needed to accommodate the changing living situations. However, the existing buildings that are supposed to satisfy the needs of households are typically designed with static features, resulting in a mismatch between supply and demand (Greden, 2005). As a response, adaptability should be considered a key principle in designing new buildings to achieve resource efficiency. Adaptability refers to the capacity of a building to be modified to accommodate new situations or conditions (Schmidt III and Austin, 2016). This can encompass regular changes such as varying day–night uses or utilising (re)movable partitions to connect the rooms when larger space is needed, as well as long-term adjustments like designing modular apartments that can be combined or separated to align with household needs. Integrating flexibility and adaptability into the design process (as suggested by Özinal and Erman [2021] and Hosseini Raviz et al [2015]) creates spaces that can be easily modified and reconfigured to meet changing needs. Improving the design of the buildings eliminates the need for constant expansion or reconstruction, as spaces can be adapted to meet evolving user requirements.

Some other trends (that is, digitalisation, sharing economy and urbanisation) do not necessarily have a direct impact on the household structure, but they lead

to changes in households' needs and habits and, therefore, influence the space use pattern in the residential sector. While these trends may have the potential to reduce space consumption (for example, higher prices and limited available space in cities leading to decreased living space), they may also increase the need for more space (for example, the uptake of digitalisation leading to the need for additional space to work from home). New approaches and innovative solutions are needed to counteract this increase in space need. To address this, alternatives for more flexible use of existing housing should be promoted. This would involve rethinking how space is used and encouraging individuals to adapt their behaviour to make the most efficient use of available space. Maximising the use of existing space can reduce the need for additional construction and minimise resource consumption. This could include providing communal spaces (recreation facilities, co-working spaces, social events) to reduce the need for additional individual rooms in each dwelling or promoting collective living arrangements. The role of such social innovations in reducing consumption has already been discussed in the literature (for example, Jaeger-Erben et al, 2015; Lorek and Spangenberg, 2019). Raising environmental awareness and reducing barriers for changes could help promote this approach and shift from traditional space use patterns to more innovative ones.

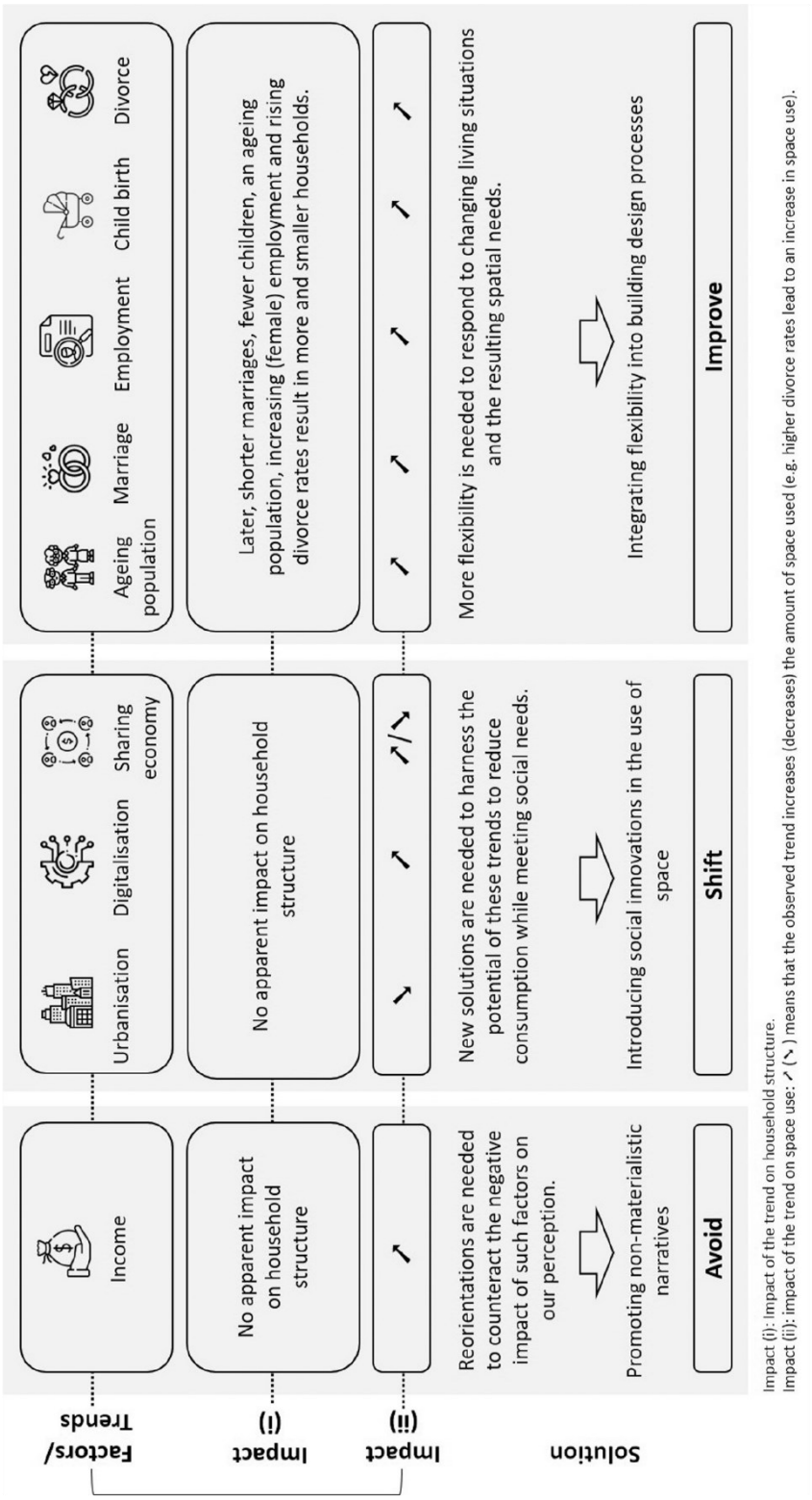
Lastly, consumption patterns, lifestyles and behaviours are influenced by, among other things, social norms and values, which play an important role in shaping our perceptions of what is desirable or acceptable in society. These perceptions are influenced by factors like income, as higher income usually results in higher consumption. Non-materialistic values have been suggested to lead to attitudes of sufficiency and consumption of 'just enough' (see, for example, McDonald et al, 2006; Boulanger, 2010). Reorienting social norms towards value-driven and non-materialistic norms may lead to less resource and material-intensive behaviour. By understanding these influences, we can avoid the need for high consumption and work towards promoting sustainable lifestyles and creating a built environment that supports both individual well-being and environmental sustainability.

To summarise, this article highlights potential social and technical changes that could facilitate space use reduction as illustrated in Figure 4. From the social perspective, focusing on households, the need for space consumption can be avoided by promoting non-materialistic narratives and shifted by introducing social innovations in the use of space. From a technical point of view and focusing on buildings, integrating flexibility into design processes can improve space efficiency. It is essential to acknowledge that individual behaviours and habits are shaped by a variety of factors at different levels, including sociodemographics, as well as cultural and geographical identities. Variations in thermal comfort needs across different ages and genders, the tendency in certain cultures to live in large families or host substantial gatherings, and the higher consumption levels typically seen in high-income households are just a few examples of how these factors can impact energy consumption. Recognising and addressing these diverse needs and backgrounds is crucial for understanding and developing effective solutions to the residential sector's significant space and energy consumption challenges.

Limitations and outlook

We could identify some important trends based on our literature search. Nevertheless, this conceptual overview has a number of shortcomings. First, we were not able to

Figure 4: Summary of the studied factors and their impacts, and suggestions for improvement



quantify the importance of each trend based on our analyses as we only selected them qualitatively and derived some implications. Future studies should try to quantify the influences over time and build a more complex framework of influences and effects of these trends on space use. Furthermore, we only analysed the relationships in one direction as illustrated in Figure 1. However, one may assume that the effects are not linear, but are mutually reinforcing, not only in a top-down manner but also in a bottom-up way. We do not suggest the existence of a causal effect as shown in this figure, nor do we deny causality in the other direction. Furthermore, the behavioural categories examined in this article relate to standard and common activities carried out in an average household. Our conclusions highlight the significant impact of habits and behaviours on space requirements and use. However, a more in-depth study of activities, such as childcare or eldercare with specific space requirements, may provide further insights into other types of impacts on space use and should be stimulated by the current research. Additionally, our focus has been solely on activities within dwellings. Yet, there are other behavioural categories that occur outside the home and can significantly influence space use. For instance, mobility behaviour, including transportation preferences (for example, car ownership and having a garage, bike, public transportation), can impact location choices (for example, proximity to the tram lines), the need for specific spaces (for example, parking space) and spatial dimensions (for example, smaller affordable flats in the city centre). Including such activities in future research would provide a comprehensive overview of factors affecting space use pattern and reveal inter-sectoral connections, such as those between the transport and residential sectors.

Note

[1] According to Eurostat (2011), a dwelling is defined as overcrowded if the household living in it has at its disposal less than the minimum number of rooms equal to: one room for the household, one room per couple in the household, one room for each single person aged 18 or more, one room per pair of single people of the same gender between 12 and 17 years of age, one room for each single person between 12 and 17 years of age and not included in the previous category, and one room per pair of children under 12 years of age.

Funding

This work was enabled by internal funding from the Fraunhofer Institute for Systems and Innovation Research ISI. The contribution of Josephine Tröger was also made possible through funding from the project H2020 FULFILL - Fundamental decarbonisation through sufficiency by lifestyle changes (Grant agreement ID 101003656), supported by the European Commission.

Acknowledgements

The authors would like to thank Heike Brugger and Elisabeth Dütschke for their valuable guidance and support throughout this research and acknowledge their contributions in reviewing and providing feedback on earlier versions of this manuscript. We are also thankful to David Hutzler and Kevan Skorna for their assistance in data collection.

Conflict of interest

The authors declare that there is no conflict of interest.

References

Benedikter, R. (2012) Lifestyles, in H. Anheier and M. Juergensmeyer (eds) *Encyclopedia of Global Studies*, Los Angeles: SAGE, pp 1076–80.

Bjørn, A., Kalbar, P., Nygaard, S.E., Kabins, S., Jensen, C.L., Birkved, M., et al (2018) Pursuing necessary reductions in embedded GHG emissions of developed nations: Will efficiency improvements and changes in consumption get us there?, *Global Environmental Change*, 52: 314–24. doi: 10.1016/j.gloenvcha.2018.08.001

Blanchet, T., Chancel, L. and Gethin, A. (2019) *How Unequal is Europe? Evidence From Distributional National Accounts, 1980-2017, World Inequality Lab Working Papers hal-02877000*.

Blau, D.M. and van der Klaauw, W. (2013) What determines family structure?, *Economic Inquiry*, 51(1): 579–604. doi: 10.1111/j.1465-7295.2010.00334.x

BMEL (2023) *Deutschland, wie es isst: Der BMEL-Ernährungsreport 2023*, Berlin: BMEL, https://www.bmel.de/SharedDocs/Downloads/DE/Broschueren/ernaehrungsreport-2023.pdf?__blob=publicationFile&v=4.

Bosserman, P. (1983) Cultural values and new life-styles, in *Problems of Culture and Cultural Values in the Contemporary World*, Paris: UNESCO, pp 23–35.

Boulanger, P.M. (2010) Three strategies for sustainable consumption, *Surveys and Perspectives Integrating Environment and Society*, 3(2): 1022. doi: https://journals.openedition.org/sapiens/1022.

Bourdieu, P. (1987) *Choses Dites*, Paris: Éd. de Minuit.

Coelho, T., Chkoniya, V., Oliveira Madsen, A. and Figueiredo, C. (2020) Leading the way to a sustainable future, in V. Chkoniya, A.O. Madsen and P. Buxrašvili (eds) *Anthropological Approaches to Understanding Consumption Patterns and Consumer Behavior*, Hershey, PA: IGI Global, pp 1–21.

Corral Naveda, A.N. (2022) Telecommuting as a sustainable transportation measure in Ecuador, *Enfoque UTE*, 13(1): 23–41. doi: 10.29019/enfoqueute.786

Creutzig, F., Roy, J., Lamb, W.F., Azevedo, I.M.L., Bruine de Bruin, W., Dalkmann, H., et al (2018) Towards demand-side solutions for mitigating climate change, *Nature Climate Change*, 8(4): 260–3. doi: 10.1038/s41558-018-0121-1

Dalkmann, H. and Brannigan, C. (2007) Transport and climate change: Module 5e: sustainable transport: a sourcebook for policy-makers in developing cities, https://changing-transport.org/wp-content/uploads/2007_dalkmann_brannigan_transportandclimatechange.pdf.

Dervojeda, K., Verzijl, D., Nagtegaal, F., Lengton, M., Rouwmaat, E., Monfardini, E., et al (2013) *The Sharing Economy: Accessibility Based Business Models for Peer-to-Peer Markets, Report*, Brussels: European Comission.

Destatis (2013) Zeitverwendung (ZVE) 2012/2013, https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Zeitverwendung/Tabellen/aktivitaeten-alter-zve.html.

Destatis (2022) Income, consumption and living conditions, https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Ausstattung-Gebrauchsgueter/_inhalt.html.

Destatis (2023) Entwicklung der privaten Haushalte zwischen 1991 und 2040, https://www.destatis.de/DE/Themen/Querschnitt/Demografischer-Wandel/Hintergruende-Auswirkungen/demografie-privathaushalte.html.

Doyal, L. and Gough, I. (1984) A theory of human needs, *Critical Social Policy*, 4(10): 6–38. doi: 10.1177/026101838400401002

EEA (2023) *Trends and Projections in Europe 2023*, Copenhagen: European Environment Agency, https://www.eea.europa.eu/publications/trends-and-projections-in-europe-2023

European Commission (2023) Continuing urbanization, https://knowledge4policy.ec.europa.eu/continuing-urbanisation_en.

European Parliament (2021) Demografischer ausblick für die Europäische Union, https://www.europarl.europa.eu/RegData/etudes/STUD/2021/690528/EPRS_STU(2021)690528_DE.pdf.

Eurostat (2010) *Income and Living Conditions in Europe*, Luxembourg: Publication Office of the European Union, http://publications.europa.eu/de/publication-detail/-/publication/4a04fa94-25ed-479c-8941-1f50febe7c5a.

Eurostat (2011) *Glossary*, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Category:Glossary.

Eurostat (2017) Glossary:Household – social statistics, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Household_-_social_statistics#:~:text=A%20household%20includes%20either%20one,a%20living%20or%20sitting%20room.

Eurostat (2022a) Energy consumption in households, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy_products_used_in_the_residential_sector.

Eurostat (2022b) Rise in EU population working from home, https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20221108-1.

Eurostat (2023a) Employed persons working from home as a percentage of the total employment, by sex, age and professional status (%), https://ec.europa.eu/eurostat/databrowser/view/lfsa_ehomp/default/table?lang=en.

Eurostat (2023b) Employment – annual statistics, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Employment_-_annual_statistics#Employment_in_2022_compared_with_the_EU_target.

Eurostat (2023c) Employment and activity by sex and age – annual data, https://ec.europa.eu/eurostat/databrowser/view/lfsi_emp_a/default/bar?lang=en.

Eurostat (2023d) Estimated average age of young people leaving the parental household by sex, https://ec.europa.eu/eurostat/databrowser/view/yth_demo_030/default/table?lang=en.

Eurostat (2023e) Household composition statistics, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics.

Eurostat (2023f) Income and living conditions, https://ec.europa.eu/eurostat/cache/metadata/en/ilc_sieusilc.htm.

Eurostat (2023g) Marriage indicators, https://ec.europa.eu/eurostat/databrowser/view/DEMO_NIND__custom_684975/bookmark/table?lang=en&bookmarkId=c708cdbf-c5c0-434f-af18-2281ac691d98.

Eurostat (2023h) Population structure and ageing, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_structure_and_ageing#The_share_of_elderly_people_continues_to_increase.

Eurostat (2023i) Proportion of population aged 65 and over, https://ec.europa.eu/eurostat/databrowser/view/tps00028/default/table?lang=en.

Gram-Hanssen, K. (2012) Sustainable lifestyles, in S.J. Smith (ed) *International Encyclopedia of Housing and Home*, Amsterdam: Elsevier, pp 117–23.

Greden, L.V. (2005) Flexibility In Building Design: A Real Options Approach And Valuation Methodology To Address Risk, PhD Thesis, Cambridge, MA: Massachusetts Institute of Technology, Department of Architecture.

Greenwood, J., Guner, N. and Vandenbroucke, G. (2017) Family economics writ large, *Journal of Economic Literature*, 55(4): 1346–434. doi: 10.1257/jel.20161287

Hamari, J., Sjöklint, M. and Ukkonen, A. (2016) The sharing economy: Why people participate in collaborative consumption, *Journal of the Association for Information Science and Technology*, 67: 2047–59. doi: 10.1002/asi.23552

Højrup, T. (2003) *State, Culture and Life-Modes: The Foundations of Life-Mode Analysis*, Aldershot: Ashgate.

Hosseini Raviz, S.R., Nik Eteghad, A., Uson Guardiola, E. and Armesto Aira, A. (2015) Flexible housing: The role of spatial organization in achieving functional efficiency, *Archnet-IJAR: International Journal of Architectural Research*, 9(2): 65–76. doi: 10.26687/archnet-ijar.v9i2.422

Hubacek, K., Guan, D. and Barua, A. (2007) Changing lifestyles and consumption patterns in developing countries: A scenario analysis for China and India, *Futures*, 39(9): 1084–96. doi: 10.1016/j.futures.2007.03.010

Hung, H. (2021) Recent trends in global economic inequality, *Annual Review of Sociology*, 47(1): 349–67. doi: 10.1146/annurev-soc-090320-105810

ifd Allensbach (2022) Essen gehen – Häufigkeit in der Freizeit in Deutschland 2022, *Statista*, https://de.statista.com/statistik/daten/studie/171133/umfrage/haeufigkeit-des-ausgehens-zum-essen-in-der-freizeit/?locale=de.

ifo Konjunkturumfragen (2022) Homeoffice setzt sich durch – aber nicht überall, https://www.ifo.de/pressemitteilung/2022-12-09/homeoffice-setzt-sich-durch-aber-nicht-ueberall.

IPCC (2022) Demand, services and social aspects of mitigation, in Intergovernmental Panel on Climate Change (ed) *Climate Change 2022 – Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge: Cambridge University Press, pp 503–612.

Jackson, T. (2005) Live better by consuming less? Is there a 'double dividend' in sustainable consumption?, *Journal of Industrial Ecology*, 9(1–2): 19–36. doi: 10.1162/1088198054084734

Jaeger-Erben, M., Rückert-John, J. and Schäfer, M. (2015) Sustainable consumption through social innovation: A typology of innovations for sustainable consumption practices, *Journal of Cleaner Production*, 108: 784–98. doi: 10.1016/j.jclepro.2015.07.042

Kapella, O. and Rille-Pfeiffer, C. (2010) Familien in Europa: trends und Entwicklungen, https://jugendhilfeportal.de/artikel/familien-in-europa-trends-und-entwicklungen.

Kravchenko, O., Leshchenko, M., Marushchak, D. and Vdovychenko, Y. (2019) Digitalization as a global trend and growth factor of the modern economy, *CEUR Workshop Proceedings*, 2422: 434–43.

Lorek, S. and Spangenberg, J.H. (2019) Energy sufficiency through social innovation in housing, *Energy Policy*, 126: 287–94. doi: 10.1016/j.enpol.2018.11.026

Lund, S., Madgavkar, A., Manyika, J., Smit, S., Ellingrud, K., Meaney, M., and Robinson, O. (2021) *The Future of Work After COVID -19*, report, San Francisco, CA: McKinsey Global Institute https://www.mckinsey.de/~/media/mckinsey/locations/europe%20and%20middle%20east/deutschland/news/presse/2021/2021-02-18%20-%20mgi%20future%20of%20work%20after%20covid-19/mgi_the%20future%20of%20work%20after%20covid-19_report_feb%202021.pdf.

Mason, P.L. (2023) Transformations in family structure, in P.L. Mason (ed) *The Economics of Structural Racism: Stratification Economics and US Labor Markets*, Cambridge: Cambridge University Press, pp 140–66.

McDonald, S., Oates, C.J., Young, C.W. and Hwang, K. (2006) Toward sustainable consumption: Researching voluntary simplifiers, *Psychology and Marketing*, 23(6): 515–34. doi: 10.1002/mar.20132

Meadows, D. (1999) Leverage points, *Leverage Points: Places to Intervene in a System*,Hartland: The Sustainability Institute, https://donellameadows.org/wp-content/userfiles/Leverage_Points.pdf.

Menyhért, B. (2022) *The Effect of Rising Energy and Consumer Prices on Household Finances, Poverty and Social Exclusion in the EU*, Luxembourg: Publications Office of the European Union.

Merriam-Webster (2023) *Household*, https://www.merriam-webster.com/dictionary/household.

Newmark, N.L. and Thompson, P.J. (1977) *Self, Space, and Shelter: An Introduction to Housing*, San Francisco, CA: Canfield Press.

O'Brien, W. and Yazdani Aliabadi, F. (2020) Does telecommuting save energy? A critical review of quantitative studies and their research methods, *Energy and Buildings*, 225: 110298. doi: 10.1016/j.enbuild.2020.110298

ODYSSEE-MURE (2023) *Odyssee database*, https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html.

OECD (2021) *Brick by Brick: Building Better Housing Policies* Paris: OECD Publishing.

OECD (2022) *Housing Taxation in OECD Countries*, OECD Tax Policy Studies, n 29, Paris: OECD Publishing, https://www.oecd.org/en/publications/2022/07/housing-taxation-in-oecd-countries_1ee79763.html.

OECD Time Use Database (2016) OECD time use 2009–2016, https://stats.oecd.org/Index.aspx?DataSetCode=TIME_USE.

Oliveira, G.M., Vidal, D.G. and Ferraz, M.P. (2020) Urban lifestyles and consumption patterns, in W. Leal Filho, A. Marisa Azul, L. Brandli, P. Gökçin Özuyar and T. Wall (eds) *Sustainable Cities and Communities*, Cham: Springer International Publishing, pp 851–60.

Özinal, D. and Erman, O. (2021) Housing flexibility in terms of changes, opportunities, and sustainability of goals and values, *Journal of Design for Resilience in Architecture and Planning*, 2(2): 187–205. doi: 10.47818/drarch.2021.v2i2019

Pérez-Sánchez, L.A., Velasco-Fernández, R. and Giampietro, M. (2022) Factors and actions for the sustainability of the residential sector: The nexus of energy, materials, space, and time use, *Renewable and Sustainable Energy Reviews*, 161: 112388. doi: 10.1016/j.rser.2022.112388

Prothero, A., Dobscha, S., Freund, J., Kilbourne, W.E. and Luchs, M.G. (2011) Sustainable consumption: Opportunities for consumer research and public policy, *Journal of Public Policy and Marketing*, 30(1): 31–8. doi: 10.1509/jppm.30.1.31

PwC (2015) Sharing or paring? Growth of the sharing economy, https://www.pwc.com/hu/en/kiadvanyok/assets/pdf/sharing-economy-en.pdf.

Reusswig, F., Lotze-Campen, H. and Gerlinger, K. (2003) Changing Global Lifestyle and Consumption Patterns: The Case of Energy and Food, working paper presented at The PERN workshop 'Population, Consumption and the Environment, 19 October, Montreal: The Population-Environment Research Network, https://www.populationenvironmentresearch.org/pern_files/papers/Lotze-Campen_Reusswig_Paper.pdf.

Said, M., Tahlyan, D., Stathopoulos, A., Mahmassani, H., Walker, J. and Shaheen, S. (2023) In-person, pick up or delivery? Evolving patterns of household spending behavior through the early reopening phase of the COVID-19 pandemic, *Travel Behaviour & Society*, 31: 295–311. doi: 10.1016/j.tbs.2023.01.003

Saleem, S.B. and Ali, Y. (2019) Effect of lifestyle changes and consumption patterns on environmental impact: A comparison study of Pakistan and China, *Chinese Journal of Population Resources and Environment*, 17(2): 113–22. doi: 10.1080/10042857.2019.1574454

Schmidt, R. III and Austin, S. (2016) *Adaptable Architecture: Theory and Practice*, London: Routledge.

Sen, A. (1988) Freedom of choice: Concept and content, *European Economic Review*, 32(2–3): 269–94. doi: 10.1016/0014-2921(88)90173-0

Sirgy, M.J. (2002) *The Psychology of Quality of Life*, Dordrecht: Kluwer Academic Publishers.

Sociology (2019) Family structure – sociology of family, iResearchNet, https://sociology.iresearchnet.com/sociology-of-family/family-structure/.

Statista (2018) Wie oft waschen Sie selbst Wäsche?, https://de.statista.com/statistik/daten/studie/946448/umfrage/umfrage-zur-haeufigkeit-des-waeschewaschens-in-oesterreich/?locale=de.

Statista (2022) Hungary: Daily time spent in home office 2021, *Statista*, https://www.statista.com/statistics/1246273/hungary-daily-time-spent-in-home-office/.

Statista Global Consumer Survey (2022) Statista global consumer survey, 2022: household appliances in Europe, https://www.statista.com/topics/7043/household-appliances-in-europe/#topicOverview.

Stewart, C.T. (2006) Gross national accumulation, *Business Horizons*, 49(2): 105–13. doi: 10.1016/j.bushor.2005.06.008

Thomas, P. (2019) Are Britain's houses getting smaller? (New data), https://www.labcwarranty.co.uk/news-blog/are-britain-s-houses-getting-smaller-new-data.

Statista (2023) Share of households with a bathtub in the Netherlands from 2007 to 2016, https://www.statista.com/statistics/786177/share-of-households-with-a-bathtub-in-the-netherlands/.

Tröger, J., Toulouse, E., Alexander-Haw, A., Dütschke, E., Marignac, Y., Preuß, S., et al (2022) Refinement of research design: FULFILL Deliverable D 2.3, https://fulfill-sufficiency.eu/wp-content/uploads/2022/08/FULFILL_Research_Design_202208_submitted.pdf.

TUMI (2020) COVID-19 and sustainable mobility: Observations and documentation of first developments, https://www.transformative-mobility.org/wp-content/uploads/2023/03/2020_05_TUMI_COVID-19-and-Sustainable-Mobility-sMtB7P.pdf.

United Nations (2018) *World Urbanization Prospects: The 2018 Revision*, New York, United Nations, https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.

United Nations, Human Rights Council (2022) Towards a just transformation: Climate crisis and the right to housing: Report of the Special Rapporteur on adequate housing as a component of the right to an adequate standard of living, and on the right to nondiscrimination in this context, Balakrishnan Rajagopal, https://documents.un.org/doc/undoc/gen/g22/612/32/pdf/g2261232.pdf?token=rW9sCHhO6BO51BOoSR&fe=true.

van Kessel, R., Kyriopoulos, I., Wong, B.L.H. and Mossialos, E. (2023) The effect of the COVID-19 pandemic on digital health-seeking behavior: Big data interrupted time-series analysis of Google trends, *Journal of Medical Internet Research*, 25e42401. doi: 10.2196/42401

Vita, G., Hertwich, E.G., Stadler, K. and Wood, R. (2019) Connecting global emissions to fundamental human needs and their satisfaction, *Environmental Research Letters*, 14(1): 14002. doi: 10.1088/1748-9326/aae6e0

Walters, G.D. (2006) *Lifestyle Theory: Past, Present, and Future*, New York: Nova Science.

Williams, K. (2009) Space per person in the UK: A review of densities, trends, experiences and optimum levels, *Land Use Policy*, 26: S83–92. doi: 10.1016/j.landusepol.2009.08.024

World Bank (2022) Europäische Union: Urbanisierungsgrad in den Mitgliedstaaten im Jahr 2021, https://de.statista.com/statistik/daten/studie/249029/umfrage/urbanisierung-in-den-eu-laendern/.

Wulff, M., Healy, E. and Reynolds, M. (2004) Why don't small households live in small dwellings? Disentangling a planning dilemma, *People and Place*, 12(1): 58–71.

Xie, L., Yan, H., Zhang, S. and Wei, C. (2020) Does urbanization increase residential energy use? Evidence from the Chinese residential energy consumption survey 2012, *China Economic Review*, 59: 101374. doi: 10.1016/j.chieco.2019.101374

Yougov (2021) Wie oft duschen Sie ungefähr in der Woche?, https://yougov.de/topics/society/survey-results/daily/2021/11/07/118a4/2.

Zhong, X., Hu, M., Deetman, S., Steubing, B., Lin, H.X., Hernandez, G.A., et al (2021) Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060, *Nature Communications*, 12(1): 6126. doi: 10.1038/s41467-021-26212-z

Appendix C: Original published version of Paper 4

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/enb

Reduction of gas demand through changes in heating behaviour in households: Novel insights from modelling and empirical evidence

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ARTICLE INFO

Keywords:
Gas demand
Energy crisis
Heating behaviour
Households
Short-term measures
Policy

ABSTRACT

The geopolitical situation and the energy crisis caused by the Russian invasion of Ukraine have led to proposals for immediate reduction in energy consumption within the European Union (EU). The REPowerEU Plan of the European Commission proposes behavioural changes as short-term measures to rapidly reduce the EU's dependence on Russian gas and oil. This paper investigates the energy saving potential resulting from changes in household heating behaviour. Through a comparison of modelling results with results of the analysis of empirical data collected in a survey of households in four EU Member States (Germany, the Netherlands, Greece, and Poland), the paper examines the adequacy of the short-term measures proposed by the EU and the instruments needed to leverage such measures and increase their potential impact. Although the reported changes in heating behaviour lead to a 2.0 % to 3.5 % reduction in residential gas demand in the countries studied, the study recognises that the EU targets for reducing the gas demand will not be met under current regulatory conditions, and considers the energy savings observed in this paper and in the literature as a short-term response to unexpected circumstances. The paper proposes a policy package to transform these responses into the long-term behavioural changes needed to achieve climate targets. Promoting uptake of household technical infrastructure, providing financial support and implementing information campaigns are suggested as effective approaches to achieving savings targets.

1. Introduction

Between 2013 and 2022, the share of natural gas in the total energy available for final consumption in the European Union (EU) slightly decreased, falling from 22 % to 20 % [33]. In 2013, 27 % of the gas consumed by the EU was supplied by Russia [24]. In 2022, this share fell to approximately 23 % (own calculation based on [13]). In the same decade (2013–2022), the natural gas consumption in residential buildings in the EU has been relatively stable, ranging between 825 and 1020 TWh [38], making gas the most widely used energy carrier for space and water heating [70]. Between 2013 and 2021 Europeans enjoyed a trend of falling nominal gas prices (excluding taxes and levies), which decreased from 3.89 EUR/kWh in the first half of 2013 to 3.17 EUR/kWh in the first half of 2021 [38]. With the Russian invasion of Ukraine in February 2022, this trend reversed. In the first half of 2022 gas prices drastically increased by 53 % as compared to the first half of 2021.

In response to rising gas prices and the risk of supply disruptions, demand reduction measures became urgently needed. In this context, the European Commission and the Council of the European Union have put forward several proposals and regulations aimed at gas demand reduction [11,12,25,27–29]. The proposed policy measures addressing gas consumption in buildings can be grouped into the following two main categories:

1. Building-related energy efficiency improvements and roll out of heat pumps
2. Measures aimed at stimulating building occupants' behaviour changes, such as turning down heating, using less air-conditioning or adjusting boiler settings.

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https://doi.org/10.1016/j.enbuild.2024.114257
Received 25 December 2023; Received in revised form 20 March 2024; Accepted 4 May 2024

Abbreviations

DE	Germany
EU	European Union
GR	Greece
IEA	International Energy Agency
MFH	Multi-family house
NL	Netherlands
PL	Poland
SFH	Single-family house

The European Commission expects the first category of measures to provide nearly three times more savings than the second one: 37 bcm of natural gas saved versus 13 bcm of natural gas saved, with likely overlaps leading to overall savings lower than the sum of the savings from both groups of measures. Still, infrastructure changes in buildings would require a significant amount of time for implementation as well as investment, estimated at over 56 billion euros in addition to the investments planned in the previously announced "Fit for 55" [26] measures. In this context, the second category of measures, i.e. building occupants' behaviour changes, comes to the spotlight, as they could be implemented (comparatively) quickly and, according to the European Commission, without any investment [28]. In April 2022, the International Energy Agency (IEA) and the European Commission started the *Playing my part* campaign with energy saving tips directed at households and building managers to help reduce the EU's reliance on Russian fuels [31].

Despite the paramount importance of behavioural changes in the EU policy targets set in response to the current energy crisis, there are several open questions regarding the potential impact and feasibility of short-term reductions in gas demand for space and water heating in the EU through behavioural measures. In this context, this paper:

1. analyses economic, energy-, environment-, building-, and occupant-related factors influencing household behavioural change and assesses the impact of energy saving measures, such as lowering the heating temperature, on the reduction of gas demand for space and water heating in EU households
2. evaluates the achievability of reducing the heating temperature in selected EU Member States, with different socio-economic contexts
3. makes recommendations for the EU's long-term energy policy to increase the impact of changes in household behaviour aimed at reducing gas demand for space and water heating.

Unlike previous studies that may have focused more on economic (e.g., price-related [91]) or the technical aspects of energy savings due to behaviour change (e.g., heating systems changes [79]), this paper directly investigates the short-term behavioural changes households can adopt to reduce their energy consumption, particularly in heating, in response to the energy crisis prompted by the geopolitical situation in the EU between 2021 and 2023, specifically, following the Russian invasion of Ukraine. The novelty of the study concerns also the timely analysis of the adequacy of short-term measures proposed by the EU to rapidly reduce dependence on Russian gas. The inclusion of different EU Member States with varied socio-economic and climatic conditions adds depth to the analysis, recognising the heterogeneity within the EU and the need for tailored approaches in policymaking.

This paper is structured as follows. In section 2, we provide a literature review of existing studies on heating behaviour and potential impacts of short-term behavioural measures, assessments of the achievability of such impacts, and available evidence on possible policy actions in this area. In section 3, we present the methods employed in this paper as well as the empirical basis. In section 4, we present the calculated savings potential of changes in heating behaviour (e.g. lowering indoor temperatures). We then analyse the attitudes of households across the EU towards space heating and the drivers of these attitudes. In section 5, we compare the saving potentials derived from modelling and survey results and reflect on policy objectives for the short-term reduction of gas demand for space and water heating in the EU and discuss policy implications. Finally, section 6 briefly presents the conclusions of our study.

2. Background

The Council Regulation (EU) 2022/1369 set a non-binding target for all Member States to reduce gas demand by 15 % between 1 August 2022 and 31 March 2023, compared to the average of the same period in the previous five years [11]. The reduction of indoor temperatures has been identified as a particularly important measure to reduce gas demand in buildings in the short-term [47,31,77]. However, the potential effectiveness of this measure is highly dependent on social factors, including especially the user comfort needs, and has not yet been thoroughly investigated across the EU following the start of the war in Ukraine. In a study relying on modelling, Rohde et al. [74] estimate that lowering the indoor temperature of buildings in the EU-27 by 1 °C offers a potential 9 % reduction in gas demand in terms of reduced heating degree days.

The energy savings from lowered indoor temperatures in buildings are not only uncertain, but they are also influenced by a variety of factors, including individual thermal comfort preferences, environmental attitudes, motivation to conserve energy, the cost and availability of energy, understanding of the impact of energy use, and the usability of installed thermostats (if installed at all). Some studies indicate that prompting individuals to voluntarily lower the temperature at which they heat their homes could be of limited effectiveness, since people simply want their homes warm when the weather is cold [79]. The scant scientific studies of the EU households' attitudes towards reducing indoor temperatures suggest that Europeans' willingness to lower temperatures is indeed limited. Households surveyed in Sweden in 2019 could not imagine allowing greater temperature variation in their homes to save energy [46]. A study of households in the Netherlands and Siberia found that people living in yurts care less about stable thermal conditions than typical Dutch sedentary dwellers, which indicates that psychological acceptance of a certain level of discomfort is challenging for modern societies [55]. Experiences from before the current energy crisis show that to manage inadequate space heating, people prefer to act on the energy supply side (e.g. install a bigger boiler), rather than to change their behaviour (e.g. wearing extra clothes to feel warmer), as evidenced by nationally representative surveys conducted in Sweden, Germany, Italy, Spain, and the UK (N = 10109) in 2020, which reported that the mean preferred indoor temperature in winter in these five countries is between 20.88 °C and 21.83 °C [79]. These findings are consistent with prior findings by Stazi et al. [80], which indicate that sometimes individual factors affect the heating use more than environmental ones, such as outdoor temperature. On the other hand, Canale et al. [9] find that additional technical assistance improving user awareness, such as in-home displays, can help lower the consumption of heating by 17 %. An information campaign in Italy led to a significant increase in the amount of time spent below 19 °C, yet still the average indoor air temperatures were always between 18.7 °C and 22.3 °C [8].

While many studies attempt to identify the main drivers of heating behaviour (e.g. [3,83]) some scholars go further and analyse the role of such drivers in heating behaviour. In a review of the existing literature on drivers of occupant behaviour, Wei et al. [85] identify 27 drivers that influence energy consumption in the residential sector. The authors categorise the factors as environmental, building-related, occupant-related and other, and examine whether a correlation between these factors and heating behaviour has been addressed in the literature. The results are partially shown in Table 1.

Following the Russian invasion of Ukraine in 2022, reducing gas

Table 1
Number of papers in the literature reporting on the correlation between the selected factors and heating behaviour (based on [85]).

Category	Factors	Correlation reported	No correlation reported
Economic factors	Heating price	2	1
	Income level	5	4
Building and occupant-related factors	Ownership structure	3	1
	Building type	7	0
Energy and environment-related factors	Energy carrier	1	1

demand became one of the key topics of energy policy and public debate in the EU and its Member States. Before the start of the 2022–2023 heating season, over a third of households in Germany said they would lower the temperature on their thermostat [15]. An EU-wide study on this question was conducted by a manufacturer of smart thermostats, whose users lowered the indoor temperature by various values compared to the previous heating season, ranging from 0.28 °C (the minimum result, observed in Bulgaria) to 0.99 °C (the maximum result, observed in the Netherlands and Belgium) [81]. Still, this study was restricted to smart-thermostat users and did not control for the respondents' heating source, making it difficult to draw conclusions for EU-level energy efficiency policy that should be reflective of households' economic status as well as the characteristics of household heating systems, which are important drivers of energy-related behaviour [3].

This study provides original research quantifying the impact of behavioural changes aimed at reducing gas consumption in the EU residential sector after the start of the war in Ukraine. Our modelling of the impact of behaviour change on gas consumption is compared with new empirical evidence on the heating behaviour of households in four EU Member States. For this purpose and inspired by Wei et al. [85], the relationships between heating behaviour and five selected factors in three categories are examined: economic (heating price and income level), building and occupant-related (building type and ownership structure), and energy and environment-related (energy carrier). Therefore, this research complements prior studies on consumer price elasticity of residential energy demand, which offer insight into the degree to which households are likely to adjust their energy consumption in response to price changes [6,91,72]. However, unlike the present study which offers new perspectives on price elasticity in relation to gas consumption, most previous research primarily examined price elasticity with respect to electricity usage. The figures shown in Table 1 indicate whether or not a correlation has been reported in the literature between the selected factors and hearing behaviour.

3. Methodology

3.1. Selected measures

Among the proposed behavioural changes to reduce gas demand, the reduction of heating temperature was selected for in-depth analysis in this paper. This measure is mentioned, directly or indirectly, in the Energy Sufficiency Policy Database [90], the IEA "10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas" [49], and the "Playing my part" report [50], which aims to raise awareness of ways to save money and energy and reduce reliance on imported fuels. It is one of the behavioural changes that can be implemented in the short-term, and its impact on energy savings in the short and long-term can be quantified, building on existing models and methodologies. In addition to this main measure, other energy-saving behaviours and low-investment measures (e.g. reducing ventilation rates or closing curtains in front of windows) are addressed in the paper.

3.2. Regional scope of the study

To provide a multi-faceted analysis of the role of behaviour change in reducing gas consumption, the present study focuses on gas-based heating demand in the household sector in four EU Member States. The countries were carefully selected using indicators from Eurostat database [30], to ensure a balanced representation of various levels of factors influencing heating behaviours identified in Table 1. Within each category of factors, we consider the following indicators across the EU Member States: (1) in the category of economic factors, we investigate country-specific gas prices and household income levels; (2) in the category of building and occupant-related factors, we analyse country-specific shares of multi-family residential buildings as well as shares of households that are tenants; (3) in the category of energy- and environment-related factors, we study country-specific final energy consumption for space heating in households (kWh/m^2) as well as the share of gas in final energy consumption in the residential sector. After comparing the country-specific levels of these indicators with their averages for the whole EU-27 (Fig. 1), we select the following four EU Member States for the study:

3.2.1. Germany (DE)

Between 2011 and 2019, Germany had the highest annual average heating energy demand in the whole EU (441.4 TWh/year) [84]. In 2022 German households had a median equivalised disposable income above the EU average and gas prices below the EU average. In 2020 the share of German households living in multi-family houses (MFH) was higher than the EU average, and almost half of them (49.5 %) were tenants rather than owners, which was also higher than the EU average. In 2020 the German residential sector was more dependent on gas than the EU average. Due to the relatively cold winters, the country's final energy demand for space heating per square metre was also higher than the EU mean value. The preferred mean indoor air temperature in winter in German households is 21.28 °C (according to the study of Sovacool et al. [79]), while the requirement for indoor temperature in winter according to national legislation and building codes is 20 °C [7].

3.2.2. Greece (GR)

Despite the relatively low median equivalised disposable income of Greek households, in the second half of 2022 they were exposed to gas prices that were higher than the EU average and almost two times higher than gas prices for households in Germany. This raised questions about the prominent position of natural gas in Greece's energy transition strategies [51]. In 2020 a higher proportion of Greek households lived in multi-family houses than the EU average, while the share of tenants was lower than the EU average. In the same year, Greek households were less dependent on gas than the EU average. As the country generally experiences mild winters, the final energy demand for space heating in households was below the EU average. The requirement for indoor temperature in winter according to national legislation and building codes is 20 °C [7].

3.2.3. The Netherlands (NL)

Similar to Germany, in 2022 Dutch households enjoyed a median equivalised disposable income above the EU average. However, unlike Germany, gas prices for household consumers in the Netherlands were above the EU average, reflecting the national energy mix, which relies heavily on gas-fired power stations, and the national gas market structure which is sensitive to changes in wholesale prices and hedging costs [57]. In 2020 the share of Dutch households living in multi-family houses was lower than the EU average, and almost a third of them (30.9 %) were tenants, slightly higher than the EU average (30.0 %). In 2018, 90 % of residential heating demand was covered by natural gas [48], making Dutch households significantly more dependent on gas than the average in the EU. The country's final energy demand per square metre for space heating fell slightly below the EU average. This

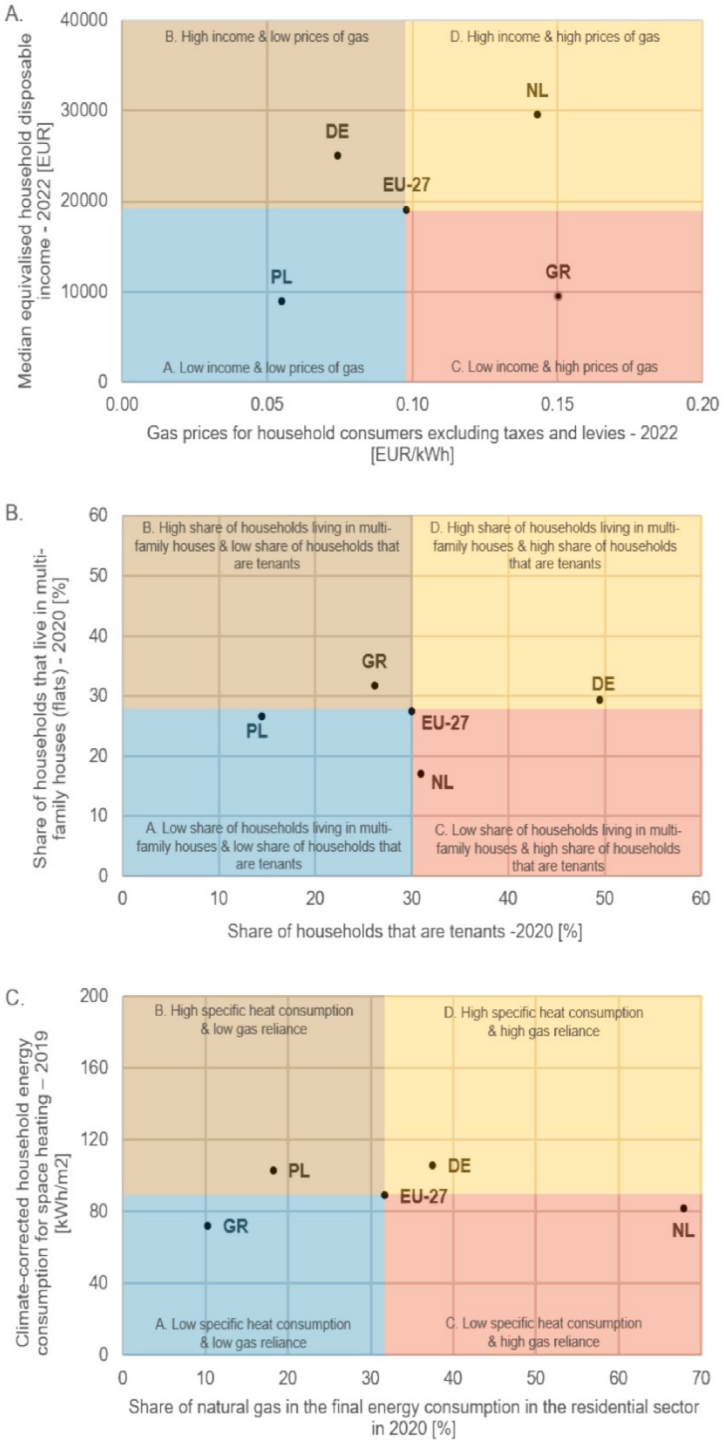

Fig. 1. Factors influencing the heating behaviour of households in the countries selected for the study: A. economic factors, B. energy- and environment-related factors, C. building- and occupant-related factors (own illustration based on data from [38] and [40] for A., [37] and [36] for B., [32] and Invert/EE-Lab for C.).

can be partly explained by the fact that the typical set point indoor temperature in the Netherlands is 18 °C, which is the lowest in the EU [84].

3.2.4. Poland (PL)

The median equivalised disposable income of Polish households was below the EU average in 2022. In the second half of the year, they enjoyed significantly lower gas prices than the EU average due to the retail gas price cap introduced by the government [20]. In 2020 a lower share of households in Poland lived in multi-family houses than the EU average, and the share of tenants was also lower than the EU average. Although Polish households have a lower reliance on gas compared to the EU average, Poland's energy demand for space heating per square metre was comparable to Germany's, and above the EU average. The requirement for indoor temperature in winter according to national legislation and building codes is 20 °C [7].

3.3. Methodological approach

To obtain a comprehensive view of the saving potentials of the studied measures, the paper used a multi-method approach [53]. Using a modelling approach, the study quantifies the energy savings resulting from the implementation of behavioural measures such as reducing the heating temperature. An online survey was used to investigate the heating behaviour of the residents. The savings potential suggested by the modelling exercise was then compared with the saving potential derived from the online survey, and with the policy changes set out in the European Commission and EU Council communications, legislative proposals, recommendations, and regulations published between the years 2021–2023 to tackle rising energy prices and to reduce the EU's dependence on Russian fossil fuels. The comparative analysis was used to draw conclusions on the adequacy of the proposed measures and the need for new ones.

3.3.1. Modelling

The modelling was carried out using the socio-techno-economic building stock model Invert/EE-Lab, described by Müller [68]. This model uses a dynamic bottom-up approach and simulates future energy demand for space heating, cooling, hot water, and lighting for a large number of building archetypes in EU Member States, taking into account parameters and boundary conditions such as economic incentives, regulatory instruments or technological progress [68,58]. Energy demand calculations follow a quasi-steady-state approach, using the same indoor temperature for all relevant building components (e.g. wall surface temperature, window surface temperature, and indoor air temperature) with monthly energy balance calculations. This reduction in complexity allows for modelling the building stock of entire countries, which would otherwise require significant computing power and time. In a direct comparison between an Invert and an EnergyPlus model of the energy consumption of different European cities, there were no systematic and significant deviations in heating demand between the two approaches [67,89], justifying the use of the model for the purposes of this paper. The effective indoor temperature in buildings is modelled as a function of dwelling size, energy performance of the building, heating energy costs and class of household income (see [65,66,68]). The model has recently been used and calibrated in several studies also for EU-27, which was the starting point for this paper (see e.g. [59]). Details on the building stock data is provided as supplementary material to this paper.

Simulations with the Invert model were carried out for the residential sector in the EU-27 and the results are presented for the EU-27 as a whole and for the four selected Member States. We start from a climate corrected base year data of 2019 (i.e. assuming average climate data for the period of 2005–2019). Based on the corresponding demand, we implement a short-term behaviour change in several distinct scenarios by reducing the indoor temperature by 0.5 °C to 4.5 °C, in steps of 0.5 °C, compared to a baseline scenario with a temperature set point of 21 °C. This baseline set point is deemed more common in building than the oftentimes used set point of 20 °C [64] and still in line with DIN EN 12831 which allows a comfort surcharge of indoor temperature set points up to 3 °C above 20 °C. In buildings that already have lower indoor temperatures to begin with (due to e.g. large floor area, high energy costs, low-income households), the indoor temperature was reduced by 0.125 °C up to 1.25 °C in 0.125 °C increments. Thus, the results show the isolated effect of a short-term change in indoor temperature levels, without considering other effects such as changes in heating systems or building retrofits, which would require longer lead-times to be realised. The model considers the climatic conditions within each country as outdoor temperature levels. Thus, the difference between indoor and outdoor temperature levels varies between countries. Thus, a temperature reduction of 1 °C in a warmer climate leads to a lower relative reduction of this temperature difference (and the resulting energy needs for space heating) during the heating season. This effect is also discussed in the results section.

In additional scenarios, we consider ambitious energy efficiency measures and changes in the used energy carriers by energy carrier shifts. Energy efficiency measures include reducing the air exchange rate, e.g. by air tightening windows, reducing the ventilation rate, reducing the use of domestic hot water, and decreasing thermal exchange rates e.g. by closing curtains in front of windows or adding window films. The energy carrier shift scenario includes an increased use of secondary heating systems (e.g. coal or biomass fuelled systems) and an increase in installed solar surface area and heat pump capacity. The energy carrier shift scenarios (increased output of secondary heating systems, increased solar surface installation rate, and increased heat pump installation rate) are combined in the final analysis. Energy efficiency measures are analysed individually. Details of the scenario specifications are given in Table 2. Energy demand for all scenarios was calculated for the entire year.

Table 2
Description of additional model scenarios. The n50 value refers to the air exchange rate occurring as a result of air leakage through the building envelope at 50 Pa.

Scenario		Description
Energy efficiency measures	Air exchange rate	Reducing n50 value to 1 h^{-1} in buildings where it was initially higher than that.
	Ventilation rate	Reducing baseline heating and ventilation air exchange rate by 30 %
	Domestic hot water	Reducing baseline hot water consumption by 30 %
	Thermal exchange rates	Reducing the heat loss of windows by subtracting 0.14 W/m^2K from the baseline u-value in 1/6 of all single-glazed windows
Energy carrier shifts	Secondary heating systems	Increasing energy output of installed coal and biomass fuelled secondary heating systems by 50 %, assuming that 15 % of current coal and biomass demand (according to Eurostat energy balances) is attributable to such systems.
	Solar surface installation rate	Increased solar surface installation rate, so that 70 % of the installation decrease between the peak year 2008 [21] and 2019 [23] is restored. For countries that increased their installed solar surface area between 2008 and 2019, an increase of 20 % in their installation rate is considered.
	Heat pump installation rate	Increased heat pump installation rate to reach 70 % of the EU target [22] in gas heated buildings with an average of 12 kW and 1500 full-load hours

3.3.2. Survey

The survey data was collected in Germany, the Netherlands, Greece and Poland using an online questionnaire. Fieldwork took place in the selected countries between 16 December 2022 and 8 January 2023 and respondents were members of a research panel managed by Dynata Market Research. Quota sampling [75] was used to ensure the representativeness of the sample in terms of household income, building type and ownership structure (tenant/owner). Eurostat datasets were used for defining the quotas. The survey questions were available in five languages (English, German, Dutch, Greek, and Polish) and the translation of the survey into the target languages was checked by native speakers to avoid misinterpretation arising out of translation errors. Pretesting and piloting ensured that the survey conveyed the authors' intentions. The English version of the survey questions is provided as supplementary material to this paper.

The parts of the survey considered in this paper focused on heating behaviour in the heating periods 2021–2022 and 2022–2023. In the surveyed countries, the heating period usually starts in October and ends in March or April and can vary slightly from year to year. To avoid confusion and to avoid influencing the responses, no specific definition of heating periods was given. The heating behaviour was investigated in three areas, namely the heating temperature, the adopted non-technical energy saving measures (e.g. keeping the doors closed while heating, wearing more clothes), and the technical improvement (e.g. changing the thermostat from a manual to a programmable one). The questions relating to the 2021–2023 winter period were answered retrospectively.

In order to investigate the impact of the selected factors from section 2 on heating behaviour, questions on ownership structure, income and the building type were included in the survey. In addition, some questions were asked to enable a comparison of the heating periods of 2021–2022 and 2022–2023, the technical improvements available in the building (e.g. thermostats), and the level of information that the respondents have about the possibilities of improvement the heating system. It is assumed that the average occupancy rate of the dwelling (i.e. the average number of days during which the dwelling was occupied or unoccupied, taking into account, for example, daily indoor and outdoor activities of household members and average holiday periods) did not change significantly between years. Long-term unoccupancy of the dwelling (e.g. long holidays) in any of the survey years is considered to be exceptional and its impact on the survey results is considered to be negligible.

The collected sample consists of 3872 responses with the following contribution: Germany 998, Greece 900, the Netherlands 1000 and Poland 974. It was aimed to keep the samples from each country at roughly the same size to ensure representativeness of the sample and to increase statistical power in the tests. Although the primary focus of the present study is on gas users and their behaviour, to allow for a comparison between gas and non-gas users, data from users of all heating energy sources were collected in the survey.

Respondents were asked to report the heating temperature during both heating periods and for the periods when someone was at home and when no one was at home. These temperatures were used to identify invalid responses. Temperature ranges between 15 °C and 30 °C for occupied dwellings and between 10 °C and 30 °C for unoccupied dwellings were considered plausible and therefore valid (see [1] for a review of temperature ranges for thermal comfort). In addition to the absolute value in each year, the inter-annual difference was used as a second criterion to remove invalid responses. Only the values between −5°C and 5 °C were considered realistic and valid. Whenever the average heating temperature is mentioned in the results, it refers to the average of the heating temperatures of occupied and unoccupied periods. The analysis of the energy saving measures was based on binary data, i.e. if a measure was selected, it takes a value of 1, otherwise it would take a value of 0. The final dataset, after removing 27 speeders and 274 invalid responses (42 invalid responses for absolute temperature and 232 invalid responses for temperature difference), contains 3571 responses (DE: 925, GR: 814, NL: 915, PL: 917).

In addition to the descriptive analysis of the results, where appropriate, hypothesis tests were carried out using t-tests and chi-squared tests to examine the statistical significance of the effects.[1] The main findings of these tests are presented in the results section and are used to formulate the policy recommendations. An overview of the statements tested and the detailed test results are presented in Table C1 – Table C12 in Appendix C. The analysis and hypothesis tests were carried out at two levels: (i) at the aggregate level, without distinguishing between countries, and (ii) by differentiating between the four countries considered in this study. Where the results are at country level, this is indicated, otherwise the presented figures refer to the whole sample.

4. Results

4.1. Saving potentials derived from bottom-up modelling

In the baseline scenario, i.e. with no changes in indoor temperature levels, the total final energy demand for space heating and hot water in residential buildings in the EU-27 is around 2500 TWh, of which almost 900 TWh (36 %) is accounted for by natural gas (see Fig. 2). These results are in line with Eurostat [35], according to which households in the EU-27 consumed around 2200 TWh of energy for space heating and hot water in 2020, of which 850 TWh (39 %) is accounted for by natural gas. In our model, space heating alone accounts for about 80 % (2000 TWh) of this demand. Total energy demand can be reduced by 102 (4 %) to 720 TWh (29 %) in the 0.5 °C and 4.5 °C reduction scenarios, respectively. However, a 4.5 °C reduction in indoor temperatures could be considered as a significant decrease in comfort. It is particularly important to consider households that are already unable to adequately heat their homes without the proposed measures. Nevertheless, this scenario shows the high saving potentials and the fact that high gas prices could force behavioural changes in at least part of the building stock. More realistically, final energy demand could be reduced by 199 TWh (8 %) in the 1 °C scenario and up to 292 TWh (12 %) in the 1.5 °C scenario. Correspondingly, natural gas demand could be reduced by 38 TWh (4 %) in the 0.5 °C scenario to 269 TWh (30 %) in the 4.5 °C scenario, with a saving potential of 74 TWh (8 %) in the 1 °C scenario and 108 TWh (12 %) in the 1.5 °C scenario. Furthermore, the reduction in energy demand does not follow a completely linear trend. The largest reductions in final energy demand were found between the baseline and the 0.5 °C scenario (reduction of 102 TWh; 14 % of total reduction potential), while the additional reductions between the 4 °C and 4.5 °C scenarios were only half as large (54 TWh; 8 % of total reduction potential). The lowest reductions in final energy demand resulted from the reduced air exchange scenario with a maximum saving potential of 0.06 TWh, followed by the reduced thermal exchange scenario with a total saving potential of 26 TWh, of which 10 TWh come from natural gas savings and a further 4 TWh from electricity and district heating savings. Improving ventilation behaviour leads to a total saving of 72 TWh, of which 43 TWh is from gas-related energy carriers (natural gas, district heating, electricity), and reducing hot water use leads to a potential saving of 121 TWh (46 TWh for natural gas, 29 TWh for electricity and 14 TWh for district heating). Shifting energy carriers leads to a reduction of 32 TWh for natural gas and 25 TWh for district heating, while the demand for solar heating increases by 0.7 TWh and for electricity by 1.1 TWh due to the electricity demand of heat pumps. A detailed overview of the results can be found in Table A1 in Appendix A.

Looking at the four studied countries individually, the relative saving

[1] The hypothesis tests were initially carried out as multivariate regression analyses to account for confounding factors. These regressions, however, were susceptible to a lack of power due to a relatively low number of observations in each group, and the comparisons were hence made using t-tests, which are presented in this paper.

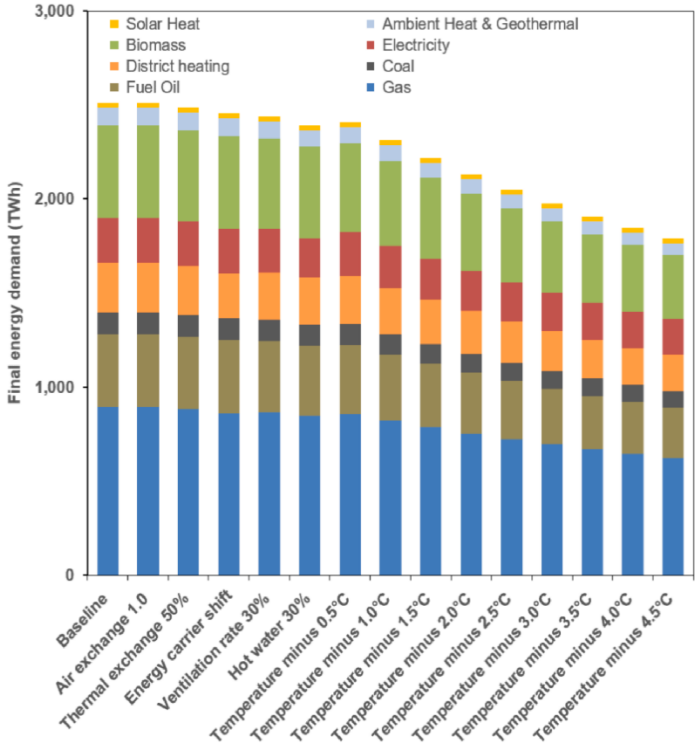

Fig. 2. Final energy demand for space and water heating in different scenarios, EU-27.

potentials for natural gas demand are highest in Greece with a reduction between 7 % for the minus 0.5 °C scenario and 50 % for the minus 4.5 °C scenario (see Fig. 3). For the other countries, the saving potentials are quite similar for the low temperature reduction scenarios (e.g. between 3 % and 5 % for the minus 0.5 °C scenario). Only for the higher temperature reduction scenarios (minus 2.0 °C or more) the savings start to diverge between countries, but still remain in a similar range (e.g. between 24 % and 31 % for the minus 4.5 °C scenario). The differences can

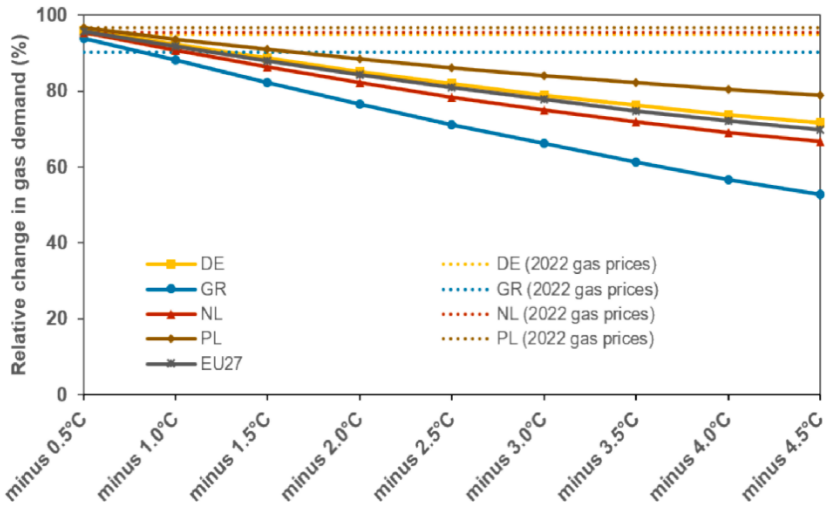

Fig. 3. Relative changes in residential natural gas demand for space and water heating in different scenarios of indoor temperature (solid lines) and estimates of the impact of behavioural changes due to price increases (dotted lines).

mainly be explained by the different climatic conditions, but are also related to the different effective indoor temperature levels in the baseline scenario and the different building stock constellations in each country. Poland shows the lowest saving potentials, followed by Germany and the Netherlands. For the EU-27 Member States combined, our models calculate saving potentials between 4 % (minus 0.5 °C scenario) and 28 % (minus 4.5 °C scenario), meaning that of the four countries studied, only Poland had a lower saving potential than the EU-27 average. One reason for the relatively strong effect of a 1 °C temperature reduction in warmer countries such as Greece is that the average temperature difference between indoor and outdoor temperature over the heating season is lower than in colder climatic areas. Thus, by reducing the indoor temperature by 1 °C, the relative decrease of the temperature difference between indoor and outdoor temperature in Greece is higher than in the colder countries.

Single-family houses (SFH) account for the majority of natural gas demand in the surveyed countries, with the exception of Greece, where 87 % of the natural gas demand comes from multi-family houses as shown in Fig. 4. For the EU-27, these shares are roughly equal, with 51 % of natural gas demand coming from single-family houses and 49 % from multi-family houses. The importance of the building categories for the impact of gas saving policies therefore appears to vary considerably between countries.

In 2022, Greek and Polish gas consumers experienced the highest (84 %) and the lowest (29 %) increases in energy prices respectively [38]. The dotted lines in Fig. 3 show the impact of the energy price increase as it occurred in the year 2022 on gas demand as estimated in the model Invert/EE-Lab [68] and the underlying short-term price elasticity. The analysis reveals that, Greece again has the highest estimated saving (triggered by the 2022 price increase) of 10 %. The estimated impact on price triggered savings for the other countries are in the range of the minus 0.5 °C and minus 1.0 °C scenarios, similar to Greece (PL: 3 %, DE: 5 %, NL: 5 %). Further research is needed to gain insight into the price responses of different households in terms of energy consumption, which is beyond the scope of this study.

4.2. Survey results and derived saving potentials

4.2.1. Socio-economic and building characteristics

The distribution of age groups among respondents varies from country to country. However, as the survey is addressed to the household as a whole (i.e. including all household members), the age of the respondent is not expected to influence the answers given. Residents living in all building age groups are represented in the sample. The quotas set for data collection in terms of building type, ownership structure and income (described in section 3.3.2) were largely met (see Table A2 in Appendix A), resulting in a maximum absolute deviation from official statistics of 7 % (in only one case). For most groups there is a small deviation of up to 2 % from the official statistics. The largest deviations are observed in Greece, where certain groups (e.g. low-income households living in rented single-family houses) proved difficult to reach. For building types and ownership structures, a negligible proportion of respondents fall into the "others" category. In the remainder of this section this category is not considered when presenting the results for these indicators. A detailed overview of the occupant and building characteristics of the survey sample is presented in Table A3 and Table A4 in Appendix A.

4.2.2. Heating behaviour

4.2.2.1. Heating temperature. On average, the reported heating temperature in the heating period 2022–2023 is slightly lower than in the heating period 2021–2022 (Table C1). The stated indoor temperature decreased between the heating season 2021–2022 and the heating season 2022–2023 from 19.44 °C to 19.16 °C in Germany, from 19.02 °C to 18.96 °C in Greece, from 18.00 °C to 17.70 °C in the Netherlands and from 20.37 °C to 20.20 °C in Poland. These figures take into account all survey responses, those reporting a reduction in the heating temperature and those reporting either an increase or no change in average temperature between years. On average, slightly above 30 % of respondents (DE: 33 %, GR: 28 %, NL: 34 %, PL: 30 %) reported a reduction in their heating temperature compared to the previous year. If only this group is considered, the reduction in heating temperature is much higher (around 1.6 °C) than if all observations are taken into account (see Fig. 5).

4.2.2.2. Energy saving measures. To get an overview of the (non-technical) approaches followed by households to save energy, and also to identify changes in behaviour in this respect, respondents were asked whether they had taken certain measures during the previous and current heating periods. The list included measures for reducing heat demand (e.g. shortening the heating period and reducing the heating hours, not using one or more rooms), lowering energy losses (e.g. keeping doors, windows, shutters and blinds closed) and compensating

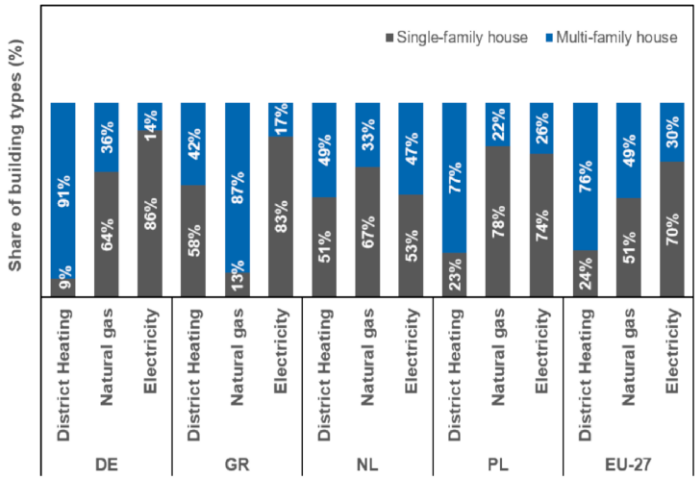

Fig. 4. Share of building type in total final energy demand by energy carriers with high sensitivity to gas prices.

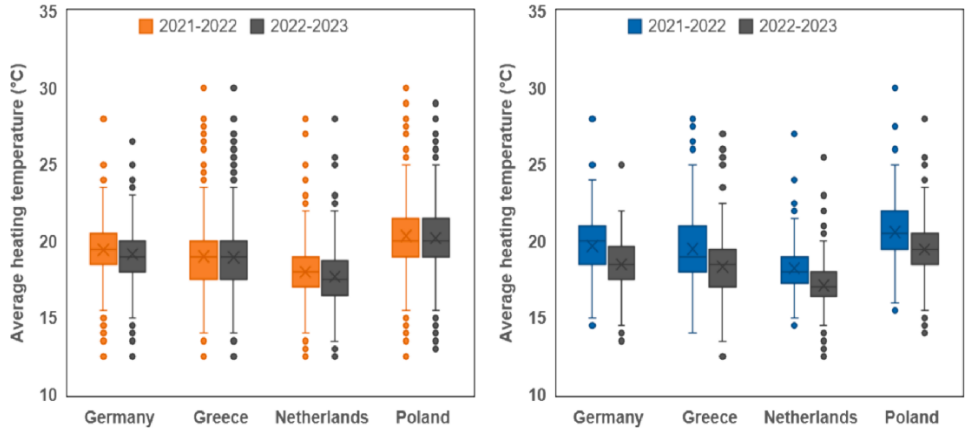

Fig. 5. Distribution of the average heating temperature- left: all households, right: only households that reported a temperature reduction (in each diagram the box shows the middle 50% of the data, the line and the cross in each box indicate the median and mean, respectively).

for heat demand by other means (e.g. wearing more clothes and using a blanket or hot-water bottle).

The overall picture of adopted approaches varies between countries, however, in 2021–2022 (Fig. 6) keeping windows and doors closed is the most chosen approach in all surveyed countries, followed by not heating unused rooms (DE, NL, PL) and closing shutters and wearing more clothes (GR). Between 11 % (DE, NL) and 21 % (PL) of respondents did not take any energy saving measures. The results of the survey show an average increase of 24 % in the number of energy saving measures applied by each household in the heating period 2022–2023 compared to the previous year (Fig. 7). Although the largest increase (around 30 %) was reported in the Netherlands, certain measures received high attention in all countries in the current heating period compared to last year, namely: shortening the heating period, reducing the heating hours and wearing more clothes. In addition, the use of a blanket or hot-water bottle to save heating energy has increased between the years in Germany and the Netherlands.

In addition to these non-technical saving measures, the use of alternative (more efficient) heating systems was examined. This showed an average increase of 44 % between years, with the lowest increase in Germany (35 %) and the highest in Poland (58 %).

4.2.2.3. Technical improvements. The technical ability to control the temperature of the heating system facilitates the implementation of the desired changes in heating temperature. For this reason, the survey asked respondents about the type of thermostat in their heating system and what improvements they had made between the two heating seasons, in terms of temperature control, e.g. switching from a manual thermostat to a programmable or smart thermostat. Fig. 8 presents the results concerning the technical improvements in the surveyed countries.

Around a fifth of respondents (DE: 21 %, GR: 18 %, NL: 16 %, PL: 22

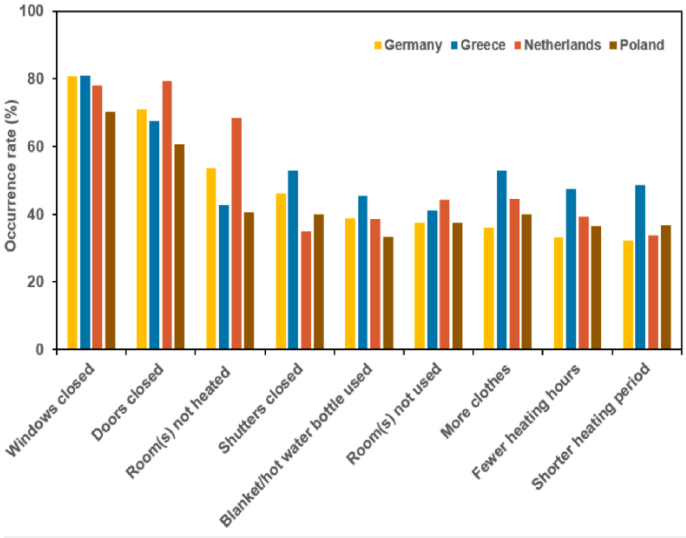

Fig. 6. Overview of the stated adopted energy saving approaches in the heating period 2021–2022.

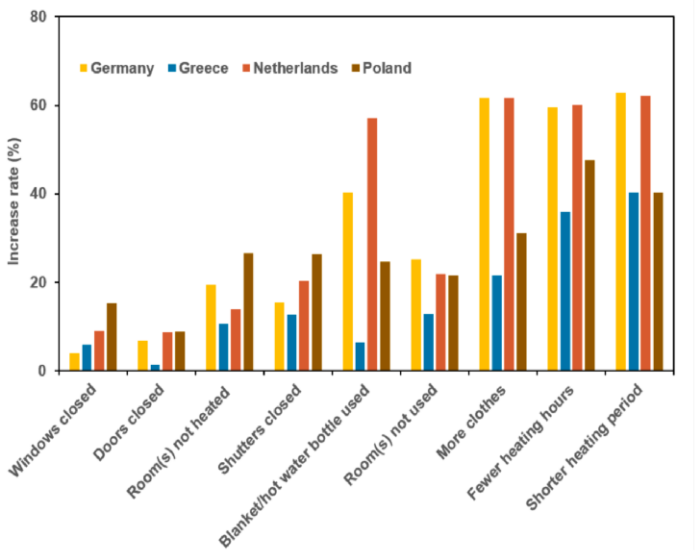

Fig. 7. Increase in popularity of energy saving approaches in the heating period 2022–2023 compared to 2021–2022.

%) made a technical improvement e.g. by changing the thermostat before the 2022–2023 heating period. Of the remainder who did not make such a change, around two-thirds had no information about the possibility of such improvements – of these, on average 75 % had not searched for information and around 15 % had not found any useful information despite searching – and a third had not made any improvements despite being aware of the possibilities. More than half of this group consider such changes to the controller to be either too expensive or not worth the potential energy savings. 10 % do not have the time to consider such improvements. Among the other reasons given for not being informed about the possibilities for improvement or not implementing the changes despite being informed, the dominant one is that they are tenants and therefore have no influence on the decisions and actions, chosen by around 30 % of respondents who selected this category.

4.2.3. *Reasons for the adopted heating behaviour*

4.2.3.1. Heating temperature. The type of energy carrier used by the household appears to have a statistically significant effect on the temperature reduction. In general, households using gas as an energy source reported a greater reduction in heating temperature than those using other energy sources. At country level, this trend seems to be general in at least three countries, Germany, Greece and the Netherlands, but not in Poland (Table C2). In addition, households in the countries with higher gas dependency (NL, DE) reported a higher reduction of the heating temperature compared to those with lower gas dependency (GR, PL) (Table C5). Looking at the ownership structure, the analysis shows that in all countries, a higher percentage of owners than tenants have reduced the heating temperature in the current heating period (Fig. 9). At the aggregated level, as well as at the country level, with the exception of Poland, tenant-occupied dwellings heat at a lower temperature on average and have reduced the heating temperature between years to a lesser extent than owner-occupied dwellings. Heating at a lower temperature is also reported in single-family dwellings in the whole sample and in the individual countries except for Germany (see Table C7 and Table C8). In both heating periods, the average heating temperature is directly related to the wealth of the household at the aggregated level (Fig. 10). A similar trend can also be seen within individual countries, i.e. wealthier households tend to heat at a higher temperature. However, no relationship is observed between income level and temperature reduction (Table C4).

4.2.3.2. Energy saving measures. The type of energy carrier does not seem to play a role in the absolute number of energy saving measures adopted by households in each heating period. However, even in this case, Germany and the Netherlands show a slightly larger increase in adopted energy saving measures in the heating period 2022–2023 compared to the previous year and compared to Greece and Poland (Fig. 11). One possible explanation for this is the higher gas dependency of the first two countries, which could make consumer gas prices in these countries more vulnerable to external price shocks. In general, the overview of adopted energy saving measures in both heating periods shows that the occupants of single-family houses adopted slightly more of these measures. The same is true for rented dwellings (Table 3). However, no consistent trend could be observed at the country level with regard to building type and ownership. Looking at income level, low-income households (quintiles 1 and 2) already adopted a higher number of energy saving measures in the heating period 2021–2022 and had a lower increase in the number of adopted measures between the two heating periods compared to middle and high-income households (quintiles 3–5). Nevertheless, the trend is also observed in the current heating period at both the individual and aggregated levels, with the exception of Germany (Fig. 12). It should be noted that the individual energy saving measures are not directly comparable, especially in terms of costs and saving potentials, therefore a more detailed analysis of energy saving measures was not possible with the data collected for this paper.

4.2.3.3. Technical improvements. According to the analysis, the type of energy carrier seems to have an influence on the occurrence of technical improvements. In all countries, dwellings heated by district heating are the least likely to have undergone technical improvements. In Germany, the Netherlands and Poland, wood is in second place. In these countries, households using electricity have (almost) the highest rate of technical improvements (Table 4). Focusing on gas, there is generally no

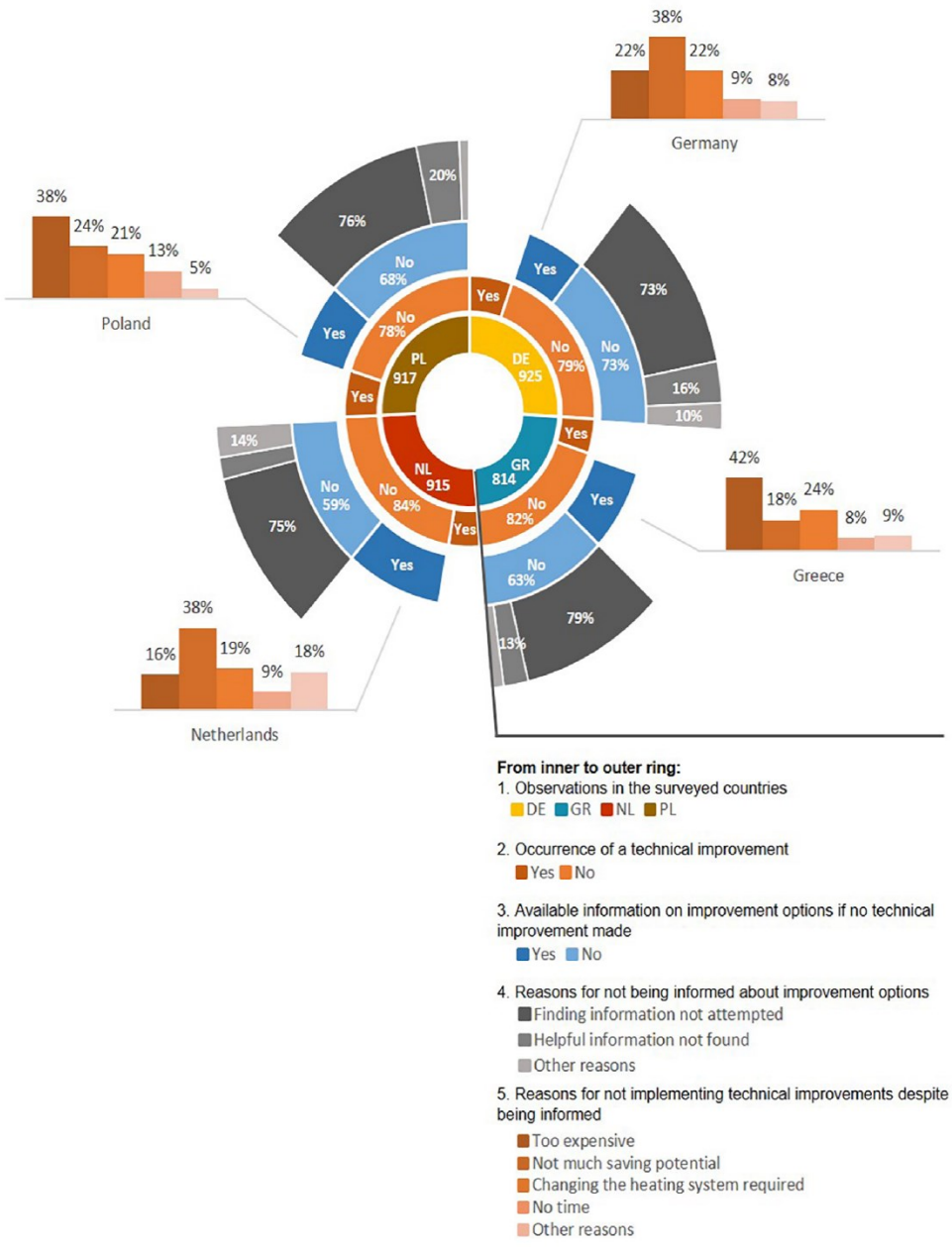

Fig. 8. An overview of technical improvements in the studied countries between the two heating periods.

statistically significant trend across countries when it comes to technical improvements undertaken by households using gas heating compared to the others (Table C12). Looking at countries individually, in Germany a higher proportion of households with gas heating made a technical improvement than households with other energy sources. Counterintuitively, the opposite trend was observed in the Netherlands. Within the total sample, technical improvements are more frequent in owner-occupied dwellings and also in single-family houses (Table 5). At country level, some of these associations were not statistically significant (Table C9 and Table C10). Regarding the financial situation, low-income households (quintiles 1 and 2) are less likely to invest in technical improvements than middle and high-income households (quintiles 3–5) in the whole sample. This trend is also observed in Germany and the Netherlands and is statistically significant (Table C11).

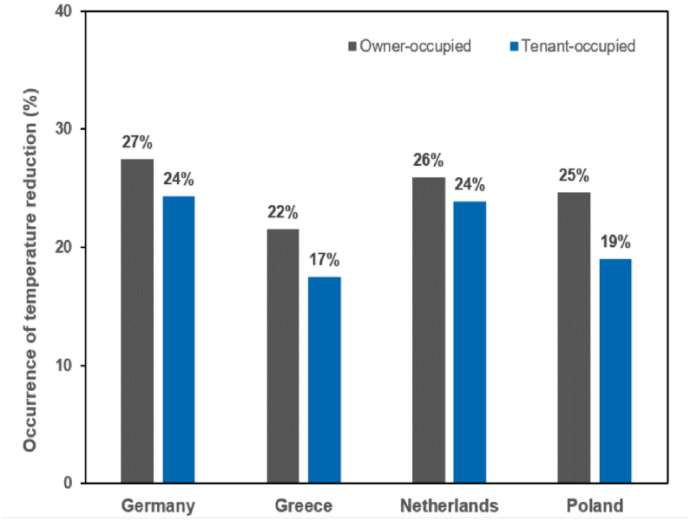

Fig. 9. Occurrence of a heating temperature reduction by ownership structure.

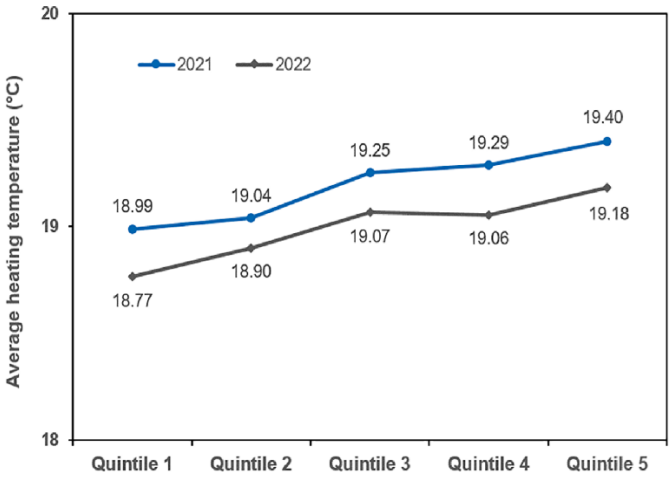

Fig. 10. Average heating temperature by income level.

4.3. Relationship between the studied factors and heating behaviour

Combining the results of the modelling (section 4.1) and the survey (section 4.2) for the countries studied, this section summarises the relationships that could be identified between the studied factors and heating behaviour (Table 6). Statements on heating temperature and technical improvement have been made whenever the effect was statistically significant. The statement for energy prices comes from the modelling results, and for energy saving measures no statistical test was possible due to the nature of the data collected. Cells are blank where no clear relationship could be found. It should be noted that this table does not imply any causality between the studied factors (e.g. although larger temperature reductions are reported in the more gas-dependent countries (NL and DE), this does not mean that the reductions are only due to the choice of the energy carrier or its price, as other factors may influence the temperature reduction).

5. Discussion

5.1. Comparative analysis of saving potentials: Model vs. survey and policy targets

Combining the results of the survey with the saving potential calculated by the modelling exercise, it is possible to reflect on the achievability of the demand reduction targets set by the EU following the Russian invasion of Ukraine in early 2022. Around 30 % of households in the sample report having reduced their average heating temperature in the heating period 2022–2023 compared to the previous year. The figure for Germany (33 %) corresponds to the reported willingness to reduce the temperature before the start of the current heating period [15]. However, the average temperature reduction of around 0.3 °C reported in Germany would only lead to a reduction in gas demand in the residential sector of around 2.5 %. The same applies to the

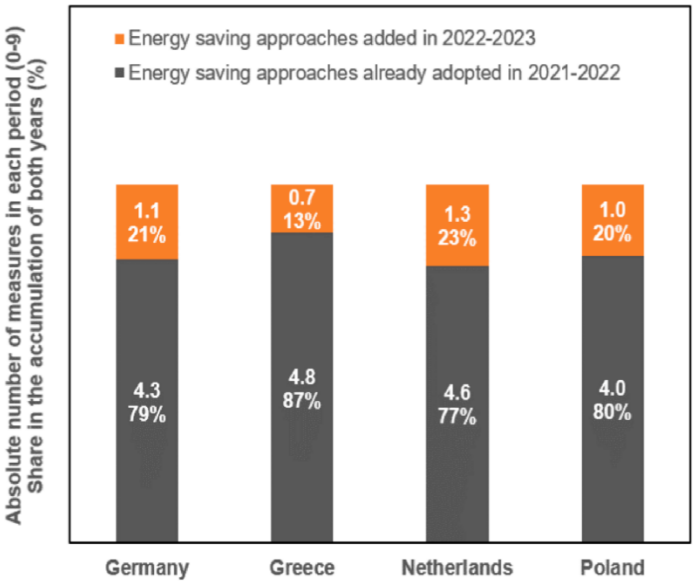

Fig. 11. Overview of saving measures adopted (absolute values and relative increase between heating periods).

Table 3
Adopted energy saving measures by ownership structure and building type.

Number of measures	Owner-occupied	Tenant-occupied	MFH	SFH
Average 2021–2022	4.34	4.48	4.23	4.54
Average 2022–2023	5.43	5.51	5.26	5.54
Added	1.09	1.03	1.03	1.00

other countries (GR: 3.5 %, NL: 2.8 %, PL: 2.0 %).

Nevertheless, the study points to a change in heating behaviour as a possible effect of the gas crisis following the war in Ukraine. At the micro level, it is observed that households using gas as an energy source report a higher temperature decrease than the others. Similarly, at the macro level, a larger temperature decrease is observed in the countries with higher gas dependency (DE and NL). Moreover, the increase in energy saving measures in the heating period 2022–2023, especially in the gas-dependent countries, may indicate a reaction to the energy crisis. Although the actual change in energy prices varied between countries, with the highest increase in the months immediately following the Russian invasion, similar changes in behaviour were observed in all the surveyed countries. Therefore, lowering the temperature and following the energy saving measures could be the result of both a real increase in the energy bill and the perception of higher gas prices conveyed by the media. In contrast to the experience before the energy crisis [79], the use of more clothes to save heating energy increased by more than 60 % in gas-dependent countries compared to the last heating period. However,

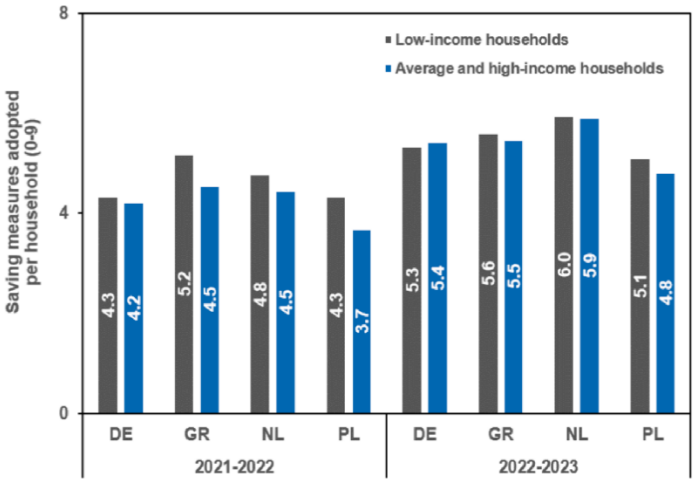

Fig. 12. Overview of the adopted saving measures by income in each heating period.

Table 4
Occurrence of technical improvements by energy carrier.

Energy carrier	DE	GR	NL	PL
Charcoal				27%
District heating	10%	13%	3%	9%
Electricity	28%	15%	33%	46%
Gas	25%	21%	13%	25%
Gasoil		19%		
Heat pump	20%	22%	22%	35%
Solar			34%	
Oil	22%			
Wood/pellet	16%	19%	8%	19%

Table 5
Occurrence of technical improvements by ownership structure and building type (%).

	Owner-occupied	Tenant-occupied	MFH	SFH
Germany	24.5	18.1	19.2	24.0
Greece	20.1	14.0	16.9	20.5
Netherlands	17.7	10.9	14.5	16.0
Poland	22.3	17.6	14.2	28.4

this may be a short-term measure, possibly influenced by fears of a possible gas shortage or the actual increased prices. Transforming such short-term behavioural changes into sustainable long-term practices is key to achieving demand reduction targets. This will require a range of policy instruments, for which further evidence from the survey may also be relevant.

The main reason given for not making technical improvements such as changing the thermostat is the financial burden. However, in the Southern and Eastern European countries surveyed (GR and PL), the direct and immediate costs of such a change have the greatest negative impact, while in the Western European countries surveyed (DE and NL) the focus is on the saving potential and the payback period. Generally

Table 6
Summary of identified relationships between heating behaviour and selected factors (own illustration).

	Heating behaviour					
	Heating temperature		Energy saving measures		Technical improvements	
	Country level	Aggregated	Country level	Aggregated	Country level	Aggregated
Building type	–	SFH residents heat with a lower temperature compared to MFH residents (Table C7)	–	SFH residents slightly adopt more measures than MFH residents (Table 4)	–	SFH residents are more likely to invest in technical improvements than MFH residents (Table C10)
Energy carrier	Larger temperature reductions in gas using households in DE, GR, NL (Table C2); Larger temperature reductions in gas-dependent countries than in others (Table C5)	Larger temperature reduction reported in gas using households compared to the rest (Table C2)	Residents in countries with higher gas-dependency added relatively more energy saving measures between the years than the other countries (Fig. 11)	–	Least technical improvements in district heating (Table 4); In DE more improvements are made by gas users, in NL the opposite trend is observed (Table C12)	–
Ownership structure	Only in DE tenants heat at a lower average temperature than owners (Table C8)	Tenants heat at a lower average temperature than owners (Table C8)	–	Tenants adopted slightly more saving measures than owners (Table 4)	Owner-occupied households in DE, GR, NL are more likely to invest in technical improvements compared to the tenant-occupied ones (Table C9)	Owner-occupied households are more likely to invest in technical improvements compared to the tenant-occupied ones (Table C9)
Income level	Wealthier households in DE, NL and PL tend to heat at a higher temperature than lower income households (Table C3)	Wealthier households tend to heat at a higher temperature than lower income households (Table C3)	Number of saving measures followed in each period is inversely related to income (except for DE in 2022) (Fig. 12)	Number of saving measures followed in each period is inversely related to income (Fig. 12)	In DE and NL, average to high-income households are more likely to invest in technical improvements than low-income households (Table C11)	–
Energy price	Higher increase in energy prices results in higher energy savings.					

Germany and the Netherlands show similar heating behaviour in terms of technical improvements and energy saving measures. The same applies to Greece and Poland. Taking this into account, experience from one country could be used for policy recommendations in the other.

Between 50–70 % of the respondents (DE: 53 %, GR: 50 %, NL: 72 %, PL: 58 %) reported the measured heating temperature, in other cases the reported temperature was estimated. The ability to measure the temperature (e.g. using a thermometer or smart thermostat) could be associated with better control and possibly reduction of the temperature, however, there was no statistically significant difference between the reported reduction of the heating temperature for those who estimated and those who measured (Table C6). It is also not surprising that even before the energy crisis, low-income households had already adopted many energy saving measures and were less likely to invest in technical improvements than the other income groups, possibly due to lower disposable income. Considering that already in 2021 on average 6.5 % of households in the studied countries were not able to keep their dwellings adequately warm (from 2.4 % in NL to 17.5 % in GR) [39], this income group already has a very low gas demand and therefore cannot be expected to make a large additional contribution to gas demand reduction by lowering the heating temperature.

Policy instruments to address rising energy prices were already provided by EU regulators in 2021, as wholesale electricity prices in the EU and many other regions increased by 200 % to an annual basis, due to increased global demand [25]. Less than two weeks after the Russian invasion of Ukraine, the European Commission and the Council of the European Union initiated a series of interrelated communications, regulatory proposals, recommendations and regulations aimed at reducing dependence on Russian fossil fuels, reducing EU gas demand and protecting households and economy from excessively high gas prices (Table 7).

The data collected in the present study suggests that the behavioural changes of building occupants investigated in this study, such as lowering the indoor temperature, are unlikely to make a significant contribution to the EU policy target for gas savings through behavioural change, i.e. 13 bcm of natural gas saved [28]. We can speculate on the reasons for the gap between the energy saving targets set by policy and the weak energy savings observed in this paper and in the literature. One reason could be poor implementation of the proposed policies. Another possible reason for not meeting the targets could be poor design of the measures in the first place or an overestimation of the savings potential of measures designed to appeal to individual behaviour changes.

Table 7
EU-level policy instruments addressing the reduction of gas demand and prices in 2021–2022.

Date	Reference	Policy instrument	Policy document type
13 October 2021	[25]	"Tackling rising energy prices: a toolbox for action and support"	Communication
8 March 2022	[29]	Outline of "REPowerEU: joint EU action for more affordable, secure, and sustainable energy"	Communication
23 March 2022	[27]	Commission proposal to amend the Security of Gas Supply Regulation and a Communication: "Security of supply and affordable energy prices: Options for immediate measures and preparing for next winter"	Regulation proposal, Communication
18 May 2022	[28]	The Commission REPowerEU Plan to rapidly reduce dependence on Russian fossil fuels	Communication, Regulation proposal, Recommendation
5 August 2022	[11]	Regulation (EU) 2022/1369 on coordinated demand-reduction measures for gas	Regulation
22 December 2022	[12]	Regulation (EU) 2022/2578 establishing a market correction mechanism to protect Union citizens and the economy against excessively high prices	Regulation

On the one hand, policy responses to the urgent need to reduce gas demand for space and water heating in the EU were not closely coordinated, as the EU-level regulation only provided a list of exemplary measures that could be implemented by Member States (Article 6 of Council Regulation 2022/1369). No clear targets, timetables and budgets were set for behaviour change campaigns [11,12,25,27–29]. In Germany, the national energy saving campaign was not successful in achieving the national government's target of a 20 % reduction in gas consumption [60,78]. In Finland, the *Down a degree* programme, which aimed to reduce indoor temperatures also ran an awareness campaign [2]. In Sweden, households were encouraged to decrease their electricity consumption in order to reduce gas consumption in power plants [19].

On the other hand, Germany, the Netherlands, and Poland introduced retail price caps for gas consumption in the residential sector [43,76,44]. Greece introduced a subsidy per unit of gas consumed by households [54]. While these policy instruments aimed to minimise increases in gas bills for the most vulnerable consumers, such measures blunted the price signals that play an important role in promoting behavioural changes towards reducing energy demand [61].

5.2. Reflection on policy implications

According to the modelling results for the EU-27 countries, a 0.5 °C reduction in indoor temperature leads to a 4 % decrease in gas demand for residential space and water heating. A 1.0 °C reduction lowers gas demand by about 8 %. The impact is higher under warmer climatic conditions and depends on the mix of buildings and the uptake of the measure in different building types. It suggests that achieving the 15 % gas demand reduction target by only lowering the indoor temperature would require heating with on average 2 °C lower temperatures. Indoor temperature requirements for thermal comfort in winter vary between 15 and 21 °C across the EU, with the lower and upper limits reported in only one country and most of the remaining countries in the 19–20 °C range [7]. However, the average heating temperature in residential buildings in the EU is over 22 °C [31], which is about 3 °C higher than the average heating temperature recorded in the survey, which may indicate some social desirability bias in the survey responses. The 2 °C reduction needed to meet the targets would require the surveyed households to heat at an average temperature of 17.2 °C, which is around the minimum recommended room temperature in Germany [62,82]. Considering that the reported average temperature in the surveyed countries is already quite low compared to the EU average, further lowering the temperature may cause health issues as living in cold rooms can lead to various illnesses, sleep disorders or depression [87]. Nevertheless, the survey found only an average temperature reduction of 0.3 °C when comparing the heating period 2022–2023 with the previous year, which is much lower than the assumed reduction potential.

The observed decrease in EU gas consumption in the building sector in 2022 is partly due to the climatic conditions and the mild winter, leading to a decrease in the number of heating degree days compared to 2021 [52]. Changes in heating behaviour as a result of the war in Ukraine might also have played a role. About 6 % of the decrease in EU gas consumption between 2019 and 2022 and 7–11 % of the gas savings in the German building sector in 2022 are attributed to changes in heating behaviour [18,41]. However, this effect is expected to be temporary, stimulated or forced by the war in Ukraine and higher energy prices.

Improving thermostats could help achieve the goal of heating at a lower temperature by making it easier to control the temperature. A large proportion of respondents (around two-thirds) who had not improved the way they control the temperature between the heating periods report that they had no information about this option. Although

this was partly (around 75 %) because they had not looked for information, around 15 % could not find any helpful information despite trying. Lack of time was also cited as a barrier to such changes. Technical improvements, such as upgrading thermostats, could be better promoted and facilitated by offering all-in-one packages that include consultation and information on the available options, installation of the chosen technology and after-sales service. This could be included in the annual inspection of the heating system and offered by the responsible companies.

High costs and long payback periods were compelling enough reasons for more than half of the survey respondents not to make technical improvements despite having the information. Therefore, measures involving financial support in various forms could be provided to overcome the financial barriers to the acquisition of technical improvements. The higher rate of technical improvements reported in the single-family and owner-occupied dwellings, as well as in the more affluent families, points to the role of socio-economic factors in setting the priority for investment in such technical changes, and may also indicate the existence of a landlord-tenant dilemma regarding investment in household infrastructure improvements. Tailored measures targeting specific groups such as tenants and low-income households, could therefore be useful to reach a larger population.

The reported higher temperature reduction and the greater increase in the number of adapted measures in Germany and the Netherlands, the two more gas-dependent countries, compared to the other surveyed countries, might indicate the (mental) impact of the energy crisis on heating behaviour and the need for information campaigns (as also studied by e.g. [10,71]). Presumably, this is partly due to the sharp rise in energy prices and the fear of not being able to pay heating bills in the coming winter [52], and partly due to the anticipation of gas shortages. In both cases, there is an incentive to change behaviour towards lower consumption (a pure price incentive in the first case and a longer-term incentive to save resources in the second). Hence, information campaigns could be an effective way of raising public awareness of the long-term scarcity of resources and the importance of reducing energy consumption, as well as the economic and environmental impact of reducing energy consumption. However, to achieve greater savings, such information policy instruments aimed at the general public could be complemented by detailed, tailor-made information, e.g. through direct feedback on energy consumption patterns [16,17]. The resulting awareness of energy consumption seems to have a positive effect on changes in heating behaviour, i.e. lower heating temperatures and better control of heating (see [45,63,69]) and to lead to energy savings of different ranges depending on the strategy used [88]. The role of digitalisation in providing immediate and detailed feedback on energy consumption (e.g. installation of gas meters) could be promoted to support demand response efforts for the grid as well as to monitor consumer's own consumption.

Changes in heating behaviour in response to energy price increases are discussed in several studies (e.g. [86,14]) and confirmed by the sensitivity analysis in this paper. Thus, well-designed fiscal measures could be another effective way to stimulate energy savings. As also suggested by Koasidis et al. [56] in their study on monetising behaviour changes, lower consumption could be encouraged through financial incentives and rewarded with bonuses. An example of such incentives is the concept of feed-in tariff for energy savings (i.e., the users receive a financial incentive for each energy unit they save), whose potential characteristics and impact was already explored a decade ago (see [5,42]). On the other hand, high-consumers could be induced to reduce consumption through progressive prices and additional taxes, bearing in mind that only small tax increases may not lead to immediate responses in energy consumption [73]. However the level of taxation should be carefully defined to achieve the desired demand reduction, while avoiding unintended energy poverty in the less affluent households [4]. In the long-term, vulnerable consumers could be also protected through targeted policies (e.g. direct transfers) rather than price caps and consumption-based subsidies.

5.3. Limitations and future work

We have selected a set of countries based on the factors considered relevant for the scope of this paper (see section 3.2). However, due to the diversity of countries and their energy systems within the EU, the study does not claim to cover a fully representative set of countries. Similar studies should be repeated in other countries, taking into account other aspects and dimensions, in order to get a complete picture of the situation in the EU.

The nature of the data collection method for the survey imposes some limitations on the conclusions that can be drawn from this study. The survey responses relate to self-reported behaviour rather than observed behaviour. In addition, as the survey asks for information on past behaviour, some social desirability bias cannot be excluded. Furthermore, gender perspective was not considered in this study, as the focus of the survey was primarily on household heating behaviour. Future research should consider gender as a variable of analysis to explore how the gender of the respondents may influence the results.

Due to the different underlying characteristics (such as climatic conditions, social, economic, and demographic characteristics) of the studied countries, a direct comparison of temperature differences between countries is not necessarily very enlightening. However, these temperature differences, can be interpreted within each country. Moreover, according to the analysis in this paper, the location of the respondents (country) has a greater effect on the results than socio-demographic factors (e.g. income, age). Therefore, a similar study with more observations in each country is recommended for a more detailed cross-country analysis.

The impact of building energy performance and dwelling size on the effective indoor temperature used in the modelling is derived from empirical data for Germany (see literature quoted in section 3.3.1, [65,66]). A detailed analysis of the extent to which the derived functions are valid for other countries within Europe could not be carried out within the scope of this paper and is left for further research.

Finally, a direct comparison between the modelling and survey results could be misleading without taking into account the limitations of the data used. The modelling results were calculated with climatic data for 2019 while the survey was conducted in the heating periods 2021–2022 and 2022–2023. However, while the heating degree days in 2022 were significantly lower than in 2021, they did not deviate much from the 2015–2019 average [34], allowing for at least some comparability. At EU-27 level, the number of heating degree days in 2022 was about 4 % lower than the 2015–2019 average. This differed from country to country. For example, in Belgium, the Netherlands and Germany the number of heating degree days was 92 % (Belgium) and 95 % (Germany) of the average, while in Poland and the Baltic states the number of heating degree days was about 2 to 5 % higher than the average. In terms of demographics and building characteristics, the survey data largely matches the input data used for modelling. As explained in section 4.2.1, the survey sample is broadly representative of the population of the studied countries, at least in terms of building type, ownership and income. The input data used for modelling is also based on official statistics. As the survey refers to the year 2022–2023 and the model uses data from the base year, there may be some differences between the two datasets simply due to the evolution of the building stock and demographics, but we do not expect a major change within only a few years. Therefore, the fact that both datasets are representative of the countries allows for some comparability.

6. Conclusion

The present research is a case study to investigate the effectiveness of the measures recommended by the European Commission (e.g. REPowerEU) and the Council of the European Union (e.g. Council Regulation

(EU) 2022/1369) in achieving the policy targets set by the EU or the Member States. The study focuses on gas demand and the EU target to reduce it by 15 % in Member States between 1 August 2022 and 31 March 2023, compared to the average for the same period in the previous five years. Due to the high share of the residential sector in EU gas demand, this sector is expected to make a large contribution to energy savings. Using modelling and survey approaches in four selected European countries, the paper examines the energy savings in this sector resulting from changes in heating behaviour with a particular focus on reducing heating temperatures. The survey was conducted in Germany, Greece, the Netherlands and Poland and examined the changes in household heating behaviour between the 2021–2022 and 2022–2023 heating periods in three aspects: heating temperature reduction, energy saving measures (e.g. not heating unoccupied rooms) and technical improvements (e.g. replacing manual thermostats with programmable ones).

The observations of the whole sample (N = 3571) showed an average temperature reduction of 0.2 °C between years, from 19.2 °C to 19.0 °C. This corresponds to a 2–3.5 % reduction in gas demand of the studied countries. Overall around 30 % of respondents reported a reduction in their heating temperature. The energy saving measures covered in the survey included the ones aimed at reducing heat demand, lowering energy losses and compensating for heat demand by other means. The most commonly reported measure in 2021–2022 was keeping doors and windows closed. There was an average increase of 24 % between years, so that in 2022–2023 the most common practices were: shortening the heating period, reducing the heating hours and wearing more clothes. On average, 20 % of respondents have made a technical improvement to better control the heating temperature. Two-thirds of the remainder had no information on the possibilities for such an improvement.

The study also looked at the impact of selected building characteristics and socio-economic factors on changes in heating behaviour. Households using gas as an energy source reported a greater reduction in heating temperature than those using other energy sources. Occupants of single-family houses heat at lower temperatures and are more likely to invest in technical improvements than occupants of multi-family houses. While tenants heat at a lower average temperature than owner-occupiers, they are less likely to invest in technical improvements. Wealthier households tend to heat at higher temperatures and take fewer measures to save energy. Analyses were carried out at the aggregate and country levels. Respondents in the gas-dependent countries (DE and NL) reported higher temperature reductions and added more energy saving measures compared to the other countries.

The paper recognises that individual measures may not be sufficient to achieve the EU targets. Furthermore, the observed behavioural changes leading to reduced energy consumptions may be a temporary effect of unexpected circumstances, such as high energy prices or geopolitical situations. Hence, to maximise the impact of such measures and to facilitate the transformation of these short-term responses into long-term behaviour, they need to be designed in conjunction with other measures and as part of a policy package. We therefore recommend a number of policy measures to encourage and facilitate reductions in heating energy consumption. These include (i) promoting technical improvements, such as the upgrading of thermostats, by providing financial and technical support (e.g. all-in-one packages providing consultation, installation and after-sales services), (ii) raising public awareness of the need to reduce consumption in the face of resource scarcity, while motivating energy savings through the provision of detailed and tailored information (e.g. direct feedback on consumption patterns) and (iii) using financial incentives in the form of bonus schemes to reward lower consumption or as progressive prices or additional taxes to penalise higher consumption.

CRediT authorship contribution statement

Mahsa Bagheri: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Maksymilian Kochański:** Conceptualization, Methodology, Writing – Original draft preparation. **Lukas Kranzl:** Conceptualization, Methodology, Writing – review & editing. **Katarzyna Korczak:** Resources. **Lukas Mayrhofer:** Software, Writing – Original draft preparation. **Andreas Müller:** Conceptualization, Resources. **Ece Özer:** Software, Formal analysis. **Swaroop Rao:** Formal analysis, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

This work was supported by European Union's Horizon 2020 research and innovation programme under the project newTRENDs with the grant agreement no. 893311. The authors would like to thank Heike Brugger, Joshua Fragoso, Markus Fritz and Clemens Rohde for their valuable feedback on earlier versions of this paper and Kevan Skorna for providing support for creation of the graphical abstract.

Appendix A. Summary tables

Table A1
Summary of the modelling results: Final energy demand in TWh for the EU-27 countries as well as the four surveyed countries Germany, Greece, Netherlands and Poland for all model scenarios. Total final energy demand is shown in the same row as the scenario names and additionally the final energy demand of some selected energy carriers (gas, district heating and electricity) is listed for each scenario.

	EU-27 [TWh]	Germany [TWh]	Greece [TWh]	Netherlands [TWh]	Poland [TWh]
Baseline	2 511	558	39	96	224
Gas	894	271	5	72	30
District heating	263	45	0	4	51
Electricity	239	24	2	10	16
Air exchange 1.0	2 511	558	39	96	224
Gas	894	271	5	72	30
District heating	263	45	0	4	51

(*continued on next page*)

Table A1 (*continued*)

	EU-27 [TWh]	Germany [TWh]	Greece [TWh]	Netherlands [TWh]	Poland [TWh]
Electricity	239	24	2	10	16
Thermal exchange 50 %	2 485	554	39	95	221
Gas	884	269	5	71	30
District heating	260	45	0	4	50
Electricity	237	24	2	10	16
Secondary heating	2 456	553	38	93	219
Gas	862	268	5	70	29
District heating	238	44	0	3	49
Electricity	240	24	2	10	15
Ventilation rate 30 %	2 439	539	39	93	217
Gas	868	261	5	69	29
District heating	252	43	0	4	48
Electricity	234	24	2	9	16
Hot water 30 %	2 389	534	37	90	215
Gas	848	259	4	68	29
District heating	249	43	0	4	49
Electricity	209	22	2	8	14
Temperature minus 0.5 °C	2 409	537	37	91	216
Gas	857	260	5	68	29
District heating	254	44	0	4	49
Electricity	232	24	2	9	15
Temperature minus 1.0 °C	2 312	516	34	87	209
Gas	821	250	4	65	28
District heating	245	42	0	4	48
Electricity	225	23	2	9	15
Temperature minus 1.5 °C	2 220	496	32	83	202
Gas	786	240	4	62	27
District heating	236	40	0	3	46
Electricity	219	22	2	9	15
Temperature minus 2.0 °C	2 132	477	30	79	196
Gas	754	231	4	59	27
District heating	228	39	0	3	44
Electricity	213	22	2	8	14
Temperature minus 2.5 °C	2 051	459	29	76	190
Gas	723	222	3	56	26
District heating	220	37	0	3	43
Electricity	208	21	2	8	14
Temperature minus 3.0 °C	1 976	443	27	72	185
Gas	695	214	3	54	25
District heating	212	36	0	3	41
Electricity	203	20	2	8	14
Temperature minus 3.5 °C	1 907	428	26	69	180
Gas	669	207	3	51	25
District heating	205	34	0	3	40
Electricity	198	20	2	8	13
Temperature minus 4.0 °C	1 845	415	25	67	176
Gas	645	200	3	49	24
District heating	198	33	0	3	39
Electricity	194	20	2	7	13
Temperature minus 4.5 °C	1 791	403	23	65	172
Gas	625	194	3	48	24
District heating	192	32	0	3	38
Electricity	191	19	2	7	13

Table A2
Comparison of survey data with official statistics (the figures in the column Official statistics are own calculations based on [36] for building type and [37] for ownership structure and income groups).

		Official statistics				Survey data			
		DE	GR	NL	PL	DE	GR	NL	PL
Building type	SFH	41 %	41 %	75 %	56 %	43 %	34 %	75 %	52 %
	MFH	56 %	59 %	21 %	44 %	57 %	66 %	24 %	48 %
Ownership structure	Owner	51 %	74 %	69 %	86 %	51 %	69 %	70 %	85 %
	Tenant	50 %	26 %	31 %	14 %	49 %	29 %	30 %	14 %
Income groups	Quantile 1	20 %	20 %	20 %	20 %	19 %	14 %	20 %	17 %
	Quantile 2	20 %	20 %	20 %	20 %	19 %	21 %	21 %	21 %
	Quantile 3	20 %	20 %	20 %	20 %	20 %	22 %	20 %	21 %
	Quantile 4	20 %	20 %	20 %	20 %	21 %	19 %	21 %	21 %
	Quantile 5	20 %	20 %	20 %	20 %	20 %	24 %	19 %	21 %

Table A3
Summary of the survey sample: Occupant-related characteristics.

		Germany	Greece	Netherlands	Poland
Observations		925	814	915	917
Age of respondents	18–25	3.9 %	8.0 %	3.2 %	11.8 %
	26–35	12.6 %	20.5 %	12.5 %	30.0 %
	36–45	21.0 %	32.3 %	15.3 %	24.1 %
	46–55	16.5 %	2.8 %	22.3 %	6.2 %
	56–65	21.9 %	25.8 %	20.1 %	18.4 %
	Above 65	24.0 %	10.6 %	26.7 %	9.5 %
Ownership structure	Owner	50.8 %	69.2 %	69.8 %	84.6 %
	Tenant	49.1 %	28.9 %	30.2 %	14.3 %
	Others	0.1 %	2.0 %	0.0 %	1.1 %
Income groups	Quantile 1	19.4 %	13.9 %	19.5 %	17.1 %
	Quantile 2	19.2 %	21.3 %	20.7 %	20.6 %
	Quantile 3	19.8 %	22.4 %	20.2 %	20.6 %
	Quantile 4	21.2 %	18.9 %	20.5 %	20.6 %
	Quantile 5	20.4 %	23.6 %	19.1 %	21.0 %
Household size	1	21.4 %	11.4 %	19.6 %	12.6 %
(Number of people living in the household)	2	42.5 %	26.5 %	45.4 %	24.8 %
	3	20.4 %	29.7 %	15.1 %	30.3 %
	4	12.0 %	24.4 %	15.0 %	20.5 %
	5	2.8 %	6.1 %	4.2 %	8.2 %
	6 or more	0.9 %	1.7 %	0.9 %	3.6 %

Table A4
Summary of the survey sample: Building-related characteristics.

		Germany	Greece	Netherlands	Poland
Observations		925	814	915	917
Year of construction	< 1945	12.8 %	1.5 %	9.8 %	9.7 %
	1945–1969	21.4 %	9.1 %	15.2 %	14.5 %
	1970–1979	19.5 %	20.8 %	18.5 %	18.5 %
	1980–1989	14.8 %	20.9 %	19.1 %	16.0 %
	1990–1999	12.5 %	16.5 %	12.1 %	11.8 %
	2000–2010	9.7 %	26.3 %	13.9 %	13.4 %
	2010–2020	7.6 %	4.8 %	8.4 %	13.7 %
	> 2020	1.7 %	0.2 %	3.0 %	2.3 %
Building type	Single-family house	42.8 %	34.2 %	75.2 %	51.8 %
	Multi-family house	57.0 %	65.5 %	24.2 %	47.8 %
	Others	0.2 %	0.4 %	0.7 %	0.4 %
Heating type	Individual heating	22.6 %	33.3 %	16.8 %	23.7 %
	Central heating	62.5 %	18.6 %	63.0 %	68.2 %
	Single-story heating	9.0 %	46.3 %	18.8 %	5.6 %
	No info	5.9 %	1.8 %	1.4 %	2.6 %
Energy carrier	Coal	0.3 %	0.2 %	0.2 %	19.8 %
	District heating	16.1 %	2.0 %	6.7 %	28.9 %
	Electricity	4.2 %	22.4 %	9.2 %	4.3 %
	Gas	52.5 %	23.2 %	72.1 %	27.6 %
	Gasoil	0.5 %	39.1 %	0.1 %	0.9 %
	Heat pump	4.4 %	2.2 %	3.5 %	3.7 %
	Solar	0.2 %	0.2 %	3.5 %	0.3 %
	Oil	16.3 %	0.9 %	0.3 %	0.8 %
	Wood/pellet	3.5 %	7.9 %	2.6 %	13.4 %
	Others/ no info	1.8 %	2.0 %	1.7 %	0.3 %

Appendix B. Statistically tested statements

Table B1
Overview of the statistically tested statements.

ID	Description	Test
H1	The average heating temperature in the heating period 2022–2023 is lower than that of 2021–2022	paired t-test
H2	Households using gas as an energy carrier, show a higher heating temperature reduction than households using other energy carriers	two-sample t-test with equal variances assumed
H3	Low-income households (quintiles 1 and 2) heat with a lower temperature compared to the average and high-income households (quintiles 3–5)	two-sample t-test with equal variances assumed
H4	Low-income households (quintiles 1 and 2) have reduced their heating temperature more than the average and high-income households (quintiles 3–5)	two-sample t-test with equal variances assumed

(*continued on next page*)

Table B1 (*continued*)

ID	Description	Test
H5	Households in the countries with higher gas dependency (NL, DE) performed a higher heating temperature reduction compared to the ones with lower gas dependency (GR, PL)	two-sample t-test with equal variances assumed
H6	Households in which data was estimated have reported a higher temperature reduction than the households in which data was measured	two-sample t-test with equal variances assumed
H7	Households in SFH heat with a lower temperature compared to the households in MFH	two-sample t-test with equal variances assumed
H8	Owner-occupied households heat with a higher temperature compared to the tenant-occupied households	two-sample t-test with equal variances assumed
H9	Technical improvements occur more often in owner-occupied households	Chi-squared test
*H*10	Technical improvements occur more often in single-family houses	Chi-squared test
*H*11	High-income households (quintiles 3–5) are more likely to invest in the technical improvement than the low-income households (quantiles 1 and 2)	Chi-squared test
H12	Energy carrier has an influence on the occurrence of technical improvements (gas vs. other energy carriers)	Chi-squared test

Appendix C. Results of statistical hypothesis testing

Table C1

H1 - The average heating temperature in the heating period 2022–2023 is lower than that of 2021–2022. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N	Mean heating temperature 2022–2023 (°C)	Mean heating temperature 2021–2022 (°C)	Difference (°C)	t	df	p
All countries	3571	19.00	19.21	0.20	12.77	3570	0.00
Germany	925	19.16	19.44	0.27	9.44	924	0.00
Greece	814	18.96	19.02	0.06	1.55	813	0.12
Netherlands	915	17.70	18.00	0.30	10.52	914	0.00
Poland	917	20.20	20.37	0.16	5.26	916	0.00

Table C2

H2 – Households using gas as an energy carrier, show a higher heating temperature reduction than households using other energy carriers. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_gas	N_other	Mean heating temperature reduction (gas heating households) (°C)	Mean heating temperature reduction (households using other heating) (°C)	Difference (°C)	t	df	p
All countries	1588	1983	0.34	0.12	−0.21	−5.65	3569	0.00
Germany	486	439	0.32	0.14	−0.18	−2.73	923	0.01
Greece	189	625	0.29	0.01	−0.29	−2.63	812	0.01
Netherlands	660	255	0.45	0.24	−0.21	−2.60	913	0.00
Poland	253	664	0.12	0.17	0.05	0.68	915	0.49

Table C3

H3 – Low-income households (quintiles 1 and 2) heat with a lower temperature compared to the average and high-income households (quintiles 3–5). "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_Q1,Q2	N_Q3-Q5	Mean heating temperature, Q1,Q2 (°C)	Mean heating temperature, Q3-Q5 (°C)	Difference (°C)	t	df	p
2021–2022								
All countries	1356	2215	19.01	19.34	0.33	4.31	3569	0.00
Germany	357	568	19.27	19.54	0.27	2.21	923	0.01
Greece	286	528	18.97	19.04	0.08	0.42	812	0.34
Netherlands	367	548	17.73	18.18	0.45	4.00	913	0.00
Poland	346	571	20.13	20.51	0.38	2.67	915	0.00
2022–2023								
All countries	1356	2215	18.82	19.12	0.30	3.85	3569	0.00
Germany	357	568	19.00	19.27	0.27	2.17	923	0.02
Greece	286	528	18.90	18.99	0.08	0.46	812	0.32
Netherlands	367	548	17.48	17.85	0.37	3.17	913	0.00
Poland	346	571	20.01	20.32	0.31	2.16	915	0.02

Table C4
H4 – Low-income households (quintiles 1 and 2) have reduced their heating temperature more than the average and high-income households (quintiles 3–5). "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_Q1, Q2	N_Q3-Q5	Mean heating temperature reduction, Q1,Q2 (°C)	Mean heating temperature reduction, Q3-Q5 (°C)	Difference (°C)	t	df	p
All countries	1356	2215	0.22	0.18	0.03	1.00	3569	0.31

Table C5
H5 – Households in the countries with higher gas dependency (NL, DE) performed a higher heating temperature reduction compared to the ones with lower gas dependency (GR, PL). "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_ DE,NL	N_ GR,PL	Mean heating temperature reduction, DE,NL (°C)	Mean heating temperature reduction, GR,PL (°C)	Difference (°C)	t	df	p
All countries	1840	1731	0.29	0.11	−0.17	−5.39	3569	0.00

Table C6
H6 – Households in which data was estimated have reported a higher temperature reduction than the households in which data was measured. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_ measured	N_ estimated	Mean heating temperature reduction (if temperature measured) (°C)	Mean heating temperature reduction (if temperature estimated) (°C)	Difference (°C)	t	df	p
All countries	1914	1294	0.20	0.17	0.31	0.94	3206	0.34

Table C7
H7 – Households in SFH heat with a lower temperature compared to the households in MFH. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_SFH	N_MFH	Mean heating temperature_SFH (°C)	Mean heating temperature_MFH (°C)	Difference (°C)	t	df	p
2022–2023								
All countries	1837	1719	18.83	19.20	0.37	4.93	3554	0.00
Germany	396	527	19.34	19.03	0.32	2.56	921	0.06
Greece	278	533	18.81	19.05	−0.23	−1.29	809	0.10
Netherlands	688	221	17.62	17.93	−0.32	−2.39	907	0.01
Poland	475	438	20.17	20.23	−0.06	−0.43	911	0.33
2021–2022								
All countries	1837	1719	19.05	19.39	0.34	4.55	3554	0.00
Germany	396	527	19.62	19.30	0.32	2.62	921	0.00
Greece	278	533	18.83	19.13	−0.30	−1.62	809	0.05
Netherlands	688	221	17.95	18.12	−0.17	−1.28	907	0.10
Poland	475	438	20.29	20.44	0.15	1.10	911	0.13

Table C8
H8 – Owner-occupied households heat with a higher temperature compared to the tenant-occupied households. "t" denotes the t-score of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_owner	N_tenant	Mean heating temperature (owner) (°C)	Mean heating temperature (tenant) (°C)	Difference (°C)	t	df	p
2022–2023								
All countries	2448	1096	19.11	18.78	0.32	4.01	3552	0.00
Germany	470	454	19.36	18.95	0.42	3.42	922	0.00
Greece	563	235	19.00	18.86	0.14	0.73	796	0.23
Netherlands	639	276	17.72	17.65	0.08	0.63	913	0.26
Poland	776	131	20.16	20.46	−0.29	−0.43	905	0.33
2021–2022								
All countries	2448	1096	19.32	18.95	0.37	4.61	3542	0.00
Germany	470	454	19.65	19.21	0.43	3.62	922	0.00
Greece	563	235	19.10	18.83	0.28	1.42	796	0.08
Netherlands	639	276	18.03	17.93	0.10	0.81	913	0.21
Poland	776	131	20.36	20.45	−0.09	−0.47	905	0.32

Table C9
H9 – Technical improvements occur more often in owner-occupied households. "Chi2" denotes the Chi2 statistic of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N	N_owner	N_tenant	Percentage of home-owners who made technical improvements	Percentage of tenants who made technical improvements	Chi2	df	p
All countries	3544	2448	1096	20.99	15.33	15.65	1	0.00
Germany	924	470	454	24.46	18.06	5.65	1	0.02
Greece	798	563	235	20.07	14.04	4.03	1	0.05
Netherlands	915	639	276	17.68	10.87	6.78	1	0.01
Poland	907	776	131	22.30	17.56	1.49	1	0.22

Table C10
*H*10 – Technical improvements occur more often in single-family houses. "Chi2" denotes the Chi2 statistic of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N	N_MFH	N_SFH	Percentage of MFH residents who made technical improvements	Percentage of SFH residents who made technical improvements	Chi2	df	p
All countries	3556	1719	1837	16.57	21.61	14.50	1	0.00
Germany	923	527	396	19.16	23.98	3.15	1	0.07
Greece	811	533	278	16.88	20.50	1.61	1	0.20
Netherlands	909	221	688	14.48	15.98	0.29	1	0.59
Poland	913	438	475	14.15	28.42	27.41	1	0.00

Table C11
*H*11 – High-income households (quintiles 3–5) are more likely to invest in the technical improvement than the low-income households (quantiles 1 and 2). "Chi2" denotes the Chi2 statistic of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_Q1, Q2	N_Q3-Q5	Percentage of households in Q1,Q2 who have invested in technical improvements	Percentage of households in Q3-Q5 who have invested in technical improvements	Chi2	df	p
All countries	1356	2215	18.36	19.68	0.95	1	0.94
Germany	357	568	18.49	23.06	2.74	1	0.01
Greece	286	528	20.63	16.67	1.97	1	0.16
Netherlands	367	548	12.26	17.88	5.27	1	0.02
Poland	346	571	22.83	20.84	0.51	1	0.48

Table C12
H12 – Energy carrier has an influence on the occurrence of technical improvements (gas vs. other energy carriers). "Chi2" denotes the Chi2 statistic of the hypothesis test, "df" the associated degrees of freedom, "p" the associated p-score.

	N_gas heating	N_other heating	Percentage of households using gas heating that have invested in technical improvements	Percentage of households using other heating that have invested in technical improvements	Chi2	df	p
All countries	1588	1983	19.45	18.96	0.114	1	0.71
Germany	486	439	24.60	17.53	7.03	1	0.01
Greece	189	625	21.16	17.12	1.60	1	0.21
Netherlands	660	255	13.18	21.96	10.75	1	0.00
Poland	253	664	24.50	20.48	1.75	1	0.19

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enbuild.2024.114257.

References

[1] F.S. Arsad, R. Hod, N. Ahmad, M. Baharom, Ja'afar, M. H., Assessment of indoor thermal comfort temperature and related behavioural adaptations: a systematic review, Environ. Sci. Pollut. Res. 30 (29) (2023) 73137–73149, https://doi.org/10.1007/s11356-023-27089-9.

[2] Astetta Alemmas Campaign, Down a degree – To ensure energy for us all, 2022, https://www.astettaalemmas.fi.

[3] F. Belaïd, H. Joumni, Behavioral attitudes towards energy saving: Empirical evidence from France, Energy Policy 140 (2020) 111406, https://doi.org/10.1016/j.enpol.2020.111406.

[4] P. Bertoldi, Policies for energy conservation and sufficiency: Review of existing policies and recommendations for new and effective policies in OECD countries, Energ. Buildings 264 (2022) 112075, https://doi.org/10.1016/j.enbuild.2022.112075.

[5] P. Bertoldi, S. Rezessy, V. Oikonomou, Rewarding energy savings rather than energy efficiency: Exploring the concept of a feed-in tariff for energy savings, Energy Policy 56 (2013) 526–535, https://doi.org/10.1016/j.enpol.2013.01.019.

[6] L. Blázquez, N. Boogen, M. Filippini, Residential electricity demand in Spain: New empirical evidence using aggregate data, Energy Econ. 36 (2013) 648–657, https://doi.org/10.1016/j.eneco.2012.11.010.

[7] N. Brelih, Thermal and acoustic comfort requirements in European standards and national regulations, REHVA (2013) 16–19, https://www.rehva.eu/fileadmin/REHVA_Journal/REHVA_Journal_2013/RJ_issue_2/p16-19_Thermal_and_acoustic_comfort_RJ1302.pdf.

[8] L. Canale, G. Ficco, I. Bertini, M. Dell'Isola, About the effect of tailored energy feedback on space heating consumption and indoor air temperature in social

housing buildings: An experimental investigation, Energ. Buildings 292 (2023) 113149, https://doi.org/10.1016/j.enbuild.2023.113149.
[9] L. Canale, B. Peulicke Slott, S. Finsdóttir, L.R. Kildemoes, R.K. Andersen, Do in-home displays affect end-user consumptions? A mixed method analysis of electricity, heating and water use in Danish apartments, Energ. Buildings 246 (2021) 111094, https://doi.org/10.1016/j.enbuild.2021.111094.
[10] R.-A. Corbos, O.-I. Bunea, D.-C. Jiroveanu, The effects of the energy crisis on the energy-saving behavior of young people, Energ. Strat. Rev. 49 (2023) 101184, https://doi.org/10.1016/j.esr.2023.101184.
[11] Council of, the European Union, Council Regulation (EU) 2022/1369 of 5 August 2022 on coordinated demand-reduction measures for gas, 2022. https://eur-lex.europa.eu/eli/reg/2022/1369.
[12] Council of the European Union, Council Regulation (EU) 2022/2578 of 22 December 2022 establishing a market correction mechanism to protect Union citizens and the economy against excessively high prices, 2022. https://eur-lex.europa.eu/eli/reg/2022/2578/oj.
[13] Council of the European Union, Infographic - Where does the EU's gas come from?, 2024, Available at, https://www.consilium.europa.eu/en/infographics/eu-gas-supply/.
[14] R. Day, R. Hitchings, Older people and their winter warmth behaviours: understanding the contextual dynamics, 2009. https://www.birmingham.ac.uk/documents/college-les/gees/staff/winter-warmth-behaviours.pdf.
[15] Dena, Dena-Umfrage: Bundesbürger ändern wegen steigender Energiekosten ihr Heizverhalten – und wollen Fokus der staatlichen Hilfen auf Bürger mit geringen und mittleren Einkommen, 2022, Available at, https://www.dena.de/newsroom/meldungen/2022/forsa-umfrage-heizverhalten/, accessed 15.03.2023.
[16] K. Ek, P. Söderholm, The devil is in the details: Household electricity saving behavior and the role of information, Energy Policy 38 (3) (2010) 1578–1587, https://doi.org/10.1016/j.enpol.2009.11.041.
[17] K. Ellegård, J. Palm, Visualizing energy consumption activities as a tool for making everyday life more sustainable, Appl. Energy 88 (5) (2011) 1920–1926, https://doi.org/10.1016/j.apenergy.2010.11.019.
[18] Enerdata, Gas supply shock: how EU's final consumers adapted?, 2023, Available at, https://www.enerdata.net/publications/reports-presentations/gas-prices-impact-europe.html.
[19] Energimyndigheten, Sänkt elanvändning minskar risken för elstörningar i vinter, 2022. Available at, https://www.energimyndigheten.se/nyhetsarkiv/2022/sankt-elanvandning-nu-minskar-risken-for-elstorningar-i-vinter/.
[20] Euractiv, Poland to extend gas tariff protection for households until end 2027, 2022, Available at, https://www.euractiv.com/section/energy/news/poland-to-extend-gas-tariff-protection-for-households-until-end-2027/, accessed 21.11.2023.
[21] EurObserv'ER, SOLAR THERMAL BAROMETER, 2010, Available at, https://www.eurobserv-er.org/pdf/solar-thermal-and-csp-barometer-2010-fr-en/.
[22] EurObserv'ER, HEAT PUMPS BAROMETER, 2021, Available at, https://www.eurobserv-er.org/pdf/heat-pumps-barometer-2021/.
[23] EurObserv'ER, SOLAR THERMAL AND CONCENTRATED SOLAR POWER BAROMETERS, 2021, Available at, https://www.eurobserv-er.org/pdf/solar-thermal-and-csp-barometer-2021/.
[24] European Commission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL European Energy Security Strategy, 2014, Available at, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330.
[25] European Commission, Communication "Tackling rising energy prices: a toolbox for action and support, 2021. https://ec.europa.eu/commission/presscorner/detail/en/fs_21_5213.
[26] European Commission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, COM/2021/550 final, 2021.
[27] European Commission, 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. Security of supply and affordable energy prices: Options for immediate measures and preparing for next winter, 2022, Available at, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3a52022DC0138.
[28] European Commission, Commission Staff Working Document Implementing the REPower EU Action Plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets. Accompanying the Document 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. REPowerEU Plan, 2022, Available at, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2022%3A230%3AFIN.
[29] European Commission, Outline of "REPowerEU": joint EU action for more affordable, secure, and sustainable energy, 2022.
[30] European Commission, Eurostat Database, 2024, Available at, https://ec.europa.eu/eurostat/web/main/data/database, accessed 01.03.2024.
[31] European Commission & International Energy Agency, Playing my part, 2022, Available at, https://iea.blob.core.windows.net/assets/cbc97c70-8bcf-4376-a8a9-4cd875195f6a/Playingmypart.pdf.
[32] Eurostat, Energy consumption in households, 2022, Available at, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households.
[33] Eurostat, Complete energy balances European Union (27 countries) - 2022 - Total - main fuel families, 2023, Available at, https://ec.europa.eu/eurostat/cache/infographs/energy_balances/enbal.html?geo=EU27_2020&unit=KTOE&language=EN&year=2022&fuel=fuelMainFuel&siec=TOTAL&details=0&chartOptions=0&stacking=normal&chartBal=&chart=&full=0&chartBalText=&order=DESC&siecs=&dataset=nrg_bal_s&decimals=0&agregates=0&fuelList=fuelElectricity,fuelCombustible,fuelNonCombustible,fuelOtherPetroleum,fuelMainPetroleum,fuelOil,fuelOtherFossil,fuelFossil,fuelCoal,fuelMainFuel.
[34] Eurostat, Cooling and heating degree days by country - annual data, 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/nrg_chdd_a/default/table?lang=en&category=nrg.nrg_chdd.
[35] Eurostat, Disaggregated final energy consumption in households - quantities, 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/nrg_d_hhq/default/table?lang=en.
[36] Eurostat, Distribution of population by degree of urbanisation, dwelling type and income group - EU-SILC survey, 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/ILC_LVHO01/default/table?lang=en.
[37] Eurostat, Distribution of population by tenure status, type of household and income group - EU-SILC survey, 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/ILC_LVHO02_custom_137548/bookmark/map.
[38] Eurostat, Gas prices for household consumers - bi-annual data (from 2007 onwards), 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_202_custom_4234988/default/table?lang=en, accessed 15.03.2023.
[39] Eurostat, Inability to keep home adequately warm - EU-SILC survey, 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes01/default/table?lang=en.
[40] Eurostat, Mean and median income by age and sex - EU-SILC and ECHP surveys, 2023, Available at, https://ec.europa.eu/eurostat/databrowser/view/ilc_di03/default/table?lang=en.
[41] Expertenrat für Klimafragen, Prüfbericht zur Berechnung der deutschen Treibhausgasemissionen für das Jahr 2022. Prüfung und Bewertung der Emissionsdaten gemäß §12 Abs. 1 Bundes-Klimaschutzgesetz, 2023, Available at, https://expertenrat-klima.de/content/uploads/2023/05/ERK2023_Pruefbericht-Emissionsdaten-des-Jahres-2022.pdf.
[42] N. Eyre, Energy saving in energy market reform—The feed-in tariffs option, Energy Policy 52 (2013) 190–198, https://doi.org/10.1016/j.enpol.2012.07.042.
[43] Federal Ministry for Economic Affairs and Climate Action, Bundestag adopts energy price caps – important relief for consumers, 2022, Available at, https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221215-bundestag-adopts-energy-price-caps-important-relief-for-consumers.html, accessed 15.03.2023.
[44] Government of the Netherlands, Price cap for gas, electricity and district heating, 2023, Available at, https://www.government.nl/topics/energy-crisis/cabinet-plans-price-cap-for-gas-and-electricity, accessed 15.03.2023.
[45] E. de Groot, M. Spiekman, I. Opstelten, Dutch research into user behaviour in relation to energy use of residences, in: Proceedings PLEA 2008, 2008, http://web5.arch.cuhk.edu.hk/server1/staff1/edward/www/plea2018/plea/2008/content/papers/oral/PLEA_FinalPaper_ref_361.pdf.
[46] S. Hagejärd, G. Dokter, U. Rahe, P. Femenías, My apartment is cold! Household perceptions of indoor climate and demand-side management in Sweden, Energy Res. Social Sci. 73 (2021) 101948, https://doi.org/10.1016/j.erss.2021.101948.
[47] G.U. Harputlugil, M. Bedir, Effects of occupant behavior on the energy performance of dwellings: a sensitivity analysis, J. Architect. Plann. Res. 33 (2) (2016) 159–178, http://www.jstor.org/stable/44987374.
[48] IEA, The Netherlands 2020. Energy Policy Review, 2020, Available at, https://iea.blob.core.windows.net/assets/93f03b36-64a9-4366-9d5f-0261d73d68b3/The_Netherlands_2020_Energy_Policy_Review.pdf.
[49] IEA, A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas, 2022, Available at, https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas.
[50] IEA, Playing my part. How to save money, reduce reliance on Russian energy, support Ukraine and help the planet, 2022, Available at, https://www.iea.org/reports/playing-my-part.
[51] IEA, Greece 2023. Energy Policy Review, 2023, Available at, https://iea.blob.core.windows.net/assets/5dc74a29-c4cb-4cde-97e0-9e218c58c6fd/Greece2023.pdf.
[52] IEA, Europe's energy crisis: What factors drove the record fall in natural gas demand in 2022?, 2023, Available at, https://www.iea.org/commentaries/europe-s-energy-crisis-what-factors-drove-the-record-fall-in-natural-gas-demand-in-2022, accessed 22.11.2023.
[53] F. Kasirye, An Overview of Mixed and Multi Method Research, 2021. https://doi.org/10.31124/advance.14681643.v1.
[54] Kathimerini, Natural gas subsidy set at 90 euros per megawatt hour for households, 2022, Available at, https://www.ekathimerini.com/economy/1193785/natural-gas-subsidy-set-at-90-euros-per-megawatt-hour-for-households/, accessed 15.03.2023.
[55] D. Khovalyg, A. Chatterjee, A.J. Sellers, W. van Marken Lichtenbelt, Behavioral adaptations to cold environments: A comparative study of active nomadic and modern sedentary lifestyles, Build. Environ. 243 (2023) 110664, https://doi.org/10.1016/j.buildenv.2023.110664.
[56] K. Koasidis, V. Marinakis, A. Nikas, K. Chira, A. Flamos, H. Doukas, Monetising behavioural change as a policy measure to support energy management in the residential sector: A case study in Greece, Energy Policy 161 (2022) 112759, https://doi.org/10.1016/j.enpol.2021.112759.
[57] B. Koenraadt, Energieprijzen Nederland veel hoger dan in rest van Europa, 2022, Available at, https://www.energievergelijk.nl/nieuws/energieprijzen-nederland-veel-hoger-dan-in-rest-van-europa, accessed 21.11.2023.
[58] L. Kranzl, E. Aichinger, R. Büchele, S. Forthuber, M. Hartner, A. Müller, A. Toleikyte, Are scenarios of energy demand in the building stock in line with

Paris targets? Energ. Effi. 12 (1) (2019) 225–243, https://doi.org/10.1007/s12053-018-9701-1.
[59] L. Kranzl, M. Fallahnejad, R. Büchele, A. Müller, M. Hummel, T. Fleiter, T. Mandel, M. Bagheri, G. Deac, C. Bernath, J. Miosga, C. Kiefer, J. Fragoso, S. Braungardt, V. Bürger, D. Spasova, J. Viegand, R. Naeraa, S. Forthuber, Renewable space heating under the revised Renewable Energy Directive : ENER/C1/2018-494: final report, Publications Office of the European Union (2022), https://doi.org/10.2833/525486.
[60] N.J. Kurmayer, Germany's gas savings are too low, agency chief warns, 2022, Available at, https://www.euractiv.com/section/energy/news/germanys-gas-savings-are-too-low-agency-chief-warns/.
[61] K. Van Dender, A. Elgouacem, G. Garsous, H. Belgroun, M. Mateo, A.C. Prentice, Why governments should target support amidst high energy prices, 2022, https://www.oecd-ilibrary.org/docserver/40f44f78-en.pdf?expires=1717088951&id=id&accname=guest&checksum=99CE4B0140473044C1C80DC75A06B201.
[62] A. Lee, I. Sinha, T. Boyce, J. Allen, P. Goldblatt, Fuel poverty, cold homes and health inequalities, 2022, Available at, https://www.instituteofhealthequity.org/resources-reports/fuel-poverty-cold-homes-and-health-inequalities-in-the-uk/read-the-report.pdf.
[63] A.-L. Lindén, A. Carlsson-Kanyama, B. Eriksson, Efficient and inefficient aspects of residential energy behaviour: What are the policy instruments for change? Energy Policy 34 (14) (2006) 1918–1927, https://doi.org/10.1016/j.enpol.2005.01.015.
[64] T. Loga, R. Born, M. Großklos, M. Bially, Energiebilanz-Toolbox. Arbeitshilfe und Ergänzungen zum Energiepass Heizung, Warmwasser, 2001, ISBN: 3-932074-52-1, https://www.iwu.de/fileadmin/tools/ephw/ephw-toolbox.pdf.
[65] T. Loga, M. Großklos, J. Knissel, Der Einfluss des Gebäudestandards und des Nutzerverhaltens auf die Heizkosten. Konsequenzen für die verbrauchsabhängige Abrechnung, 2003, Available at, https://www.iwu.de/fileadmin/publikationen/energie/neh_ph/2003_IWU_LogaEtAl_Der-Einfluss-des-Geb%C3%A4udestandards-und-des-Nutzerverhaltens-auf-die-Heizkosten.pdf.
[66] T. Loga, B. Stein, Use of energy performance certificates for realistic prognoses - A method to calibrate the national calculation procedure by the average actual consumption, 2022, https://www.iwu.de/fileadmin/publikationen/energie/2022_eceee_Loga-Stein_Use-of-energy-performance-certificates-for-realistic-prognoses.pdf.
[67] L. Mayrhofer, A. Müller, M. Bügelmayer-Blaschek, A. Malla, L. Kranzl, Modelling the effect of passive cooling measures on future energy needs for the Austrian building stock, Energ. Buildings 296 (2023) 113333, https://doi.org/10.1016/j.enbuild.2023.113333.
[68] A. Müller, Energy demand assessment for space conditioning and domestic hot water : a case study for the Austrian building stock, TU Wien (Ed.), 2015.
[69] D.K. Newman, D. Day, The American energy consumer, Ballinger, Cambridge, Mass., 1975.
[70] ODYSSEE-MURE, Household energy consumption by energy in the EU, 2020, Available at https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/energy-consumption-eu.html, accessed 15.03.2023.
[71] OECD, Confronting the energy crisis: Changing behaviours to reduce energy consumption, OECD Policy Responses on the Impacts of the War in Ukraine, OECD Publishing, Paris, 2023, https://doi.org/10.1787/5664e8a9-en.
[72] A. Ohler, D.G. Loomis, Y. Marquis, The Household Appliance Stock, Income, and Electricity Demand Elasticity, Energy J. 43 (1) (2022) 241–262, https://doi.org/10.5547/01956574.43.1.aohl.
[73] L. Ott, S. Weber, How effective is carbon taxation on residential heating demand? A Household-Level Analysis, Energy Policy 160 (2022) 112698, https://doi.org/10.1016/j.enpol.2021.112698.
[74] C. Rohde, E. Dütschke, M. Gigli, M. Bles, Behavioural climate change mitigation options. Domain Report Housing, 2012, Available at, https://climate.ec.europa.eu/system/files/2016-11/housing_report_en.pdf.
[75] D. Rukmana, Quota Sampling. In: Michalos, A. C. (Ed.): Encyclopedia of Quality of Life and Well-Being Research. Dordrecht: Springer Netherlands, pp. 5382-5384, 2014. https://doi.org/10.1007/978-94-007-0753-5_2393 .
[76] Sejm of the Republic of Poland, Act of December 15, 2022 on special protection of certain consumers of gaseous fuels in 2023 due to the situation on the gas market (Ustawa z dnia 15 grudnia 2022 r. o szczególnej ochronie niektórych odbiorców paliw gazowych w 2023 r. w związku z sytuacją na rynku gazu) (Dz. U. 2022 poz. 2687), 2022, https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20220002687/T/D20222687L.pdf.
[77] U.D. Shamas, F. Sadaf, European Energy Crises, Climate Action and Emerging Market of Carbon-Neutral LNG, J. European Studies (JES) 39 (1) (2023) 33. https://doi.org/10.56384/jes.v39i1.287.
[78] P. Sorge, Germany Saved Too Little Gas in Recent Weeks, Regulator Warns, 2023, Available at, https://www.bnnbloomberg.ca/germany-saved-too-little-gas-in-recent-weeks-regulator-warns-1.1878864.
[79] B.K. Sovacool, C. Demski, L. Noel, Beyond climate, culture and comfort in European preferences for low-carbon heat, Glob. Environ. Chang. 66 (2021) 102200, https://doi.org/10.1016/j.gloenvcha.2020.102200.
[80] F. Stazi, F. Naspi, M. D'Orazio, A literature review on driving factors and contextual events influencing occupants' behaviours in buildings, Build. Environ. 118 (2017) 40–66, https://doi.org/10.1016/j.buildenv.2017.03.021.
[81] Tado, 80 % der deutschen Haushalte haben im Winter 2022 die Heizung heruntergedreht, 2023, Available at 2023, https://www.tado.com/de-de/pressemitteilungen/Heating_Winter_2022, accessed 06.02.2023.
[82] UBA, Richtiges Heizen schützt das Klima und den Geldbeutel, 2022, Available at, https://www.umweltbundesamt.de/umwelttipps-fuer-den-alltag/heizen-bauen/heizen-raumtemperatur.
[83] K.L. van den Broek, I. Walker, C.A. Klöckner, Drivers of energy saving behaviour: The relative influence of intentional, normative, situational and habitual processes, Energy Policy 132 (2019) 811–819, https://doi.org/10.1016/j.enpol.2019.06.048.
[84] A. Veljkovic, D.A. Pohoryles, D.A. Bournas, Heating energy demand estimation of the EU building stock: Combining building physics and artificial neural networks, Energ. Buildings 298 (2023) 113474, https://doi.org/10.1016/j.enbuild.2023.113474.
[85] S. Wei, R. Jones, P. de Wilde, Driving factors for occupant-controlled space heating in residential buildings, Energ. Buildings 70 (2014) 36–44, https://doi.org/10.1016/j.enbuild.2013.11.001.
[86] H. Wilhite, H. Nakagami, T. Masuda, Y. Yamaga, H. Haneda, A cross-cultural analysis of household energy use behaviour in Japan and Norway, Energy Policy 24 (9) (1996) 795–803, https://doi.org/10.1016/0301-4215(96)00061-4.
[87] World Health Organization, WHO housing and health guidelines, 2018, Available at, https://www.ncbi.nlm.nih.gov/books/NBK535293/.
[88] P. Zangheri, T. Serrenho, P. Bertoldi, Energy Savings from Feedback Systems: A Meta-Studies' Review, Energies 12 (19) (2019) 3788, https://doi.org/10.3390/en12193788.
[89] P. Zangheri, R. Armani, M. Pietrobon, L. Pagliano, M. Boneta, A. Müller, J. Kockat, C. Rohde, Heating and cooling energy demand and loads for building types in different countries of the EU, 2014. https://api.semanticscholar.org/CorpusID:158045588.
[90] C. Zell-Ziegler, B. Best, J. Thema, F. Wiese, B. Vogel, L. Cordroch, European Sufficiency Policy Database, 2022, Available at, https://energysufficiency.de/policy-database/.
[91] X. Zhu, L. Li, K. Zhou, X. Zhang, S. Yang, A meta-analysis on the price elasticity and income elasticity of residential electricity demand, J. Clean. Prod. 201 (2018) 169–177, https://doi.org/10.1016/j.jclepro.2018.08.027.

Appendix D: Original published version of Paper 5

Implementing housing policies for a sufficient lifestyle

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ABSTRACT

The German buildings sector is currently facing a double challenge: meeting emission reduction targets and providing affordable housing in rapidly growing cities. Living space per person has a major impact on household energy consumption and it has increased significantly in recent decades. New construction increases the demand for often energy-intensive building materials, and energy demand during the use phase of buildings is positively related to the size of the space. Optimising the allocation of living space therefore offers great potential for addressing both challenges. Sufficiency policies such as flat exchanges, a financial bonus for moving and the provision of moving advice aim to reduce the total floor area in the housing sector by using existing space more efficiently. However, the effectiveness of such measures is not yet fully understood. As the sufficiency approach relies heavily on individual choices, residents' involvement, perception and acceptance are crucial for the success of such measures. An investigation in selected German housing companies shows that the potential of these measures is not fully exploited under the current political and social framework in Germany. Social acceptance, new norms and business models for landlords are needed for the effective use of these measures.

POLICY RELEVANCE

How effective is the implementation of sufficiency measures for space utilisation in the German rental housing sector? The success factors and limiting barriers of the measures along with the acceptability and effectiveness of these measures are investigated by interviewing housing companies (some of them social housing providers) that have the potential to implement such policies in their housing stock. Improvements are needed in the social and technical infrastructure to increase the effectiveness of the measures. Raising awareness, rethinking communications and designing effective financial incentives are recommended to make the measures attractive to the public. Involving all stakeholders, keeping the issue on the political agenda and engaging in dialogue with policymakers are considered effective steps in the process of achieving space sufficiency in the housing sector.

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KEYWORDS:
downsizing; housing; housing policy; landlords; occupancy; residential sector; spatial optimisation; sufficiency; tenants; Germany

TO CITE THIS ARTICLE:
Bagheri, M., Roth, L., Siebke, L., Rohde, C., & Linke, H.-J. (2024). Implementing housing policies for a sufficient lifestyle. *Buildings and Cities*, 5(1), pp. 300–315. DOI: https://doi.org/10.5334/bc.435

1. INTRODUCTION

Human wellbeing is already threatened by climate change, and will be increasingly so in the future (Gough 2020). Achieving the goal of keeping global warming well below 2°C, as part of the legally binding United Nations' Paris Agreement, requires rapid and deep cuts in greenhouse gas emissions. The latest report of the Intergovernmental Panel on Climate Change (IPCC) states that much additional effort will be needed to achieve the climate goals (IPCC 2022). The main drivers of climate change are increasing total and per capita consumption of energy, land and other resources, which pose concrete challenges to global and local environmental sustainability. This trend is the result of global urban development, characterised in its structure, institutions, and household behaviour and trends such as sprawl, spread, expansion of large technical systems and growing populations (Jin 2017). Previous studies have linked energy consumption to human wellbeing (Burke 2020). For instance, a recent meta-analysis investigated the threshold of rising energy consumption beyond which it no longer correlates with increasing human wellbeing. Overall, the results suggest that European energy consumption has reached such a threshold where increased consumption no longer implies increased wellbeing (Gynther 2021).

The German buildings sector fails to meet its environmental targets (Umweltbundesamt 2020). It is responsible for high resource consumption, typically accounting for 30% of the country's final energy demand (Dena 2019) and 14% of total energy-related emissions (Sach *et al.* 2021). To achieve climate neutrality in the buildings sector by 2045, a goal set by the German government (Federal Climate Change Act 2021), CO_2-equivalent emissions must be reduced by 8.57 million tonnes annually from 2022 (Breidenbach *et al.* 2021). Energy use in the buildings sector includes the energy required to construct and operate buildings, which depends on factors such as the need for new buildings, room temperatures or the size of the heated space.

Ellsworth-Krebs (2020) argues that the size of houses is the most important determinant of household energy consumption, and hence the global increase in per capita floor space is a problematic trend. Bierwirth & Thomas (2019) estimate that the available savings from reducing the current per capita living space in Germany from 46.6 to 35.0 to 30.0 m² would result in a theoretical saving potential of 378,547–541,361 TJ, representing a reduction in space heating energy of 24.9–35.7%.

Over time, many techno-economic measures have been implemented to improve energy efficiency, such as the thermal building regulation, resulting in increased energy efficiency and reduced energy consumption of buildings. However, measures that address the human desire to consume more are scarce, and summarised under 'sufficiency policies'. Sufficiency policies are:

> a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries.
>
> (IPCC 2022: 63)

The concept of sufficiency is based on the idea that there is a point of enough consumption where human needs are met and that this point should not be exceeded (Princen 2005). Sufficiency in the buildings sector not only decreases emissions but also positively influences many dimensions of wellbeing and sustainable development such as health, social cohesion and economic sustainability (Wronski 2023; Hayden & Dasilva 2022).

In addition to the long-known environmental impacts, there are several social issues in the housing sector related to the availability of adequate living space and energy costs. First, there is a mismatch in the housing market, with people living in dwellings that they perceive as too large (Gavrilis 2019), while young families urgently seek larger dwellings (Breidenbach *et al.* 2021). In 2018, only 47.4% of households in German metropolitan areas had access to suitable large and affordable housing, and 34.5% of this shortage could be solved by an optimal distribution of existing housing (Holm *et al.* 2021). Second, rising gas prices, which are a burden on households (BDEW 2022), make it even more urgent to reduce the use of gas, which accounts for 44.3% of space heating in Germany based on 2019 data (Statista 2021). While 8.1% of the German population was unable to heat their homes adequately due to energy poverty in 2023 (Eurostat

2023), this figure is expected to rise with energy prices, putting an increasing number of German households at risk of being affected by rising energy prices. This underlines the importance of reducing household energy consumption (Breidenbach *et al.* 2021).

While Germany has set a target of less than 30 ha of new soil sealing per day (Deutscher Bundestag 2021), 400,000 new homes are to be built each year to meet the need for affordable housing in many German cities. Currently, sealed area for housing and transport is the fastest growing land use in Germany, increasing by 18.1% (7964 additional km^2) between 2000 and 2022 (Umweltbundesamt 2024b). This is associated with negative impacts such as loss of agricultural land, fragmentation of wildlife habitats, material and energy consumption for construction and maintenance of additional buildings and infrastructure, increased traffic with higher fuel consumption, and increased pollutants and noise (Umweltbundesamt 2024a). Intensifying the use of existing buildings and sealed land in built-up areas is one way to meet the demand for new housing in growing regions while reducing pressure on currently undeveloped areas. This can be achieved by making better use of existing densification potential in urban areas (Breidenbach *et al.* 2021).

Increasing urbanisation is leading to regional imbalances in the availability of living space. Specifically, some regions have a structural housing shortage, while others have many vacant dwellings. In Germany, the average living space per person has increased from 14.0 m^2 in 1950 (Friedrich-Ebert-Stiftung 1997) and 34.8 m^2 in 1990 (iwd 2020) to 47.4 m^2 in 2021 (Umweltbundesamt 2023b). If this trend continues, living space per person will reach 52.0 m^2 by 2030 (iwd 2020). There are many reasons for this development, such as the increasing number of one- and two-person households, the lack of small dwellings (Friedrich-Ebert-Stiftung 1997) and the remanence effect. In 2022, around three-fourths of German households consisted of only one person (41%) or two persons (34%) (Umweltbundesamt 2023a). One- and two-person households have a higher per capita living space than larger households (Umweltbundesamt 2023b). The figures for 2018 are 68 m^2 for one-person households, 49 m^2 for two-person households and 33 m^2 for households with three or more persons. While there were around 17 million one-person households in Germany in 2022, only 2.5 million dwellings were smaller than 40 m^2 (Destatis 2024). In 2021, the average size of newly built dwellings was around 74 m^2 in multi-family houses and 145 m^2 in single-family houses (Destatis 2021). The remanence effect describes the tendency of shrinking families to remain in their large dwellings (Umweltbundesamt 2023b). This means that older people often live alone in (possibly non-accessible) oversized flats, which can lead to problems in the housing market, especially in dense residential areas (Fischer *et al.* 2016). A total of 20–50% of older people with a per capita living space of over 80 m^2 feel that their living space is too large (Kenkmann *et al.* 2019). However, the cost of moving (Kenkmann *et al.* 2019) and rising rents may make it financially attractive for them to stay in their large homes (Gavrilis 2019).

The great potential and importance of well-designed energy sufficiency policies for achieving climate and sustainability goals has been recognised by the IPCC (2022), Faber *et al.* (2012) and Samadi *et al.* (2017). However, they are rarely considered as an option for achieving climate goals of the European Union member states (Zell-Ziegler *et al.* 2021). Sufficiency is often perceived as complex (Zell-Ziegler & Förster 2018), especially compared with technical emission-reduction options such as efficiency and renewable energy policies. Furthermore, the impacts, feasibility and acceptability of sufficiency policies have not been fully explored. In particular, as they rely directly on individual choices, the social perspective plays an important role. Thus, policymakers and citizens still lack guidance to make informed choices for sufficiency policies, despite a growing scientific base (Akenji *et al.* 2019; Creutzig *et al.* 2022; Vita *et al.* 2019).

Against this background, this paper investigates the effectiveness of such policies in optimising the use of living space (Figure 1). It focuses on selected policies from the Sufficiency Policy Database (Best *et al.* 2022) that directly address residential space use, and examines their perceptions and acceptability, as well as their limiting barriers and success factors, through qualitative analysis of semi-structured interviews with selected German housing companies. The study explores the lessons that can be learnt for better policy design in the housing sector.

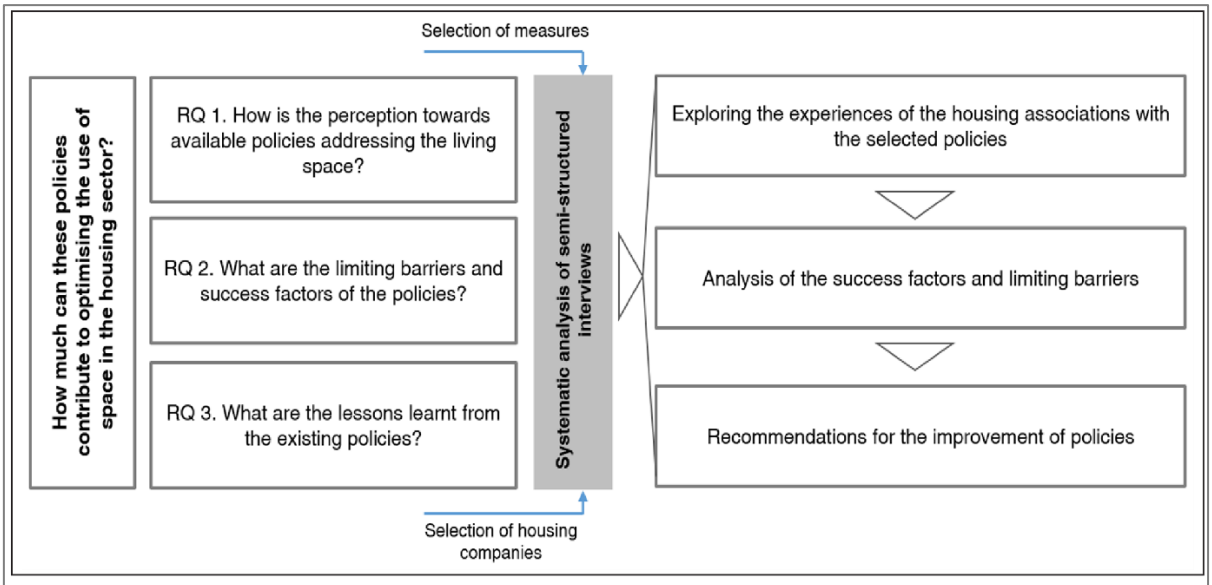


Figure 1: Research design of the study.

2. METHODS

2.1 CONTEXT

More than half of German households live in rented accommodation (Eurostat 2021) and more than a third of rental housing is owned and managed by professional owners, including private housing companies, public authorities, housing cooperatives and non-profit organisations (Savills 2019). With access to a large number of rental dwellings, housing companies have the technical capacity to implement innovative approaches and plans to help balance the availability of living spaces and reduce the housing shortage. Therefore, they are considered to be important stakeholders in promoting such sufficiency policies and were selected as interviewees for this study.

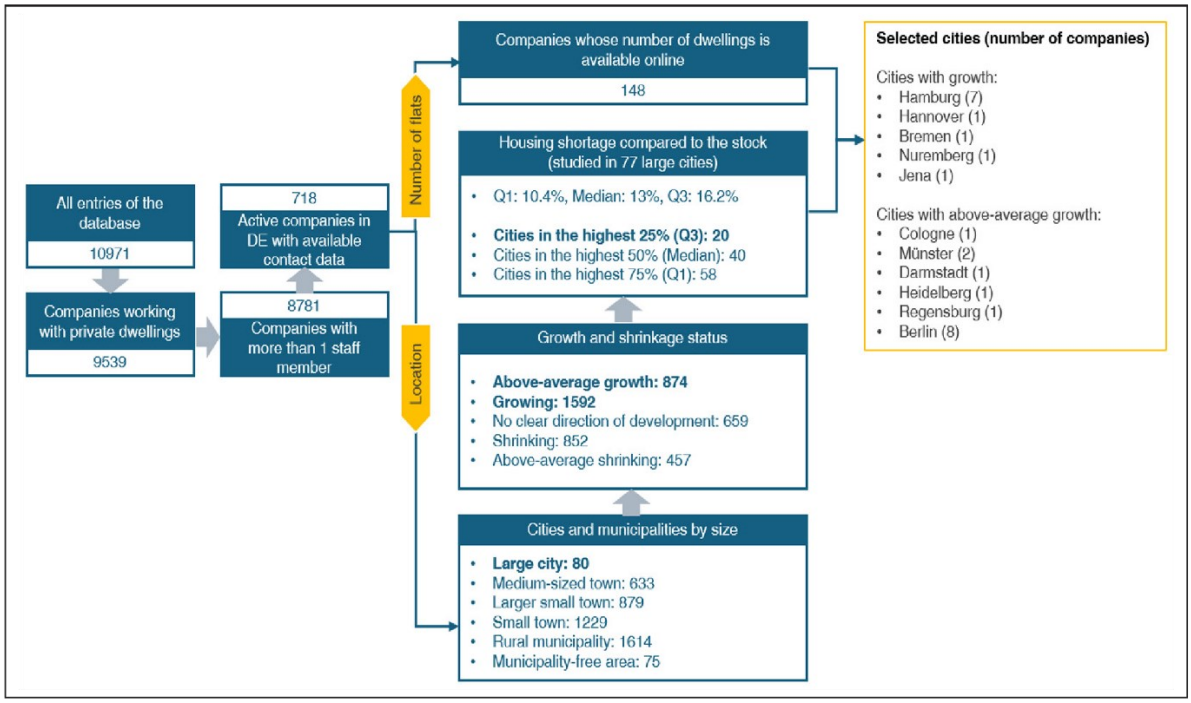
2.2 SELECTED HOUSING COMPANIES

In order to select the potential housing companies for the interviews, a list of all companies in the field of real estate leasing and rentals (N = 10,971) was first extracted from a company database provided by Dun & Bradstreet Corporation. From these, only those companies in Germany with more than one employee and dealing with private dwellings whose contact details were available in the database were filtered out (N = 718). In the next step, the location of the company and the number of rental apartments owned or managed by it were used as two criteria to narrow down the list further. This was done in two parallel steps. The number of apartments available in the companies' stock was considered to be an important factor in the degree of flexibility of the companies to implement different measures. Therefore, the database was extended to include data on this indicator, extracted from the companies' websites. These data were publicly available for 148 companies. For the second criterion (location), two indicators were considered, namely growth potential and housing shortage. In shrinking cities, the population moves out of the city and gradually more housing becomes available for rent, whereas in growing cities the demand for housing is constantly increasing. Therefore, growing cities are considered relevant for this study. On the other hand, cities with a housing shortage are considered to benefit most from the successful implementation of the measures studied in this paper.

According to a report by HBS (2019), of all German cities and municipalities, 80 are classified as large cities, the rest as medium-sized (N = 633) and small towns (N = 2018) or municipalities (N = 1614). Of these, 2466 are (above average) growing, 1309 are (above average) shrinking and the remaining 659 do not show any significant direction. The BBSR (2020) examines the housing shortage in 77 large German cities as the ratio of the required flats in the city to the current building stock. This ranges from 6.0% in Wolfsburg to 31.4% in Heidelberg.

For reasons of data availability, only the large cities for which data on housing shortages were available were considered. A threshold for the housing shortage was defined and all cities with a housing shortage above this threshold were kept in the list. All cities in this list for which at least one company with available data on the number of rental dwellings was listed were considered as potential interview partners. Figure 2 summarises the selection process. The 25 companies selected are located in 11 cities and nine states (regional distribution) and have different characteristics (commercial, non-profit, from the church or municipality).

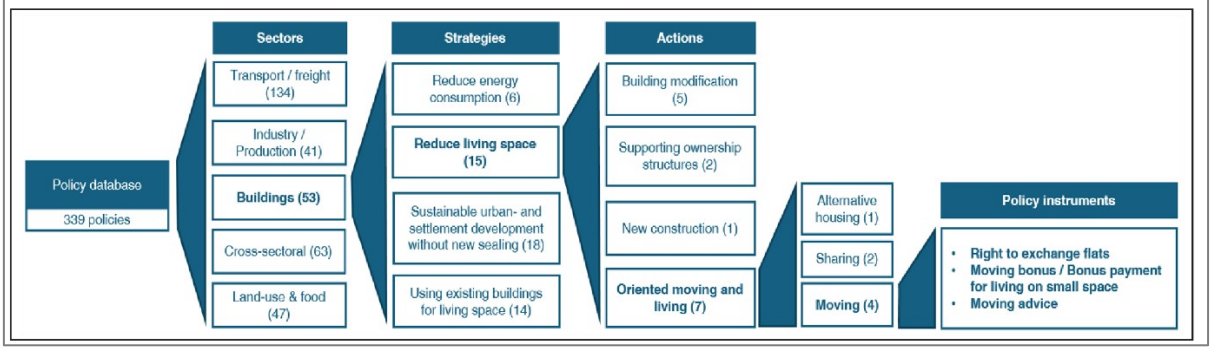
Figure 2: Selection process for the housing companies.



2.3 SELECTED MEASURES

Over 300 policies are listed in the Energy Sufficiency Policy Database,[1] 53 of which are related to the buildings sector (as of March 2024). These include a variety of sufficiency strategies, among those reducing living space, which is the focus of this paper. This strategy triggers different actions, including building modifications, supporting ownership structures, new construction and oriented moving and living. The aim of this paper is to focus on the low-hanging fruit, *i.e.* measures that require only organisational effort which involve both the supply side (housing companies) and the demand side (private households). Therefore, the category of oriented moving and living is relevant, which in turn covers policy instruments related to sharing, alternative housing and moving. The first two are excluded from this study as they are either mostly relevant to homeowners or not feasible within the housing company building stock. Under moving, which is the focus of this study, the following policy instruments are listed: exchange of flats; moving bonus; and moving advice (Figure 3).

Figure 3: Process for selecting measures.



2.4 DATA COLLECTION AND ANALYSIS

Data for this study were collected through guideline-based semi-structured interviews conducted virtually using Microsoft Teams in March 2024. The interviews were conducted in German and translated for this paper. See ***Table S1*** in the supplemental data online for a translated version of interview questions. The systematic analysis of the interviews was carried out in MAXQDA software and followed the six-step approach introduced by Rädiker & Kuckartz (2020). After systematically entering, preparing and organising the interview transcripts in the software, a first set of categories was developed based on the research questions and the interview guide (see ***Table S2*** in the supplemental data online). These categories were used for the basic coding of the transcripts. In order to ensure high-quality coding, the first interview was coded by two team members and the results were compared and discussed. Where necessary, the coding was corrected. In the next round, the subcategories were developed, the text passages were coded accordingly and the main content of the coded segments was noted. Next, the appropriate analysis for the coded data was selected and carried out. Finally, the analysis result was documented.

2.5 INTERVIEW GUIDE

The interview guide contains questions in two main categories: the interviewed housing company and the studied measures. In the first category, the characteristics of the company (*e.g.* location, structure and form, number of flats) and the mechanism for allocating dwellings are examined. The second part, on the policies, includes the description of the policy, documentation on its implementation and impact, failure and success factors. The final questions deal with suggestions for improving these policies.

3. RESULTS

Of the 25 contacted housing companies, 13 responded to the request for an interview, three of which were unable to give an interview despite their interest in the topic. In one case, the main focus of the company had changed, making it unsuitable for the study. With the remaining nine companies, an interview was scheduled but one was cancelled, resulting in eight complete interviews. The eight interviews covered five cities and four states. Both cooperative and privatised housing companies as well as those owned by municipalities or churches were represented. The respondents have different financial, legal and ownership forms, and the size of their housing stock ranges from 2000 to 200,000 dwellings. Figure 4 provides more details on the characteristics of the respondents. The interviewees were the chief executive officers of the companies (the majority) or their deputies, chief operating officers, chairmen of the board or managing directors. Half of the companies interviewed allocate part of their stock to social and subsidised housing. All companies take into account household income and household size (*i.e.* number of people in the household) when allocating their dwellings. This information is only gathered at the time of allocation and is not updated. Other aspects such as age of children, non-discriminatory selection, social mix in the neighbourhood and special situation of a household (*e.g.* violence, disability) are among the soft factors considered when allocating flats.

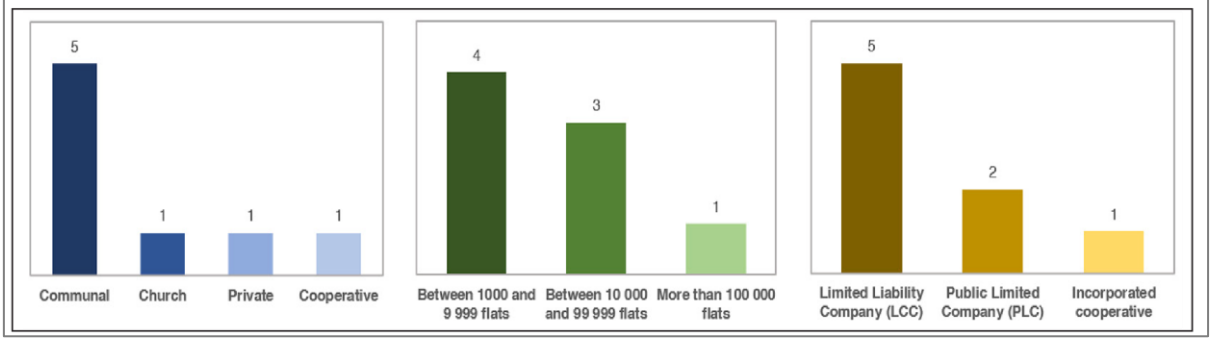


Figure 4: Characteristics of the interviewed companies: (left) owner; (middle) stock size; and (right) legal form.

3.1 EXPERIENCE WITH THE STUDIED MEASURES

This section summarises the experience of the interviewed companies with the studied measures, whether or not they offer the measure, and how they communicate the measure.

3.1.1 Flat exchange

This measure is implemented by companies in two different ways: *flat change*, where a household moves from its current dwelling to another, and *flat swap*, where two households exchange dwellings, *i.e.* the first household moves into the dwelling of the second household, and vice versa. Both options are offered, but the flat changes are more common. Four of the interviewed companies offer a flat change, one offers only a change from a larger to a smaller dwelling, and for two a change is generally possible but is not explicitly offered. On the other hand, flat swap is only offered by two companies, in two it is part of a larger swap programme (with other companies or within the municipality) and in one it is possible but not explicitly offered. In the companies that offer a flat swap, either a new rental contract is signed with new conditions (*i.e.* market price, but considering the price caps, the smaller flats will usually have lower rents) or the basic rent per m^2 remains unchanged, which means that the tenants have a financial advantage by moving to a smaller flat.

In three companies the tenant receives a new contract with new conditions after a flat change. Although it is assumed that in case of a move to a smaller flat the new rent will not be higher than the old one, there is no guarantee that this will actually happen. Some companies have considered the financial incentive. One company offers the new flat at a lower m^2 price than the normal price when moving to a smaller flat. One of the companies keeps the m^2 rent the same and the other one pays attentions to the point that a change should not lead to a financial burden. Usually, the tenants are temporarily relocated when the building is being renovated. In this context, companies usually offer a permanent flat change, as this also reduces the financial and organisational costs compared with the time when the household has to return to the original flat. Another reason for offering this instrument is to free up space in the larger dwellings and to have the possibility to increase the occupancy rate.

3.1.2 Moving bonus

Three companies offer financial support as a general rule: in one company tenants receive a bonus when they move, even if they move out of the company; in another, the moving costs are covered; in the third, a subsidy is paid when tenants move from a larger to a smaller flat, and the amount of subsidy depends on the m^2 reduction of the new flat compared with the old one. In three other companies, financial support is offered only in exceptional cases, *i.e.* when the move is due to, or in connection with, renovation work, or when the company recognises that the household is in financial difficulty. Two companies offer organisational assistance with the move, which is particularly helpful for older tenants. The legal form of the company was mentioned by two companies as a reason for not offering a moving bonus.

3.1.3 Moving advice

In two companies, consultation is offered and regularly communicated, but not exclusively on relocation. Two companies offer moving advice only when a new building is planned or in the framework of a flat change. In both cases, the high administrative costs and low output of the consultations is the reason for not offering them regularly. Four interviewees mentioned that tenants are aware that the organisation is there when they need it.

Table 1: Overview of the studied measures in the interviewed companies

FLAT CHANGE	FLAT SWAP	MOVING BONUS	MOVING ADVICE
• Four offer a flat change	• Two offer a flat swap	• Three offer financial support	• Two offer general consultation not only for moving
• One offers a change only from large to small	• Two offer it in cooperation with larger programmes	• Three offer financial support in exceptional cases	• One offers only when new construction is planned
• Two have no specific programme but a change is possible	• One has the possibility but does not offer it exclusively	• Two offer organisational support	• One offers only within the flat change
			• Four tenants know they can contact them

Table 1 summarises these offers in the interviewed companies. All these offers are communicated in different ways: sending an email, tenant meetings, verbal conversations, information events, word of mouth, personal visits to the site (in the case of new construction), website, tenant newspaper, social media, flyers and information stands in the housing areas. The documentation of the implementation and acceptance of the offers varies between the companies. While two companies comprehensively document and evaluate the measure, most have no specific documentation of cases. In a few companies the data are recorded but not evaluated. Only successful cases of flat swaps and flat changes are documented. Moving bonuses and moving advice are always coupled with flat exchanges.

In the remainder of this section, only flat swaps and flat changes are discussed, regardless of the incentives that led to them.

3.2 ACCEPTANCE AND EFFECTIVENESS

Three companies reported very little success with the flat swap measure, three others reported that the measure is not (or no longer) offered because they do not expect (or have not observed) much success and therefore the effort is not worthwhile. Even if successful, it creates more administrative work for the company, which is a reason why one of the companies does not advertise it, although it is generally possible to swap flats. On the contrary, another company offers the measure because it wants to avoid the higher future costs of an unstable neighbourhood.

Although flat changes are more common than flat swaps, companies report very low success rates for this measure, despite advertising the offer through various communication channels. Some companies even contacted all tenants who might be eligible for a flat change, but this not only failed to achieve much success, but in some cases led to negative feedback from tenants who felt they were being evicted.

Looking at some figures, one company estimates the success rate of flat swaps (*i.e.* the proportion of successful flat swaps from initial enquiries) at 4%. Approximately half of the swap requests are initiated for the purpose of enlarging the dwelling. In another company, around three-fourths of the flat changes in 2023 were due to lack of space in the old home, resulting in a 41% increase in living space. None of the changes involved moving to a smaller flat. As a positive example, one of the companies interviewed had an annual average of around 17 changes from large to smaller dwellings between 2011 and 2022, resulting in an average reduction of 22% in living space. In general, the companies reported a wide range of one to 80 cases of flat swaps and changes in their housing stock in recent years.

3.3 SUCCESS FACTORS AND LIMITING BARRIERS

Experience with swaps shows that location plays a role in the success rate. Changes within the neighbourhood and those that bring tenants closer to the city centre are more successful. Similarly, if the amount of space remains the same and only the location changes through a swap, there is a higher chance of success. When it comes to flat changes, tenants who really want to move will do so without any advertising. Nevertheless, communication plays a very important role because there is a very fine line between counselling and harassment, and by crossing that line, companies can invade tenants' privacy. Too much advertising can have a negative effect, as tenants may think that the companies are making a huge profit from each flat change, when in fact each change costs the companies a lot due to renovation and maintenance measures. There is sometimes mistrust between tenants and the housing company, as the companies are biased as landlords and contractual partners and the advice comes from the party that could benefit from it. For this reason, it makes more sense that the municipalities or non-profit organisations take over the communication. In general, accessibility for wheelchairs and walking aids, lifts (especially to the underground car park), affordable rents and lower operating and energy costs, and proximity to the previous flat and therefore to social contacts are the factors that increase the chances of a successful flat change.

Interviewees also gave several reasons for the very low rate of swaps. From a financial point of view, the rent is usually very low and therefore there is no financial pressure for households to

reduce the rent. On the other hand, after a flat swap, one has to sign a new contract usually with a rent which is much higher than the old one. Therefore, there is no financial incentive to move out of larger dwellings as households may end up paying the same or even more for less space. In addition, the financial transaction costs of moving (*e.g.* new furniture, new kitchen) are high. In addition to the financial aspects, there are also high social transition costs. After a move, the household and especially the children have a new environment.

Although the means are available, there is little willingness on the part of tenants in large flats to reduce their space, which leads to a mismatch between offers from people in small flats looking for a larger flat and people in large flats willing to move. Furthermore, both parties want to improve or at least maintain their current living situation and therefore have high and sometimes unrealistic expectations. This makes the likelihood of finding a match very low. The swap is often not successful because of details such as the orientation of the flats, the direction of the living room and the lack of an ideal parking space. As far as flat changes are concerned, there is a very low vacancy rate in the housing stock and tenants rarely move out, so it is not technically feasible for companies to offer a flat change to every tenant. There is a strong emotional attachment to the flat, especially after a long period of living there. Tenants have usually built their social structures in proximity to their current flat: friends, neighbours, even a family doctor. Moving to a new flat means a new start, a new neighbourhood and new neighbours, which is not easy, especially for older people. On the other hand, the old contract with a really low rent leads to a lock-in effect, as there is usually no financial advantage in moving. In addition, financial incentives are usually not important. In some cases, decisions are not made rationally (from an outsider's point of view), *e.g.* in the extreme case that an elderly tenant in need of care living on the third floor of a building without a lift is unwilling to move to the ground floor of the same building. The tenants have high expectations of their future flat: well-located, barrier-free, cheap, and it is not possible to meet all these expectations.

3.4 SUGGESTED IMPROVEMENTS

After discussing the measures and their factors of success and failure, interviewees were asked for their views on various instruments that could encourage more people to move out of under-occupied dwellings. According to Eurostat (2011) under-occupied dwellings are those in which the number of rooms is excessive in relation to the number of people living in the household. The suggestions are grouped under the categories of information and communication, financial, and regulation, and are described below.

3.4.1 Information and communication

The issue of high per capita living space and its environmental impacts should be kept alive in discussions, just like the discussion on the impact of meat consumption and flights. Public campaigns, financially supported by government, should aim to raise awareness and create a narrative on the issue that brings about positive dynamic in society. Communication should also be improved at various levels. First, there should be an exchange between housing companies to learn from each other, as some are more open about the topic than others. Second, it should be the responsibility of the municipalities and non-profit organisations to provide information and advice on (moving) options. Lastly, the issue should be communicated positively by all parties involved, *i.e.* tenants' companies, public administration, non-profit organisations and politicians. It should be openly communicated that new housing cannot be built for every generation, but the existing buildings should be used efficiently.

3.4.2 Financial

The public sector (state and national authorities) should encourage freeing up under-occupied dwellings by providing financial incentives to both tenants and housing companies. By subsidising the costs of moving, especially to smaller dwellings where there are no direct cost benefits, the financial burden will no longer be a barrier to action. The provision of bonuses and subsidies to housing companies also plays an important role in incentivising them to promote such measures, given the high renovation and maintenance costs that housing companies might incur after each flat change, as highlighted in the interviews. These costs depend, however, on the condition of the flat and the extent of renovation work already carried out. The very high costs addressed by the

interviewees are probably due to the current renovation requirements in the building sector and the fact that the flat changes often occur after a very long stay, meaning that the flat is typically not in a good condition.

Other sufficiency measures, such as the promotion of flat-sharing, should also be encouraged through high financial incentives. Providing an empty flat through this measure would be more cost-effective (considering high construction costs) and time-efficient (considering the lengthy process required for new construction) than acquiring a flat through new construction. Based on an example given in one of the interviews, offering two households a relatively high hypothetical moving bonus of €10,000 each to incentivise them to share a flat and thereby freeing up the other flat would still be at least 10 times cheaper and faster for the housing company than building a new flat.

3.4.3 Regulation

Some interviewees felt that 'home' was a sensitive issue and that individual choices about their homes should be respected. They did not believe that tenants could or should be forced to leave their homes by regulation, as being too restrictive would be not only undemocratic but also unlikely to be very successful. However, some possible regulations and models were suggested. The first suggestion is to set a per capita rule for social housing (following the Swiss example). In this model, the occupancy rate (*i.e.* the number of people living in the flat) is defined, and if the household size becomes smaller than required over time, the household has to vacate the flat, with the possibility of moving to one of the flats offered by the housing company. The second suggestion goes in the same direction as the first and is a prerequisite for it. Almost all interviewees mentioned the misallocation tax (in German, *Fehlbelegungsabgabe*) as an effective measure that existed in Germany for publicly subsidised housing and was gradually abolished over time. Under this model, tenants had to continuously report their income to prove that they still met the criteria for social housing, otherwise they had to pay a tax to the municipality. A similar measure where tenants either have to comply with the rules (*e.g.* occupancy rate) or to pay taxes was considered effective in motivating tenants of under-occupied flats to move to smaller dwellings. Another suggestion is to increase all rents up to a certain amount and set a transition period for the occupants of the under-occupied flats to move to a smaller flat. If they do not move out by the end of the transition period, their tenancy will be renewed at the higher rent. The fourth proposal is a model in which the rent is capped for a certain amount of floor space per person (*e.g.* 30 m^2). The rent will be differentiated for new and old buildings. Any floor space above this threshold would have to be rented at the market price. For example, if a household wants extra space for a home office, the space will be rented at the market price for office space. Finally, one interviewee suggested the right to swap flats as an option, while believing that this measure would not increase the number of swaps already occurring.

In addition to the instruments mentioned above, the improvement of the social and technical infrastructure was considered essential. From a technical point of view, standardised processes and universal digital platforms are suggested as a solution to better organise flat swaps and flat changes. A universal platform could provide a comprehensive overview of all available offers. This will lead to better communication of prices and also reduce the perception of housing shortage, which leads to some unrealistic housing requests. In order to achieve a better distribution of available flats, the restrictive data protection rules, which oblige companies to regularly delete applications and result in applicants having to regularly renew their application, should be relaxed. On the social side, current social norms in the area of housing (*e.g.* a three-room apartment as standard even for one-person households), should be reconsidered and redefined. On the other hand, social acceptance of the new concepts and rules should be increased.

4. DISCUSSION AND CONCLUSIONS

In response to the much-discussed housing shortage in Germany and the need for new construction, Hunziker (2024) considers a redistribution of space as an alternative to provide the missing living space. He argues that this could be achieved if each individual gave up just 2% of their current 47.4 m^2 living space. Given that this current per capita space is about 36% more

than that of 1990, the present study investigates the success of selected sufficiency measures in reducing the average per capita floor area in German rental housing managed by housing companies. Eight housing companies in five cities and four states were interviewed through guideline-based semi-structured interviews to explore their experiences with the following measures: flat exchange (including flat swaps and flat changes), moving bonus and moving advice. What Hunziker suggests for such spatial redistribution is theoretically true, but as the author also acknowledges, it is challenging or even impossible under the current German political and social framework. While sufficiency relies greatly on individual choices, it should not be seen solely as an individual lifestyle change, as these individual choices are strongly shaped by available offers, existing infrastructure and the legal framework. To be successful, sufficiency must be regarded as a 'collective challenge' (SRU 2024) and the many small-scale initiatives observed at the municipal level need to be scaled up to the national level. Therefore, this section discusses the different instruments proposed by the housing companies in terms of their potential role in changing the social and political framework in Germany, which is essential for the full exploitation of sufficiency.

Moving advice is an important first instrument that can trigger further measures such as flat swaps and changes. However, the fact that it is the responsibility of the housing companies does not seem to be optimal. Given the sense of attachment, especially for older tenants (in terms of both age and time spent in a flat), housing is a sensitive issue that needs to be handled carefully. As housing companies are usually seen as contractors, communication on this issue is challenging for them and not very successful. Giving the municipalities, as neutral stakeholders, the responsibility can build trust and lead to more success. The city of Tubingen already offers such a programme, informing residents who have too much living space about options such as downsizing or alternative living forms (Tübingen Universitätsstadt 2019). An evaluation of the consultations conducted under this programme between late 2020 and December 2021, reported by Bierwirth *et al.* (2022), shows a high level of satisfaction with the offer and information provided. The consultations are reported to have given participants relatively positive encouragement for their plans. Participants were also largely confident that they would implement their plan. The restrictions imposed by COVID-19 affected the quantity and quality of the consultations carried out during this period, and the relocations and flat swaps were rarely reasons for taking up the consultation offer. Therefore, the results presented by Bierwirth *et al.* are not directly comparable with the success rates reported by housing companies. However, the lessons learned in Tubingen may still be helpful in designing the programme in other municipalities.

The moving bonus by itself does not seem to have an impact on the initiation of relocation, especially in cases where there is no direct financial benefit from moving to a smaller dwelling (when there is no price guarantee after a move). However, once the barrier of moving costs has been removed, it can be an effective instrument in combination with other financial incentives. Public authorities should therefore support this instrument by providing financial incentives to tenants and housing companies. The city of Frankfurt am Main offers such bonuses when tenants move from a social housing flat to one that is at least 15 m^2 smaller (Stadt Frankfurt am Main 2024). Similarly, in Dusseldorf, landlords can receive a bonus if the move is due to a flat swap (Tauschwohnung 2024). Such a subsidy could also be given to housing companies so that they receive a bonus for each successful flat change. Such investments contribute positively to the multiple objectives of the buildings sector: providing affordable housing, preventing soil sealing and reducing emissions.

Flat swaps and flat changes can be effective in freeing up under-occupied dwellings for use by larger households. However, in most cases they do not provide an incentive for residents to move. A combination of different financial incentives that reward downsizing (such as the package offered by ProPotsdam 2023, which includes a living space bonus, a bonus for a shared flat and a moving bonus) could make such instruments attractive. Furthermore, other instruments are needed as catalysts to make the most of these potentially effective instruments. The need for a universal platform has been raised as a technical prerequisite to facilitate flat swaps. An example of such a platform already exists on a small scale in Berlin[2] with the participation of six housing companies. Another example is the French *Echanger Habiter*, a platform for social housing with the participation of around 40 housing companies. Since its launch in 2018, around 3000 flat swaps have taken place, with a success rate of 4%, not higher than the success rate already communicated in the interviews. This

confirms the need to improve the social infrastructure to complement this technical infrastructure, also suggested by the interviewees. Information campaigns should promote sufficiency as a social practice in all sectors. However, the sense of attachment, as one of the notions of wellbeing and mentioned in many interviews as a reason for the failure of the studied measures, has to be considered as a key factor when promoting sufficiency. This is crucial not only for increasing the success of these measures, but also to prevent the unwanted social and psychological implications of forcing such measures, intensively discussed by scholars in the context of forced relocations, unhoming and displacement (*e.g.* Westin 2021; Elliott-Cooper *et al.* 2020). The multiple benefits of sufficiency measures for the climate (*e.g.* lower energy and material consumption) and individual wellbeing (*e.g.* stronger community ties, increased sense of equity) should be communicated, so that people voluntarily follow the measures on the basis of the information they have.

This could be done, for example, by importing already practiced and accepted social norms from other European countries. The Swiss minimum occupancy rate (Stadt Zürich 2024), repeatedly mentioned in the interviews, is one such example. Tenants of social housings in Zurich have to meet the requirements of household size and income level in order to continue living in their flats. This is similar to the misallocation tax that used to exist in Germany, which was abolished for two reasons, first, it required significant administrative efforts and, second, it led to less social heterogeneity in neighbourhoods, as higher income tenants had to move out. Adapting and reactivating this old law will make it possible to identify under-occupied dwellings that could potentially be occupied by larger families. Merely enforcing a tax on high-income households will not improve the situation, as they will simply pay and continue to live in their under-occupied dwellings. Therefore, the focus of this measure should be on household size, so that the high-income households can still stay in the neighbourhood and contribute to its heterogeneity. The high administrative costs of regular data collection can be overcome by improvements in digitalisation. Finally, residents seem to react only to significant price increases. According to one interviewee, tenants saved a lot of energy following the 2022 energy crisis and the resulting sharp increase in energy prices. However, this behaviour changed when price caps were introduced. This low price elasticity, although typical for essential goods such as energy, indicates that users are not easily willing to leave their comfort zone and alter their habits towards low consumption behaviour (*e.g.* putting on extra clothes instead of turning on the heating). The rent cap has not proved to be an effective instrument. Defining an essential amount of space per person at the capped price (fulfilling the 'needs') and offering additional spaces at market price (fulfilling the 'wants') has two advantages: first, the financial pressure might incentivise freeing up the under-occupied flats; and second, it can contribute to the use of shared spaces such as shared office spaces, communal spaces for hobbies and guest accommodations. This would be similar to the already established concept of car sharing in Germany, which saves the occasional car drivers the annual high maintenance and insurance costs. In the case of such a model with a defined essential living space, besides the indicator of floor area per capita, new indicators of floor area per household size and floor area per household composition should be used when discussing the occupancy rate of the flats.

Proper documentation of successful cases can identify opportunities for improvement. Documenting and evaluating implementation cases is not a priority for many companies, mainly due to capacity and the lack of incentives and a defined target. Even where documentation is carried out, only successful swaps and changes are documented, making it impossible to understand the real reasons why tenants do not want to move. Therefore, incentivising companies to document the reasons for failure from the tenants' point of view (or perhaps even requiring them to do so, while compensating the extra cost and effort) would provide a good overview of the failure factors and identify opportunities for improvement. This point was also discussed in one of the interviews and, as a result, the authors provided a set of questions to be included in an online flat swap portal, where tenants who have initiated a flat swap, will have to enter the reason when terminating the process of a failed swap.

Although this study focuses only on rental properties managed by housing companies, this presumably niche market still accommodates around 17% of German households. The suggested instruments and the lessons learned from this part of the housing sector can also be applied

to privately rented dwellings, which together account for more than half of German dwellings. Moreover, motivating households to reconsider their spatial needs could be effectively transferred to homeowners. Given this transferability, any success in this niche sector in empowering and motivating occupants of under-occupied dwellings to downsize will ultimately play a significant role in optimising space use, reducing per capita and total space demand, and decreasing the high residential energy consumption.

While space heating is considered the main driver of high residential energy consumption in Germany and most parts of Europe, the need for space cooling is steadily increasing due to climate change and global warming. Most measures that reduce the energy demand for space heating equally contribute to improving the energy demand for space cooling. In addition to the savings achieved by reducing the need for new construction, space optimisation offers significant savings potential by decreasing the energy required to operate buildings, benefiting both occupants and the environment. Despite the small sample size, considered a limitation of the study, the findings from the interviews with the housing companies provide a valuable contribution to effective policy design that enables such space optimisation while still meeting the occupants' needs. These companies are in direct contact with the target groups, mostly highly committed to the issue and in dialogue with policymakers at various levels. As the phenomenon of significant increases in space consumption and high residential energy demand is not limited to Germany, the policy lessons may be widely applicable in other societies. Nevertheless, the study sample does not allow for an exploration of the influence of the characteristics of the housing companies (*e.g.* legal form, business model) on their interest in adopting sufficiency and the number or type of measures they offer.

Furthermore, while the study offers insights into the factors affecting the success and failure of the studied measures, the analysis of the interviews could only provide a partial picture of the various cultural, social and economic factors that influence individual decision-making, which contributes to the under-occupation of dwellings. Further research, including the views of tenants living in these dwellings, is needed to develop a more holistic understanding of the underlying factors. Additionally, a potential analysis of the studied and proposed measures in this paper could assist policymakers in the strategic allocation of resources, ensuring a balanced ratio between effort and outcome and effectively reaching each target group with the most appropriate measures.

Finally, at a time when the buildings sector, and housing companies in particular, are faced with the challenge of becoming carbon-neutral and also meeting the ever-increasing demand for housing, it is more important than ever to explore and invest in measures such as those discussed in this paper. Given the drastically increased construction costs and the high emissions associated with emission-intensive building materials, it may be ecologically and economically beneficial to redistribute and use more efficiently the existing space through such measures. This last point could and should be further explored.

NOTES

1 See https://energysufficiency.de/policy-database/.

2 See https://inberlinwohnen.de/.

ACKNOWLEDGEMENTS

The authors thank Antoine Durand and Anne Kantel for insightful discussions and valuable feedback during the development of this paper; Torsten Boelting for his support in contacting the housing companies; and the representatives of the housing companies for participating in the interviews.

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COMPETING INTERESTS

The authors have no competing interests to declare.

DATA AVAILABILITY

The participants in this study did not give written consent for their data to be published. Therefore, the data collected from the interviews that support the findings of this study are not publicly available in order to protect the privacy and confidentiality of the research participants.

ETHICAL CONSENT

Informed consent was obtained from all participants prior to the interviews, in which they agreed to participate in the study on a voluntary basis and to allow the interviews to be recorded and the information provided to be processed and used for the purposes of this research.

FUNDING

This work was enabled by internal funding from the Fraunhofer Institute for Systems and Innovation Research ISI.

SUPPLEMENTAL DATA

Supplemental data for this paper can be accessed at: https://doi.org/10.5334/bc.435.s1

REFERENCES

Akenji, L., Lettenmeier, M., Toivio, V., Koide, R., & **Amellina, A.** (2019). *1.5-Degree lifestyles: Targets and options for reducing lifestyle carbon footprints*. Institute for Global Environmental Strategies (IGES). DOI: https://doi.org/10.57405/iges-6719; https://www.iges.or.jp/en/pub/15-degrees-lifestyles-2019/en

BBSR. (2020). *Wachsende und schrumpfende Städte und Gemeinden in Deutschland*. Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR). https://www.bbsr.bund.de/BBSR/DE/startseite/topmeldungen/2020-wachsend-schrumpfend.html

BDEW. (2022). *BDEW-Gaspreisanalyse April 2022*. https://www.bdew.de/media/documents/220504_BDEWGaspreisanalyse_

Best, B., Thema, J., Zell-Ziegler, C., Wiese, F., Barth, J., Breidenbach, S., Nascimento, L., & **Wilke, H.** (2022). Building a database for energy sufficiency policies. In *F1000Research*, 11, 229. DOI: https://doi.org/10.12688/f1000research.108822.2

Bierwirth, A., Gies, D., & **Moser, R.** (2022). *Evaluation der Wohnraumberatung Tübingen im Projekt OptiWohn. Analyse der durchgeführten Beratungen in Tübingen*. https://wupperinst.org/fileadmin/redaktion/downloads/projects/OptiWohn_Evaluation_Wohnraumberatung.pdf

Bierwirth, A., & **Thomas, T.** (2019). *Energy sufficiency in buildings* (Concept Paper). https://www.energysufficiency.org/static/media/uploads/site-8/library/papers/sufficiency-buildings-final__v2.pdf

Breidenbach, S., Bußmann-Welsch, T. M., Fischer, L., Grotenrath, A., Heinen, A., & **Heyl, B.** (2021). *Maßnahmenfür ein 1,5-Grad-Gesetzespaket. Arbeitsstand: September 2021*. www.germanzero.de.

Burke, M. J. (2020). Energy-sufficiency for a just transition: A systematic review. *Energies*, 13(10), 2444. DOI: https://doi.org/10.3390/en13102444

Creutzig, F., Niamir, L., Bai, X., Callaghan, M., Cullen, J., & **Díaz-José, J.** (2022). Demand-side solutions to climate change mitigation consistent with high levels of well-being. *Nature Climate Change*, 12(1), 36–46. DOI: https://doi.org/10.21203/rs.3.rs-127928/v1

Dena. (2019). *Dena-Gebäudereport kompakt 2019 Statistiken*. https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-

Destatis. (2021). *Bautätigkeit*. https://www.destatis.de/DE/Service/Bibliothek/_publikationen-fachserienliste-5.html#651444

Destatis. (2024). *Zensus 2022: Gebäude und Wohnungszählung*. https://www.zensus2022.de/DE/Ergebnisse-des-Zensus/_inhalt.html#Start

Deutscher Bundestag. (2021). *Flächenverbrauch: Bundesrepublik verfehlt 30-Hektar-Ziel*. https://www.bundestag.de/presse/hib/820154-820154

Elliott-Cooper, A., Hubbard, P., & **Lees, L.** (2020). Moving beyond Marcuse: Gentrification, displacement and the violence of un-homing. *Progress in Human Geography*, 44(3), 492–509. DOI: https://doi.org/10.1177/0309132519830511

Ellsworth-Krebs, K. (2020). Implications of declining household sizes and expectations of home comfort for domestic energy demand. *Nature Energy*, 5(1), 20–25. DOI: https://doi.org/10.1038/s41560-019-0512-1

Eurostat. (2011). *Glossary*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Category:Glossary

Eurostat. (2021). *House or flat—Owning or renting*. https://ec.europa.eu/eurostat/cache/digpub/housing/bloc-1a.html

Eurostat. (2023). *Inability to keep home adequately warm—EU-SILC survey*. DOI: https://doi.org/10.2908/ilc_mdes01

Faber, J., Schroten, A., Bles, M., Sevenster, M., Markowska, A., Smit, M., … Rohde, C., Dütschke, E., Köhler, J., Gigli, M., Zimmermann, K., Soboh, R., & **van't Riet, J.** (2012). *Behavioural climate change mitigation options and their appropriate inclusion in quantitative longer term policy scenarios*. CE Delft for European Commission, DG Climate Action. https://climate.ec.europa.eu/system/files/2016-11/main_report_en.pdf

Federal Climate Change Act. (2021). *Federal Climate Change Act (Bundes-Klimaschutzgesetz)*. https://www.gesetze-im-internet.de/englisch_ksg/englisch_ksg.html

Fischer, C., Blank, R., Brohmann, B., Cludius, J., Förster, H., Hayen, D. A., & **Keimeyer, F.** (2016). *Climate change 17/2016*. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/climate_change_17_2016_konzept_zur_absoluten_verminderung_des_energiebedarfs.pdf

Friedrich-Ebert-Stiftung. (1997). *Politik-Dossier Wohnungspolitik*. https://library.fes.de/fulltext/stabsabteilung/00518toc.htm

Gavrilis, P. (2019). Beratungen auf Bundesparteitag—Grüne bringen Recht auf Wohnungstausch ins Spiel. *Deutschlandfunk*, 13 November. https://www.deutschlandfunk.de/beratungen-auf-bundesparteitag-gruene-bringen-rechtauf-

Gough, I. (2020). Defining floors and ceilings: The contribution of human needs theory. *Sustainability: Science, Practice and Policy*, 16(1), 208–219. DOI: https://doi.org/10.1080/15487733.2020.1814033

Gynther, L. (2021). *Energy sufficiency indicators and policies*. ODYSSEE-MURE. https://www.odyssee-mure.eu/publications/policy-brief/energy-sufficiency.html

Hayden, A., & **Dasilva, C.** (2022). The wellbeing economy: Possibilities and limits in bringing sufficiency from the margins into the mainstream. *Frontiers in Sustainability*, 3, 966876. DOI: https://doi.org/10.3389/frsus.2022.966876

HBS. (2019). *Die Wohnsituation in deutschen Großstädten—77 Stadtprofile*. Hans-Böckler-Stiftung (HBS). https://www.boeckler.de/pdf_fof/100892.pdf

Holm, A., Regnault, V., Sprengholz, M., & **Stephan, M.** (2021). *Die Verfestigung sozialer Wohnversorgungsprobleme*. https://www.boeckler.de/de/faust-detail.htm?sync_id=HBS-008039

Hunziker, C. (2024). Wie viel Pro-Kopf-Wohnfläche ist angemessen? *DW*, 77(03/24), 22–26.

IPCC. (2022). Summary for policymakers. In *Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 3–48). DOI: https://doi.org/10.1017/9781009157926.001

iwd. (2020). *Größer wohnen*. https://www.iwd.de/artikel/groesser-wohnen-489720/

Jin, X. (2017). Low carbon city construction planning for the needs of residents. *Agro Food Industry Hi-Tech*, 28(1), 2472–2476.

Kenkmann, T., Cludius, J., Fischer, C., Fries, T., Keimeyer, F., Schumacher, K., & **Brischke, L.** (2019). *Flächensparend Wohnen*. https://www.umweltbundesamt.de/publikationen/flaechensparend-wohnen

Princen, T. (2005). *The logic of sufficiency*. MIT Press.

ProPotsdam. (2023). *Was ist der Wohnflächenbonus?* https://www.propotsdam-hilft.de/was-ist-der-wohnflaechenbonus/

Rädiker, S., & **Kuckartz, U.** (2020). *Focused analysis of qualitative interviews with MAXQDA. Step by step*. MAXQDA Press.

Sach, T., Beyschlag, L., Bruhin, A., Kerres, P., Lotz, B., & **Oppermann, L.** (2021). *Klimaschutz in Zahlen*. https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutz_zahlen_20

Samadi, S., Gröne, M., Schneidewind, U., Luhmann, H. J., Venjakob, J., & **Best, B.** (2017). Sufficiency in energy scenario studies: Taking the potential benefits of lifestyle changes into account. *Technological Forecasting and Social Change*, 124, 126–134. DOI: https://doi.org/10.1016/j.techfore.2016.09.013

Savills. (2019). *Das sind die größten Wohnungseigentümer in Deutschland*. https://www.savills.de/research_articles/260049/291330-0

SRU. (2024). *Suffizienz als 'Strategie des Genug': Eine Einladung zur Diskussion*. Geschäftsstelle des Sachverständigenrates für Umweltfragen (SRU). https://www.umweltrat.de/SharedDocs/Downloads/DE/04_Stellungnahmen/2020_2024/2024_03_Suffizienz.pdf?__blob=publicationFile&v=11)

Stadt Frankfurt am Main. (2024). *Umzugsprämie*. https://frankfurt.de/themen/planen-bauen-und-wohnen/wohnen/vermittlung-von-gefoerderten-wohnungen-und-fehlbelegungsabgabe/wohnungssuche---wohnungsvermittlung/umzugspraemie

Stadt Zürich. (2024). *Mietbedingungen für städtische Wohnungen*. https://www.stadt-zuerich.ch/fd/de/index/wohnen-und-gewerbe/vermietungen/mietbedingungen.html

Statista. (2021). *Raumwärme—Verteilung der Energieträger in deutschen Haushalten 2019*. https://de.statista.com/statistik/daten/studie/250403/umfrage/raumwaermebereitstellun

Tauschwohnung. (2024). *Wohnungstausch in Düsseldorf*. https://www.wohnungstauschduesseldorf.de/

Tübingen Universitätsstadt. (2019). *Haben Sie noch Platz?* https://www.tuebingen.de/29884.html#/31049

Umweltbundesamt. (2020). *Treibhausgasemissionen sinken 2020 um 8,7 Prozent*. https://www.umweltbundesamt.de/presse/pressemitteilungen/treibhausgasemissionensinken-

Umweltbundesamt. (2023a). *Bevölkerungsentwicklung und Struktur privater Haushalte*. https://www.umweltbundesamt.de/daten/private-haushalte-konsum/strukturdaten-privater-haushalte/bevoelkerungsentwicklung-struktur-privater#843-millionen-menschen

Umweltbundesamt. (2023b). *Wohnfläche*. https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/wohnflaeche#zahl-der-wohnungen-gestiegen

Umweltbundesamt. (2024a). *Bodenversiegelung*. https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/boden/bodenversiegelung#was-ist-bodenversiegelung

Umweltbundesamt. (2024b). *Siedlungs- und Verkehrsfläche*. https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/flaeche/siedlungs-verkehrsflaeche#anhaltender-flachenverbrauch-fur-siedlungs-und-verkehrszwecke-

Vita, G., Lundström, J. R., Hertwich, E. G., Quist, J., Ivanova, D., Stadler, K., & **Wood, R.** (2019). The environmental impact of green consumption and sufficiency lifestyles scenarios in Europe: Connecting local sustainability visions to global consequences. *Ecological Economics*, 164, 106322. DOI: https://doi.org/10.1016/j.ecolecon.2019.05.002

Westin, S. (2021). Un-homing with words: Economic discourse and displacement as alienation. *Cultural Geographies*, 28(2), 239–254. DOI: https://doi.org/10.1177/1474474020970251

Wronski, I. (2023). *Wellbeing through sufficiency*. https://www.eceee.org/all-news/columns/wellbeing-through-sufficiency/

Zell-Ziegler, C., & **Förster, H.** (2018). *Mit Suffizienz mehr Klimaschutz modellieren*. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/uba_texte_55_2018_zwischenbericht_mit_suffizienz_mehr_klimaschutz_modellieren.pdf

Zell-Ziegler, C., Thema, J., Best, B., Wiese, F., Lage, J., Schmidt, A., … Stagl, S. (2021). Enough? The role of sufficiency in European energy and climate plans. *Energy Policy*, 157, 112483. DOI: https://doi.org/10.1016/j.enpol.2021.112483

TO CITE THIS ARTICLE:
Bagheri, M., Roth, L., Siebke, L., Rohde, C., & Linke, H.-J. (2024). Implementing housing policies for a sufficient lifestyle. *Buildings and Cities*, 5(1), pp. 300–315. DOI: https://doi.org/10.5334/bc.435

Submitted: 09 April 2024
Accepted: 12 July 2024
Published: 24 July 2024

Buildings and Cities is a peer-reviewed open access journal published by Ubiquity Press.

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Abbreviations

ASI	Avoid-Shift-Improve
DE	Germany
EDA	Exploratory data analysis
EU	European Union
GHG	Greenhouse gas
GR	Greece
ICT	Information and communication technologies
IEA	International Energy Agency
IPCC	International Panel on Climate Change
MFH	Multi-family house
MIxedLM	Mixed Linear Models
MLM	Multilevel Model
NL	Netherlands
ODPM	Office of the Deputy Prime Minister
OISD	Oxford Institute for Sustainable Development
PL	Poland
PT	Portugal
SDG	Sustainable development goals
SE	Sweden
SFH	Single-family house

References

AGEB (2023): Auswertungstabellen zur Energiebilanz 1990 bis 2022. Available at https://ag-energiebilanzen.de/daten-und-fakten/auswertungstabellen/.

Akenji, L.; Lettenmeier, M.; Toivio, V.; Koide, R.; & Amellina, A. (2019): 1.5-Degree Lifestyles: Targets and options for reducing lifestyle carbon footprints.

Arsad, F. S.; Hod, R.; Ahmad, N.; Baharom, M.; Ja'afar, M. H. (2023): Assessment of indoor thermal comfort temperature and related behavioural adaptations: a systematic review. In: Environmental Science and Pollution Research, 30 (29), pp. 73137–73149. https://doi.org/10.1007/s11356-023-27089-9.

Astetta Alemmas Campaign (2022): Down a degree – To ensure energy for us all. Available at https://www.astettaalemmas.fi/en.

Australian Government (2019): Renting out all or part of your home. Available at https://www.ato.gov.au/businesses-and-organisations/income-deductions-and-concessions/sharing-economy-and-tax/renting-out-all-or-part-of-your-home.

Bagheri, M. (2020): Traces of Social Sustainability in Garden Cities- Karlsruhe as a Case Study. In: European Journal of Sustainable Development, 9 (4), p. 250. https://doi.org/10.14207/ejsd.2020.v9n4p250.

Bagheri, M.; Kochański, M.; Kranzl, L.; Korczak, K.; Mayrhofer, L.; Müller, A.; Özer, E.; Rao, S. (2024a): Reduction of gas demand through heating behaviour changes in households: Novel insights from modelling and empirical evidence. In: Energy and Buildings. In: Energy and Buildings. https://doi.org/10.1016/j.enbuild.2024.114257.

Bagheri, M.; Pröpper, A.; Klein, G. (2024b). *Exploring residential space use pattern: Findings from a multi-country survey*. Unpublished.

Bagheri, M.; Roth, L.; Siebke, L.; Rohde, C.; Linke, H.-J. (2024c): Implementing housing policies for a sufficient lifestyle. In: Buildings & Cities, 5 (1). https://doi.org/10.5334/bc.435.

Bagheri, M.; Tröger, J.; Freudenberg, C. (2024d): Investigating the influence of current trends and behaviours on household structures and housing consumption patterns. In: Consumption and Society, pp. 1–23. https://doi.org/10.1332/27528499Y2024D000000025.

BBSR (2020): Wachsende und schrumpfende Städte und Gemeinden in Deutschland. Available at https://www.bbsr.bund.de/BBSR/DE/startseite/topmeldungen/2020-wachsend-schrumpfend.html.

BDEW (2022): BDEW-Gaspreisanalyse April 2022. Available at https://www.bdew.de/media/documents/220504_BDEWGaspreisanalyse_.

Belaïd, F.; Joumni, H. (2020): Behavioral attitudes towards energy saving: Empirical evidence from France. In: Energy Policy, 140, p. 111406. https://doi.org/10.1016/j.enpol.2020.111406.

Benedikter, R. (2012): Lifestyles. In: Anheier, H.; Juergensmeyer, M. (Eds.): Encyclopedia of global studies. Los Angeles: Sage reference. ISBN: 9781412964296, pp. 1076–1080.

Berbegal-Mirabent, J. (2021): What Do We Know about Co-Working Spaces? Trends and Challenges Ahead. In: Sustainability, 13 (3), p. 1416. https://doi.org/10.3390/su13031416.

Bergstra, M. (2021): Ageing policies - access to services in different Member States. Annex VIII - Country study on Sweden. Available at https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662940/IPOL_STU(2021)662940(ANN08)_EN.pdf.

Bertoldi, P. (2022): Policies for energy conservation and sufficiency: Review of existing policies and recommendations for new and effective policies in OECD countries. In: Energy and Buildings, 264, p. 112075. https://doi.org/10.1016/j.enbuild.2022.112075.

Bertoldi, P.; Rezessy, S.; Oikonomou, V. (2013): Rewarding energy savings rather than energy efficiency: Exploring the concept of a feed-in tariff for energy savings. In: Energy Policy, 56, pp. 526–535. https://doi.org/10.1016/j.enpol.2013.01.019.

Best, B.; Thema, J.; Zell-Ziegler, C.; Wiese, F.; Barth, J.; Breidenbach, S.; Nascimento, L.; Wilke, H. (2022): Building a database for energy sufficiency policies. In: F1000Research, 11, p. 229. https://doi.org/10.12688/f1000research.108822.2.

Bierwirth, A. (2015): Strategische Entwicklung eines zukunftsfähigen Wohnraumangebots – ein Suffizienz-Szenario. In: uwf UmweltWirtschaftsForum, 23 (1-2), pp. 49–58. https://doi.org/10.1007/s00550-015-0355-6.

Bierwirth, A.; Gies, D.; Moser, R. (2022): Evaluation der Wohnraumberatung Tübingen im Projekt OptiWohn. Analyse der durchgeführten Beratungen in Tübingen. Available at https://wupperinst.org/fileadmin/redaktion/downloads/projects/OptiWohn_Evaluation_Wohnraumberatung.pdf.

Bierwirth, A.; Thomas, T. (2019): Energy sufficiency in buildings. Concept paper.

Bjørn, A.; Kalbar, P.; Nygaard, S. E.; Kabins, S.; Jensen, C. L.; Birkved, M.; Schmidt, J.; Hauschild, M. Z. (2018): Pursuing necessary reductions in embedded GHG emissions of developed nations: Will efficiency improvements and changes in consumption get us there? In: Global Environmental Change, 52, pp. 314–324. https://doi.org/10.1016/j.gloenvcha.2018.08.001.

Blanchet, T.; Chancel, L.; Gethin, A. (2019): How unequal is Europe? Evidence from distributional national accounts, 1980-2017. Available at http://digamoo.free.fr/wilab419.pdf.

Blau, D. M.; van der Klaauw, W. (2013): What determines family structure? In: Economic Inquiry, 51 (1), pp. 579–604. https://doi.org/10.1111/j.1465-7295.2010.00334.x.

Blázquez, L.; Boogen, N.; Filippini, M. (2013): Residential electricity demand in Spain: New empirical evidence using aggregate data. In: Energy Economics, 36, pp. 648–657. https://doi.org/10.1016/j.eneco.2012.11.010.

BMEL (2022): Häufigkeit des Kochens in Deutschland 2022 | Statista. Available at https://de.statista.com/statistik/daten/studie/92/umfrage/haeufigkeit-des-kochens/, accessed 22.03.2023.

Borkowicz, P. (4/28/2023): Weighting Your Survey Data: What You Need to Know and How to Do It Right. In: Survalyzer AG. Available at https://survalyzer.com/weighting-survey-data/.

Bosserman, P. (1983): Cultural values and new life-styles. In: Problems of culture and cultural values in the contemporary world, pp. 23–35.

Boulanger, P.-M. (2010): Three strategies for sustainable consumption. In: SAPI EN. S. Surveys and Perspectives Integrating Environment and Society, (3.2).

Bourdieu, P. (1987): Choses dites. Paris: Éd. de Minuit. ISBN: 9782707311221.

Bramley, G.; Dempsey, N.; Power, S.; Brown, C.; Watkins, D. (2009a): Social Sustainability and Urban Form: Evidence from Five British Cities. In: Environment and Planning A: Economy and Space, 41 (9), pp. 2125–2142. https://doi.org/10.1068/a4184.

Bramley, G.; Morgan, J. (2003): Building Competitiveness and Cohesion: The Role of New Housebuilding in Central Scotland's Cities. In: Housing Studies, 18 (4), pp. 447–471. https://doi.org/10.1080/02673030304245.

Bramley, G.; Power, S. (2009b): Urban form and social sustainability: The role of density and housing type. In: Environment and Planning B: Planning and Design, 36, pp. 30–48. https://doi.org/10.1068/b33129.

Breidenbach, S.; Bußmann-Welsch, T. M.; Fischer, L.; Grotenrath, A.; Heinen, A.; Heyl, B. (2021): Maßnahmenfür ein 1,5-Grad-Gesetzespaket. Arbeitsstand: September 2021. Available at www.germanzero.de.

Brelih, N. (2013): Thermal and acoustic comfort requirements in European standards and national regulations. In: REHVA, pp. 16–19.

Bryman, A. (2006): Integrating quantitative and qualitative research: how is it done? In: Qualitative Research, 6 (1), pp. 97–113. https://doi.org/10.1177/1468794106058877.

Bundesministerium der Finanzen (2022): Bundesfinanzministerium - Reform der Grundsteuer. Available at https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Steuern/Steuerarten/Grundsteuer-und-Grunderwerbsteuer/reform-der-grundsteuer.html.

Burke, M. J. (2020): Energy-Sufficiency for a Just Transition: A Systematic Review. In: Energies, 13 (10), p. 2444. https://doi.org/10.3390/en13102444.

Canale, L.; Ficco, G.; Bertini, I.; Dell'Isola, M. (2023): About the effect of tailored energy feedback on space heating consumption and indoor air temperature in social housing buildings: An experimental investigation. In: Energy and Buildings, 292, p. 113149. https://doi.org/10.1016/j.enbuild.2023.113149.

Canale, L.; Peulicke Slott, B.; Finsdóttir, S.; Kildemoes, L. R.; Andersen, R. K. (2021): Do in-home displays affect end-user consumptions? A mixed method analysis of electricity, heating and water use in Danish apartments. In: Energy and Buildings, 246, p. 111094. https://doi.org/10.1016/j.enbuild.2021.111094.

Carrigan, M.; Attalla, A. (2001): The myth of the ethical consumer – do ethics matter in purchase behaviour? In: Journal of Consumer Marketing, 18 (7), pp. 560–578. https://doi.org/10.1108/07363760110410263.

Chen, S.; Zhang, G.; Xia, X.; Chen, Y.; Setunge, S.; Shi, L. (2021): The impacts of occupant behavior on building energy consumption: A review. In: Sustainable Energy Technologies and Assessments, 45 (March), p. 101212. https://doi.org/10.1016/j.seta.2021.101212.

Cheng, M. (2016): Sharing economy: A review and agenda for future research. In: International Journal of Hospitality Management, 57, pp. 60–70. https://doi.org/10.1016/j.ijhm.2016.06.003.

Cherubini, F. (2010): The biorefinery concept: Using biomass instead of oil for producing energy and chemicals. In: Energy Conversion and Management, 51 (7), pp. 1412–1421. https://doi.org/10.1016/j.enconman.2010.01.015.

CITEO (2021): Eco-modulation 2022 for the eco-design of papers. Available at https://www.citeo.com/leco-modulation-2022-pour-leco-conception-des-papiers/.

Cochran, W. G. (1963): Sampling techniques. 2nd ed. New York: John Wiley and Sons. ISBN: 978-0471162384.

Coelho, T.; Chkoniya, V.; Oliveira Madsen, A.; Figueiredo, C. (2020): Leading the Way to a Sustainable Future. In: Chkoniya, V.; Madsen, A. O.; Buxrašvili, P. (Eds.): Anthropological approaches to understanding consumption patterns and consumer behavior. Hershey PA, USA: IGI Global, pp. 1–21. https://doi.org/10.4018/978-1-7998-3115-0.ch001.

Colantonio, A. (2007): Social Sustainability: An Exploratory Analysis of its Definition, Assessment Methods, Metrics and Tools: Best Practice from Urban Renewal in the EU. In: 2007/01: EIBURS Working Paper Series.

Colantonio, A. (2010): Urban social sustainability themes and assessment methods. In: Proceedings of the Institution of Civil Engineers - Urban Design and Planning, 163 (2), pp. 79–88. https://doi.org/10.1680/udap.2010.163.2.79.

Colantonio, A.; Dixon, T. (2009): Measuring socially sustainable urban regeneration in Europe. Available at https://www.dcu.ie/sites/default/files/community/pdfs/SocialSust.pdf.

Corbos, R.-A.; Bunea, O.-I.; Jiroveanu, D.-C. (2023): The effects of the energy crisis on the energy-saving behavior of young people. In: Energy Strategy Reviews, 49, p. 101184. https://doi.org/10.1016/j.esr.2023.101184.

Corral Naveda, A. N. (2022): Telecommuting as a Sustainable Transportation Measure in Ecuador. In: Enfoque UTE, 13 (1), pp. 23–41. https://doi.org/10.29019/enfoqueute.786.

Costa-Font, J.; Vilaplana-Prieto, C. (2022): Health shocks and housing downsizing: How persistent is 'ageing in place'? In: Journal of Economic Behavior & Organization, 204, pp. 490–508. https://doi.org/10.1016/j.jebo.2022.10.039.

Council of the European Union (2022a): Council Regulation (EU) 2022/1369 of 5 August 2022 on coordinated demand-reduction measures for gas.

Council of the European Union (2022b): Regulation (EU) 2022/2578 establishing a Market Correction Mechanism seeking to protect businesses and households from episodes of excessively high gas prices in the European Union (EU).

Council of the European Union (2024): Infographic - Where does the EU's gas come from? Available at https://www.consilium.europa.eu/en/infographics/eu-gas-supply/.

Creutzig, F.; Niamir, L.; Bai, X.; Callaghan, M.; Cullen, J.; Díaz-José, J. (2022): Demand-side solutions to climate change mitigation consistent with high levels of well-being. In: Nature Climate Change, (12(1)), pp. 36–46.

Creutzig, F.; Roy, J.; Lamb, W. F.; Azevedo, I. M. L.; Bruine de Bruin, W.; Dalkmann, H.; Edelenbosch, O. Y.; Geels, F. W.; Grubler, A.; Hepburn, C.; Hertwich, E. G.; Khosla, R.; Mattauch, L.; Minx, J. C.; Ramakrishnan, A.; Rao, N. D.; Steinberger, J. K.; Tavoni, M.; Ürge-Vorsatz, D.; Weber, E. U. (2018): Towards demand-side solutions for mitigating climate

change. In: Nature Climate Change, 8 (4), pp. 260–263. https://doi.org/10.1038/s41558-018-0121-1.

Cui, M. (2020): Introduction to the K-Means Clustering Algorithm Based on the Elbow Method. In: Geoscience and Remote Sensing, (Vol. 3), pp. 9–16. https://doi.org/10.23977/accaf.2020.010102.

Dalkmann, H.; Brannigan, C. (2007): Transport and Climate Change. Module 5e: Sustainable Transport: A Sourcebook for policy-makers in developing cities. Available at https://changing-transport.org/wp-content/uploads/2007_dalkmann_brannigan_transportandclimatechange.pdf.

Darby, S.; Fawcett, T. (2018): Energy sufficiency – an introduction: A concept paper for ECEEE. Unpublished. https://doi.org/10.13140/RG.2.2.31198.08006.

Day, R.; Hitchings, R. (2009): Older people and their winter warmth behaviours: understanding the contextual dynamics,

Dempsey, N.; Bramley, G.; Power, S.; Brown, C. (2011): The social dimension of sustainable development: Defining urban social sustainability. In: Sustainable Development, 19 (5), pp. 289–300. https://doi.org/10.1002/sd.417.

Dena (2019): Dena-Gebäudereport kompakt 2019 Statistiken. Available at https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/dena-.

Dena (2022): Dena-Umfrage: Bundesbürger ändern wegen steigender Energiekosten ihr Heizverhalten – und wollen Fokus der staatlichen Hilfen auf Bürger mit geringen und mittleren Einkommen. Available at https://www.dena.de/newsroom/meldungen/2022/forsa-umfrage-heizverhalten/, accessed 15.03.2023.

Dervojeda, K.; Verzijl, D.; Nagtegaal, F.; Lengton, M.; Rouwmaat, E.; Monfardini, E.; Frideres, L. (2013): The Sharing Economy: Accessibility Based Business Models for Peer-to-Peer Markets.

Destatis (2013): Zeitverwendung (ZVE) 2012/2013. Available at https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Zeitverwendung/Tabellen/aktivitaeten-alter-zve.html, accessed 09.03.2023.

Destatis (2018): Living floor space of households. Available at https://www.destatis.de/EN/Themes/Society-Environment/Housing/Tables/average-living-floor-space-per-person-germany.html.

Destatis (2021): Bautätigkeit. Available at https://www.destatis.de/DE/Service/Bibliothek/_publikationen-fachserienliste-5.html#651444.

Destatis (2022a): Fachserie 5 - Bauen und Wohnen. Bestand an Wohnungen - Fachserie 5 Reihe 3 - 2021. Available at https://www.destatis.de/DE/Service/Bibliothek/_publikationen-fachserienliste-5.html#651444.

Destatis (2022b): Income, consumption and living conditions. Available at https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Ausstattung-Gebrauchsgueter/_inhalt.html, accessed 15.03.2023.

Destatis (Ed.) (2022c). *Alleinlebende verbrauchen 38 % mehr Wohnenergie als der Pro-Kopf-Durchschnitt aller Haushalte*. Available at https://www.destatis.de/DE/Presse/Pressemitteilungen/Zahl-der-Woche/2022/PD22_09_p002.html.

Destatis (2023): Entwicklung der privaten Haushalte zwischen 1991 und 2040. Available at https://www.destatis.de/DE/Themen/Querschnitt/Demografischer-Wandel/Hintergruende-Auswirkungen/demografie-privathaushalte.html.

Destatis (2024): Zensus 2022: Gebäude und Wohnungszählung. Available at https://www.zensus2022.de/DE/Ergebnisse-des-Zensus/_inhalt.html#Start.

Deutscher Bundestag (Ed.) (2021). *Flächenverbrauch: Bundesrepublik verfehlt 30-Hektar-Ziel.* Available at https://www.bundestag.de/presse/hib/820154-820154.

Devinney, T. M.; Auger, P.; Eckhardt, G. M. (2010): The myth of the ethical consumer. New York [etc.]: Cambridge University Press. ISBN: 978-0-521-76694-4.

Dgb (2018): So groß ist die Wohnungsnot in deutschen Städten wirklich. Available at https://www.dgb.de/themen/++co++1fe76e9a-a204-11e8-8956-52540088cada.

Doyal, L.; Gough, I. (1984): A theory of human needs. In: Critical Social Policy, 4 (10), pp. 6–38. https://doi.org/10.1177/026101838400401002.

DSchG BW (Ed.) (1983): Gesetz zum Schutz der Kulturdenkmale (Denkmalschutzgesetz - DSchG) in der Fassung vom 6. Dezember 1983. DSchG BW. Available at https://www.landesrecht-bw.de/bsbw/document/jlr-DSchGBW1983rahmen.

EEA (2023): Trends and projections in Europe 2023. European Environment Agency. https://doi.org/10.2800/595102.

Eizenberg, E.; Jabareen, Y. (2017): Social Sustainability: A New Conceptual Framework. In: Sustainability, 9 (1), p. 68. https://doi.org/10.3390/su9010068.

Ek, K.; Söderholm, P. (2010): The devil is in the details: Household electricity saving behavior and the role of information. In: Energy Policy, 38 (3), pp. 1578–1587. https://doi.org/10.1016/j.enpol.2009.11.041.

Ellegård, K.; Palm, J. (2011): Visualizing energy consumption activities as a tool for making everyday life more sustainable. In: Applied Energy, 88 (5), pp. 1920–1926. https://doi.org/10.1016/j.apenergy.2010.11.019.

Elliott-Cooper, A.; Hubbard, P.; Lees, L. (2020): Moving beyond Marcuse: Gentrification, displacement and the violence of un-homing. In: Progress in Human Geography, 44 (3), pp. 492–509. https://doi.org/10.1177/0309132519830511.

Ellsworth-Krebs, K. (2020): Implications of declining household sizes and expectations of home comfort for domestic energy demand. In: Nature Energy, 5 (1), pp. 20–25. https://doi.org/10.1038/s41560-019-0512-1.

Enerdata (2023): Gas supply shock: how EU's final consumers adapted? Available at https://www.enerdata.net/publications/reports-presentations/gas-prices-impact-europe.html.

Energimyndigheten (2022): Sänkt elanvändning minskar risken för elstörningar i vinter. Available at https://www.energimyndigheten.se/nyhetsarkiv/2022/sankt-elanvandning-nu-minskar-risken-for-elstorningar-i-vinter/.

Euractiv. (7/12/2022): Poland to extend gas tariff protection for households until end 2027. Available at https://www.euractiv.com/section/energy/news/poland-to-extend-gas-tariff-protection-for-households-until-end-2027/, accessed 21.11.2023.

EurObserv'ER (2010): SOLAR THERMAL BAROMETER. Available at https://www.eurobserv-er.org/pdf/solar-thermal-and-csp-barometer-2010-fr-en/.

EurObserv'ER (2021a): HEAT PUMPS BAROMETER. Available at https://www.eurobserv-er.org/pdf/heat-pumps-barometer-2021/.

EurObserv'ER (2021b): SOLAR THERMAL AND CONCENTRATED SOLAR POWER BAROMETERS. Available at https://www.eurobserv-er.org/pdf/solar-thermal-and-csp-barometer-2021/.

European Commission (2014): COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL European Energy Security Strategy. Available at https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0330.

European Commission (2021a): Communication "Tackling rising energy prices: a toolbox for action and support".

European Commission (Ed.) (2021b): COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, COM/2021/550 final.

European Commission (2022a): Commission proposal to amend the Security of Gas Supply Regulation and a Communication: "Security of supply and affordable energy prices: Options for immediate measures for next winter". Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0138, accessed 15.03.2023.

European Commission (2022b): Commission Staff Working Document "Implementing the REPower EU action plan: Investment needs, hydrogen accelerator and achieving the bio-methane targets" Accompanying the document Communication from the Commission to the European Parliament, The European.

European Commission (2022c): Outline of "REPowerEU": joint EU action for more affordable, secure, and sustainable energy".

European Commission (2023): Megatrend Continuing Urbanisation. Available at https://knowledge4policy.ec.europa.eu/continuing-urbanisation_en.

European Commission (2024): Eurostat Database. Available at https://ec.europa.eu/eurostat/web/main/data/database, accessed 01.03.2024.

European Commission & International Energy Agency (2022): Playing my part. Available at https://iea.blob.core.windows.net/assets/cbc97c70-8bcf-4376-a8a9-4cd875195f6a/Playingmypart.pdf.

European Parliament (2021): Demografischer Ausblick für die Europäische Union. Available at https://www.europarl.europa.eu/RegData/etudes/STUD/2021/690528/EPRS_STU(2021)690528_DE.pdf.

European Union (2015): People in the EU. Who are we and how do we live? Luxembourg: Publications Office of the European Union. ISBN: 9789279503290.

Eurostat (2010): Income and living conditions in Europe. Luxembourg: Europäische Kommission. https://doi.org/10.2785/53320.

Eurostat (2011): Glossary. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Category:Glossary.

Eurostat (2017): Glossary:Household - social statistics. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Household_-_social_statistics#:~:text=A%20household%20includes%20either%20one,a%20living%20or%20sitting%20room., accessed 2023.

Eurostat (2020a): Household composition statistics - Statistics Explained. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php/Household_composition_statistics, accessed 22.04.2020.

Eurostat (2020b): Population structure and ageing - Statistics Explained. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing#Median_age_is_highest_in_Italy, accessed 22.04.2020.

Eurostat (2020c): Population: Structure indicators by NUTS 2 region - Eurostat. Available at https://ec.europa.eu/eurostat/web/products-datasets/product?code=demo_r_pjanind2, accessed 22.04.2020.

Eurostat (2021): House or flat – owning or renting. Available at https://ec.europa.eu/eurostat/cache/digpub/housing/bloc-1a.html.

Eurostat (2022a): Air emissions accounts by NACE Rev. 2 activity. https://doi.org/10.2908/env_ac_ainah_r2.

Eurostat (2022b): Energy consumption in households. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households.

Eurostat (2022c): Energy consumption in households. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households#Energy_products_used_in_the_residential_sector, accessed 23.02.2023.

Eurostat (2022d): Rise in EU population working from home. Available at https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20221108-1.

Eurostat (2023a): Complete energy balances European Union (27 countries) - 2022 - Total - main fuel families. Available at https://ec.europa.eu/eurostat/cache/infographs/energy_balances/enbal.html?geo=EU27_2020&unit=KTOE&language=EN&year=2022&fuel=fuelMainFuel&siec=TOTAL&details=0&chartOptions=0&stacking=normal&chartBal=&chart=&full=0&chartBalText=&order=DESC&siecs=&dataset=nrg_bal_s&decimals=0&agregates=0&fuelList=fuelElectricity,fuelCombustible,fuelNonCombustible,fuelOtherPetroleum,fuelMainPetroleum,fuelOil,fuelOtherFossil,fuelFossil,fuelCoal,fuelMainFuel.

Eurostat (2023b): Cooling and heating degree days by country - annual data. Available at https://ec.europa.eu/eurostat/databrowser/view/nrg_chdd_a/default/table?lang=en&category=nrg.nrg_chdd.

Eurostat (2023c): Disaggregated final energy consumption in households - quantities. Available at https://ec.europa.eu/eurostat/databrowser/view/nrg_d_hhq/default/table?lang=en.

Eurostat (2023d): Distribution of population by degree of urbanisation, dwelling type and income group - EU-SILC survey. Available at https://ec.europa.eu/eurostat/databrowser/view/ILC_LVHO01/default/table?lang=en.

Eurostat (2023e): Distribution of population by tenure status, type of household and income group - EU-SILC survey. Available at https://ec.europa.eu/eurostat/databrowser/view/ILC_LVHO02__custom_137548/bookmark/map.

Eurostat (2023f): Employed persons working from home as a percentage of the total employment, by sex, age and professional status (%). Available at https://ec.europa.eu/eurostat/databrowser/view/lfsa_ehomp/default/table?lang=en.

Eurostat (2023g): Employment - annual statistics. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Employment_-_annual_statistics#Employment_in_2022_compared_with_the_EU_target.

Eurostat (2023h): Employment and activity by sex and age - annual data. Available at https://ec.europa.eu/eurostat/databrowser/view/lfsi_emp_a/default/bar?lang=en.

Eurostat (2023i): Energy consumption in households. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households.

Eurostat (2023j): Estimated average age of young people leaving the parental household by sex. Available at https://ec.europa.eu/eurostat/databrowser/view/yth_demo_030/default/table?lang=en.

Eurostat (2023k): Gas prices for household consumers - bi-annual data (from 2007 onwards). Available at https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_202__custom_4234988/default/table?lang=en, accessed 15.03.2023.

Eurostat (2023l): Household composition statistics. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics#Increasing_number_of_households_composed_of_adults_living_alone, accessed 03.02.2023.

Eurostat (2023m): Inability to keep home adequately warm - EU-SILC survey. https://doi.org/10.2908/ilc_mdes01.

Eurostat (2023n): Inability to keep home adequately warm - EU-SILC survey. Available at https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes01/default/table?lang=en.

Eurostat (2023o): Income and living conditions. Available at https://ec.europa.eu/eurostat/cache/metadata/en/ilc_sieusilc.htm.

Eurostat (2023p): Marriage indicators. Available at https://ec.europa.eu/eurostat/databrowser/view/DEMO_NIND__custom_684975/bookmark/table?lang=en&bookmarkId=c708cdbf-c5c0-434f-af18-2281ac691d98.

Eurostat (2023q): Mean and median income by age and sex - EU-SILC and ECHP surveys. Available at https://ec.europa.eu/eurostat/databrowser/view/ilc_di03/default/table?lang=en.

Eurostat (2023r): Population structure and ageing. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_structure_and_ageing#The_share_of_elderly_people_continues_to_increase.

Eurostat (2023s): Proportion of population aged 65 and over. Available at https://ec.europa.eu/eurostat/databrowser/view/tps00028/default/table?lang=en.

Expertenrat für Klimafragen (2023): Prüfbericht zur Berechnung der deutschen Treibhausgasemissionen für das Jahr 2022. Prüfung und Bewertung der Emissionsdaten gemäß § 12 Abs. 1 Bundes-Klimaschutzgesetz. Available at https://www.expertenrat-klima.de/.

Eyre, N. (2013): Energy saving in energy market reform—The feed-in tariffs option. In: Energy Policy, 52, pp. 190–198. https://doi.org/10.1016/j.enpol.2012.07.042.

Faber, J.; Schroten, A.; Bles, M.; Sevenster, M.; Markowska, A.; Smit, M.; Rohde, C.; Dütschke, E.; Köhler, J.; Gigli, M.; Zimmermann, K.; Soboh, R.; van't Riet, J. (2012): Behavioural climate change mitigation options and their appropriate inclusion in quantitative longer term policy scenarios.,

Federal Climate Change Act (Ed.) (2021): Federal Climate Change Act (Bundes-Klimaschutzgesetz). Available at https://www.gesetze-im-internet.de/englisch_ksg/englisch_ksg.html.

Federal Ministry for Economic Affairs and Climate Action (2022): Bundestag adopts energy price caps – important relief for consumers. Available at https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221215-bundestag-adopts-energy-price-caps-important-relief-for-consumers.html, accessed 15.03.2023.

Feijten, P.; van Ham, M. (2009): Neighbourhood Change… Reason to Leave? In: Urban Studies, 46 (10), pp. 2103–2122. https://doi.org/10.1177/0042098009339430.

Fillies, K. (9/28/2023): „2024 so eine Art Schockstarre“ – Geywitz kassiert das 400.000-Wohnungen-Versprechen. In: WELT. Available at https://www.welt.de/vermischtes/article247703440/Maischberger-Bauministerin-Geywitz-kassiert-das-400-000-Wohnungen-Versprechen.html.

Fischer, C.; Blank, R.; Brohmann, B.; Cludius, J.; Förster, H.; Hayen, D. A.; Keimeyer, F. (2016): Climate change 17/2016. Available at https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/climate_change_17_2016_konzept_zur_absoluten_verminderung_des_energiebedarfs.pdf.

Fischer, C.; Stieß, I. (2019): Living spaces: saving energy by encouraging alternative housing options for senior homeowners. In: : ECEEE SUMMER STUDY PROCEEDINGS, pp. 1355–1364.

Ford, J. D.; Ford, L. W.; D'Amelio, A. (2008): Resistance to Change: The Rest of the Story. In: Academy of Management Review, 33 (2), pp. 362–377. https://doi.org/10.5465/AMR.2008.31193235.

Frades, I.; Matthiesen, R. (2010): Overview on techniques in cluster analysis. In: Methods in molecular biology (Clifton, N.J.), 593, pp. 81–107. https://doi.org/10.1007/978-1-60327-194-3_5.

Freude am Wohnen (2017): Umfrage für Doktorarbeit, p. 5.

Friedrich-Ebert-Stiftung (1997): Politik-Dossier Wohnungspolitik. Available at https://library.fes.de/fulltext/stabsabteilung/00518toc.htm.

Fuhrhop, D. (2015): Verbietet das Bauen! Eine Streitschrift. München: Oekom Verlag. ISBN: 9783865817334.

Gavrilis, P. (11/13/2019): Beratungen auf Bundesparteitag - Grüne bringen Recht auf Wohnungstausch ins Spiel. In: Deutschlandfunk. Available at https://www.deutschlandfunk.de/beratungen-auf-bundesparteitag-gruene-bringen-rechtauf-.

Gere, A. (2023): Recommendations for validating hierarchical clustering in consumer sensory projects. In: Current research in food science, 6, p. 100522. https://doi.org/10.1016/j.crfs.2023.100522.

Ghahramanpouri, A.; Abdullah, A. S.; Sedaghatnia, S.; Lamit, H. (2015): Urban Social Sustainability Contributing Factors in Kuala Lumpur Streets. In: Procedia - Social and Behavioral Sciences, 201, pp. 368–376. https://doi.org/10.1016/j.sbspro.2015.08.188.

Gleeson, J. (2021): An analysis of housing floorspace per person. Available at https://data.london.gov.uk/housing/research-notes/.

Goldsmith, E. B.; Goldsmith, R. E. (2011): Social influence and sustainability in households. In: International Journal of Consumer Studies, 35 (2), pp. 117–121. https://doi.org/10.1111/j.1470-6431.2010.00965.x.

Gough, I. (2015): Climate change and sustainable welfare: the centrality of human needs: Fig. 1. In: Cambridge Journal of Economics, 39 (5), pp. 1191–1214. https://doi.org/10.1093/cje/bev039.

Gough, I. (2020): Defining floors and ceilings: the contribution of human needs theory. In: Sustainability: Science, Practice and Policy, 16 (1), pp. 208–219. https://doi.org/10.1080/15487733.2020.1814033.

Government of British Columbia (2024): How the speculation and vacancy tax works. Available at https://www2.gov.bc.ca/gov/content/taxes/speculation-vacancy-tax/how-tax-works#underused-housing-tax.

Government of the Netherlands (2023): Price cap for gas, electricity and district heating. Available at https://www.government.nl/topics/energy-crisis/cabinet-plans-price-cap-for-gas-and-electricity, accessed 15.03.2023.

Gram-Hanssen, K. (2012): Sustainable Lifestyles. In: : International Encyclopedia of Housing and Home. Elsevier, pp. 117–123. https://doi.org/10.1016/B978-0-08-047163-1.00557-9.

Greden, L. V. (2006): Flexibility in building design : a real options approach and valuation methodology to address risk. Available at https://web.mit.edu/ardent/www/Real_opts_papers/Dissertation_Greden.pdf.

Greenwood, J.; Guner, N.; Vandenbroucke, G. (2017): Family Economics Writ Large. In: Journal of Economic Literature, 55 (4), pp. 1346–1434. https://doi.org/10.1257/jel.20161287.

Groot, E. de; Spiekman, M.; Opstelten, I. (2006): Dutch research into user behaviour in relation to energy use of residences. In: Natural gas, p. 2.

Gudivada, V. (2017): Data Analytics: Fundamentals. In:. ISBN: 978-0-12-809715-1, pp. 31–67.

Guerra-Santin, O.; Itard, L. (2010): Occupants' behaviour: determinants and effects on residential heating consumption. In: Building Research & Information, 38 (3), pp. 318–338. https://doi.org/10.1080/09613211003661074.

Guo, Z.; Zhou, K.; Zhang, C.; Lu, X.; Chen, W.; Yang, S. (2018): Residential electricity consumption behavior: Influencing factors, related theories and intervention strategies. In: Renewable and Sustainable Energy Reviews, 81, pp. 399–412. https://doi.org/10.1016/j.rser.2017.07.046.

Gynther, L. (2021): Energy sufficiency indicators and policies. Available at https://www.odyssee-mure.eu/publications/policy-brief/energy-sufficiency.pdf.

Hagejärd, S.; Dokter, G.; Rahe, U.; Femenías, P. (2021): My apartment is cold! Household perceptions of indoor climate and demand-side management in Sweden. In: Energy Research & Social Science, 73, p. 101948. https://doi.org/10.1016/j.erss.2021.101948.

Hamari, J.; Sjöklint, M.; Ukkonen, A. (2016): The Sharing Economy: Why People Participate in Collaborative Consumption. In: Journal of the Association for Information Science and Technology, 67, pp. 2047–2059. https://doi.org/10.1002/asi.23552.

Hammond, M.; White, S.; Walsh, S. (2018): Rightsizing: reframing the housing offer for older people. Available at https://www.greatermanchester-ca.gov.uk/media/1168/rightsizing_msa_final3.pdf.

Harputlugil, G. U.; Bedir, M. (2016): Effects of occupant behavior on the energy performance of dwellings: a sensitivity analysis. In: Journal of Architectural and Planning Research, 33 (2), pp. 159–178. https://doi.org/10.7480/abe.2017.16.3599.

Hayden, A.; Dasilva, C. (2022): The wellbeing economy: Possibilities and limits in bringing sufficiency from the margins into the mainstream. In: Frontiers in Sustainability, 3, Article No. 966876. https://doi.org/10.3389/frsus.2022.966876.

HBS (2019): Die Wohnsituation in deutschen Großstädten – 77 Stadtprofile. Available at https://www.boeckler.de/pdf_fof/100892.pdf.

Hilgers, M. (2013): Urban social sustainability and socially engaged art practice. Two literature reviews. Available at https://urbandialogues.de/wp-content/uploads/2020/03/9UB_Hilgers_on_urban_social_sustainability.pdf.

Hoeller, P.; Ziemann, V.; Cournède, B.; Bétin, M. (2023): Home, green home: Policies to decarbonise housing. https://doi.org/10.1787/cbda8bad-en.

Højrup, T. (2003): State, culture and life-modes. The foundations of life-mode analysis. Aldershot: Ashgate. ISBN: 0754632083.

Holm, A.; Regnault, V.; Sprengholz, M.; & Stephan, M. (2021): Die Verfestigung sozialer Wohnversorgungsprobleme.

Homonoff, T. A. (2018): Can Small Incentives Have Large Effects? The Impact of Taxes versus Bonuses on Disposable Bag Use. In: American Economic Journal: Economic Policy, 10 (4), pp. 177–210. https://doi.org/10.1257/pol.20150261.

Hossain, M. (2020): Sharing Economy: A Comprehensive Literature Review. In: SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3536188.

Hosseini Raviz, S. R.; Nik Eteghad, A.; Uson Guardiola, E.; Armesto Aira, A. (2015): Flexible Housing: The Role of Spatial Organization in Achieving Functional Efficiency. In: Archnet-IJAR: International Journal of Architectural Research, 9 (2), p. 65. https://doi.org/10.26687/archnet-ijar.v9i2.422.

Hubacek, K.; Guan, D.; Barua, A. (2007): Changing lifestyles and consumption patterns in developing countries: A scenario analysis for China and India. In: Futures, 39 (9), pp. 1084–1096. https://doi.org/10.1016/j.futures.2007.03.010.

Huber, J. (1995): Nachhaltige Entwicklung. Strategien für eine ökologische und soziale Erdpolitik. Berlin: Ed. Sigma. ISBN: 3894044039.

Huebner, G. M.; Shipworth, D. (2017): All about size? – The potential of downsizing in reducing energy demand. In: Applied Energy, 186, pp. 226–233. https://doi.org/10.1016/j.apenergy.2016.02.066.

Hung, H. (2021): Recent Trends in Global Economic Inequality. In: Annual Review of Sociology, 47 (1), pp. 349–367. https://doi.org/10.1146/annurev-soc-090320-105810.

Hunziker, C. (2024): Wie viel Pro-Kopf-Wohnfläche ist angemessen? In: DW, 77 (03/24), pp. 22–26.

Ibem, E.; Adeboye, A.; Alagbe, O. (2015): SIMILARITIES AND DIFFERENCES IN RESIDENTS' PERCEPTION OF HOUSING ADEQUACY AND RESIDENTIAL SATISFACTION. In: Journal of Building Performance, 6, pp. 1–14.

IEA (2019): Global Status Report for Buildings and Construction 2019. Towards a zero-emissions, efficient and resilient buildings and construction sector. Available at https://iea.blob.core.windows.net/assets/3da9daf9-ef75-4a37-b3da-a09224e299dc/2019_Global_Status_Report_for_Buildings_and_Construction.pdf.

IEA (2020): The Netherlands 2020. Energy Policy Review. Available at https://iea.blob.core.windows.net/assets/93f03b36-64a9-4366-9d5f-0261d73d68b3/The_Netherlands_2020_Energy_Policy_Review.pdf.

IEA (2021): Bonus-malus system for passenger cars, light trucks and light buses. Available at https://www.iea.org/policies/2844-bonus-malus-system-for-passenger-cars-light-trucks-and-light-buses.

IEA (2022a): A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas. Available at https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas.

IEA (2022b): Playing my part. How to save money, reduce reliance on Russian energy, support Ukraine and help the planet. Available at https://www.iea.org/reports/playing-my-part.

IEA (2023a): Greece 2023. Energy Policy Review. Available at https://iea.blob.core.windows.net/assets/5dc74a29-c4cb-4cde-97e0-9e218c58c6fd/Greece2023.pdf.

IEA (2023b): Europe's energy crisis: What factors drove the record fall in natural gas demand in 2022? – Analysis - IEA. Available at https://www.iea.org/commentaries/europe-s-energy-crisis-what-factors-drove-the-record-fall-in-natural-gas-demand-in-2022, accessed 22.11.2023.

ifd Allensbach (2022): Essen gehen - Häufigkeit in der Freizeit in Deutschland 2022 | Statista. Available at https://de.statista.com/statistik/daten/studie/171133/umfrage/haeufigkeit-des-ausgehens-zum-essen-in-der-freizeit/?locale=de, accessed 22.03.2023.

ifo Konjunkturumfragen (2022): Homeoffice setzt sich durch – aber nicht überall. Available at https://www.ifo.de/pressemitteilung/2022-12-09/homeoffice-setzt-sich-durch-aber-nicht-ueberall, accessed 21.03.2023.

Information, Directorate for Legal and Administrative (2024): Annual vacant housing tax (VLT) and vacant housing tax (VLT). Available at https://www.service-public.fr/particuliers/vosdroits/F17293?lang=en, accessed 18.03.2024.

IPCC (2022a): Demand, Services and Social Aspects of Mitigation. In: Intergovernmental Panel on Climate Change (Ed.): Climate Change 2022 - Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, pp. 503–612. https://doi.org/10.1017/9781009157926.007.

IPCC (2022b): Summary for Policymakers. In: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 3–48. https://doi.org/10.1017/9781009157926.001.

IPCC (2023): Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. https://doi.org/10.59327/IPCC/AR6-9789291691647.001.

Ishangulyyev, R.; Kim, S.; Lee, S. H. (2019): Understanding Food Loss and Waste-Why Are We Losing and Wasting Food? In: Foods (Basel, Switzerland), 8 (8). https://doi.org/10.3390/foods8080297.

iwd. (2020): Größer wohnen. Available at https://www.iwd.de/artikel/groesser-wohnen-489720/.

Jackson, T. (2005): Live Better by Consuming Less?: Is There a "Double Dividend" in Sustainable Consumption? In: Journal of Industrial Ecology, 9 (1-2), pp. 19–36. https://doi.org/10.1162/1088198054084734.

Jaeger-Erben, M.; Rückert-John, J.; Schäfer, M. (2015): Sustainable consumption through social innovation: a typology of innovations for sustainable consumption practices. In: Journal of Cleaner Production, 108, pp. 784–798. https://doi.org/10.1016/j.jclepro.2015.07.042.

Jin, X. (2017): Low carbon city construction planning for the needs of residents. In: Agro Food Industry Hi-Tech, (28(1)), pp. 2472–2476.

Kalton, G.; Kasprzyk, D. (1986): The treatment of missing survey data. In: Survey Methodology, pp. 1–16.

Kapella, O.; Rille-Pfeiffer, C. (2010): Familien in Europa: Trends und Entwicklungen. Available at https://jugendhilfeportal.de/artikel/familien-in-europa-trends-und-entwicklungen.

Kasirye, F. (2021): An Overview of Mixed and Multi Method Research. https://doi.org/10.31124/advance.14681643.v1.

Kathimerini (2022): Natural gas subsidy set at 90 euros per megawatt hour for households. Available at https://www.ekathimerini.com/economy/1193785/natural-gas-subsidy-set-at-90-euros-per-megawatt-hour-for-households/, accessed 15.03.2023.

Kemper, F.-J. (2008): Residential mobility in East and West Germany: mobility rates, mobility reasons, reurbanization. In: Zeitschrift für Bevölkerungswissenschaft, 33 (3), pp. 293–314. https://doi.org/10.1007/s12523-009-0018-1.

Kenkmann, T.; Cludius, J.; Fischer, C.; Fries, T.; Keimeyer, F.; Schumacher, K.; Brischke, L. (2019): Flächensparend Wohnen. Available at https://www.umweltbundesamt.de/publikationen/flaechensparend-wohnen.

Khanna, T. M.; Baiocchi, G.; Callaghan, M.; Creutzig, F.; Guias, H.; Haddaway, N. R.; Hirth, L.; Javaid, A.; Koch, N.; Laukemper, S.; Löschel, A.; Del Zamora Dominguez, M. M.; 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. In: Nature Energy, 6 (9), pp. 925–932. https://doi.org/10.1038/s41560-021-00866-x.

Khovalyg, D.; Chatterjee, A.; Sellers, A. J.; van Marken Lichtenbelt, W. (2023): Behavioral adaptations to cold environments: A comparative study of active nomadic and modern sedentary lifestyles. In: Building and Environment, 243, p. 110664. https://doi.org/10.1016/j.buildenv.2023.110664.

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. In: Energy Policy, 161, p. 112759. https://doi.org/10.1016/j.enpol.2021.112759.

Koenraadt, B. (7/26/2022): Energieprijzen Nederland veel hoger dan in rest van Europa. In: Energievergelijk.nl. Available at https://www-energievergelijk-nl.translate.goog/nieuws/energieprijzen-nederland-veel-hoger-dan-in-rest-van-europa?_x_tr_sl=pl&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp, accessed 21.11.2023.

Kost, C.; Brandes, J.; Senkpiel, C.; Sterchele, P.; Wrede, D.; Henning, H.-M. (2021): Modeling of Persistence, Non-Acceptance and Sufficiency in Long-Term Energy Scenarios for Germany. In: Energies, 14 (15), p. 4484. https://doi.org/10.3390/en14154484.

Kranzl, L.; Aichinger, E.; Büchele, R.; Forthuber, S.; Hartner, M.; Müller, A.; Toleikyte, A. (2019): Are scenarios of energy demand in the building stock in line with Paris targets? In: Energy Efficiency, 12 (1), pp. 225–243. https://doi.org/10.1007/s12053-018-9701-1.

Kranzl, L.; Fallahnejad, M.; Büchele, R.; Müller, A.; Hummel, M.; Fleiter, T.; Mandel, T.; Bagheri, M.; Deac, G.; Bernath, C.; Miosga, J.; Kiefer, C.; Fragoso, J.; Braungardt, S.; Bürger,

V.; Spasova, D.; Viegand, J.; Naeraa, R.; Forthuber, S. (2022): Renewable space heating under the revised Renewable Energy Directive : ENER/C1/2018-494 : final report. Publications Office of the European Union. https://doi.org/10.2833/525486.

Kravchenko, O.; Leshchenko, M.; Marushchak, D.; Vdovychenko, Y. (2019): Digitalization as a global trend and growth factor of the modern economy. In: CEUR Workshop Proceedings, 2422, pp. 434–443. https://doi.org/10.1051/shsconf/20196507004.

Kurmayer, N. J. (2022): Germany's gas savings are too low, agency chief warns. Available at https://www.euractiv.com/section/energy/news/germanys-gas-savings-are-too-low-agency-chief-warns/.

Landorf, C. (2011): Evaluating social sustainability in historic urban environments. In: International Journal of Heritage Studies, 17 (5), pp. 463–477. https://doi.org/10.1080/13527258.2011.563788.

Larimian, T.; Sadeghi, A. (2021): Measuring urban social sustainability: Scale development and validation. In: Environment and Planning B: Urban Analytics and City Science, 48 (4), pp. 621–637. https://doi.org/10.1177/2399808319882950.

Lee, A.; Sinha, I.; Boyce, T.; Allen, J.; Goldblatt, P. (2022): Fuel poverty, cold homes and health inequalities. Available at https://www.instituteofhealthequity.org/resources-reports/fuel-poverty-cold-homes-and-health-inequalities-in-the-uk/read-the-report.pdf.

Lewin, K. (1947): Frontiers in Group Dynamics. In: Human Relations, 1 (1), pp. 5–41. https://doi.org/10.1177/001872674700100103.

Liebig, S.; Schupp, J.; Goebel, J.; Richter, D.; Schröder, C.; Bartels, C.; Fedorets, A.; Franken, A.; Giesselmann, M.; Grabka, M.; Jacobsen, J.; Kara, S.; Krause, P.; Kröger, H.; Kroh, M.; Metzing, M.; Nebelin, J.; Schacht, D.; Schmelzer, P.; Schmitt, C.; Schnitzlein, D.; Siegers, R.; Wenzig, K.; Zimmermann, S.; Deutsches Institut Für Wirtschaftsforschung (2019): Socio-Economic Panel (SOEP), data for years 1984-2017. https://doi.org/10.5684/SOEP.V34.

Liew, E. (2024): ABSD Singapore Rates (2024): Additional Buyer's Stamp Duty Guide for 2nd Property, PRs and Foreigners. Available at https://www.propertyguru.com.sg/property-guides/additional-buyers-stamp-duty-guide-13034.

Lindén, A.-L.; Carlsson-Kanyama, A.; Eriksson, B. (2006): Efficient and inefficient aspects of residential energy behaviour: What are the policy instruments for change? In: Energy Policy, 34 (14), pp. 1918–1927. https://doi.org/10.1016/j.enpol.2005.01.015.

Littig, B.; Griessler, E. (2005): Social sustainability: a catchword between political pragmatism and social theory. In: International Journal of Sustainable Development, 8 (1/2), Article No. 7375. https://doi.org/10.1504/IJSD.2005.007375.

Liu, C.; Esteve, A. (2021): Living arrangements across households in Europe. In: Schneider, N. F.; Kreyenfeld, M. (Eds.): Research Handbook on the Sociology of the Family. Edward Elgar Publishing. https://doi.org/10.4337/9781788975544.00020.

Loga, T.; Born, R.; Großklos, M.; Bially, M. (2001): Energiebilanz-Toolbox. Arbeitshilfe und Ergänzungen zum Energiepass Heizung, Warmwasser. Darmstadt: IWU. ISBN: 3-932074-52-1.

Loga, T.; Großklos, M.; Knissel, J. (2003): Der Einfluss des Gebäudestandards und des Nutzerverhaltens auf die Heizkosten. Konsequenzen für die verbrauchsabhängige

Abrechnung. Available at https://www.iwu.de/fileadmin/publikationen/energie/neh_ph/2003_IWU_LogaEtAl_Der-Einfluss-des-Geb%C3%A4udestandards-und-des-Nutzerverhaltens-auf-die-Heizkosten.pdf.

Loga, T.; Stein, B. (2022): Use of energy performance certificates for realistic prognoses - A method to calibrate the national calculation procedure by the average actual consumption. In: ECEEE (Ed.): ECEEE SUMMER STUDY PROCEEDINGS, pp. 423–433. Available at https://www.iwu.de/fileadmin/publikationen/energie/2022_eceee_Loga-Stein_Use-of-energy-performance-certificates-for-realistic-prognoses.pdf.

Long, L. H.; Boertlein, C. G.; United States. Bureau of the Census (1976): The Geographical Mobility of Americans: An International Comparison. U.S. Department of Commerce, Bureau of the Census. Available at https://books.google.de/books?id=yj0LB4co6o0C.

Long, L. H.; DeAre, D. (1981): Population redistribution: 1960 to 1980. In: Washington, DC: US Bureau of the Census.

Lorek, S.; Spangenberg, J. H. (2019): Energy sufficiency through social innovation in housing. In: Energy Policy, 126, pp. 287–294. https://doi.org/10.1016/j.enpol.2018.11.026.

Lund, S.; Madgavkar, A.; Manyika, J.; Smit, S.; Ellingrud, K.; Meaney, M.; Robinson, O. (2021): The future of work after COVID-19. Available at https://www.mckinsey.com/featured-insights/future-of-work/the-future-of-work-after-covid-19#/.

Magnusson, M. (2017): The gentle art of Swedish death cleaning. How to free yourself and your family from a lifetime of clutter. Edinburgh: Canongate Books. ISBN: 9781786891082.

Mason, P. L. (2023): Transformations in Family Structure. In: Mason, P. L. (Ed.): The Economics of Structural Racism: Stratification Economics and US Labor Markets. Cambridge: Cambridge University Press, pp. 140–166. https://doi.org/10.1017/9781009290784.008.

Mayrhofer, L.; Müller, A.; Bügelmayer-Blaschek, M.; Malla, A.; Kranzl, L. (2023): Modelling the effect of passive cooling measures on future energy needs for the Austrian building stock. In: Energy and Buildings, 296, p. 113333. https://doi.org/10.1016/j.enbuild.2023.113333.

McDonald, R. I.; Crandall, C. S. (2015): Social norms and social influence. In: Current Opinion in Behavioral Sciences, 3, pp. 147–151. https://doi.org/10.1016/j.cobeha.2015.04.006.

McDonald, S.; Oates, C. J.; Young, C. W.; Hwang, K. (2006): Toward sustainable consumption: Researching voluntary simplifiers. In: Psychology and Marketing, 23 (6), pp. 515–534. https://doi.org/10.1002/mar.20132.

Meadows, D. (1999): Leverage points. In: Places to Intervene in a System, 19.

Mebratu, D. (1998): Sustainability and sustainable development. In: Environmental Impact Assessment Review, 18 (6), pp. 493–520. https://doi.org/10.1016/S0195-9255(98)00019-5.

Menyhért, B. (2022): The effect of rising energy and consumer prices on household finances, poverty and social exclusion in the EU. https://doi.org/10.2760/418422.

Merriam-Webster (2023): Household. Available at https://www.merriam-webster.com/dictionary/household, accessed 09.11.2023.

MindTake (2018): Österreich - Häufigkeit des Wäschewaschens 2018 | Statista. Available at https://de.statista.com/statistik/daten/studie/946448/umfrage/umfrage-zur-haeufigkeit-des-waeschewaschens-in-oesterreich/?locale=de, accessed 14.03.2023.

Mukherjee, S.; Narang, D. (2023): Digital Economy and Work-from-Home: The Rise of Home Offices Amidst the COVID-19 Outbreak in India. In: Journal of the Knowledge Economy, 14 (2), pp. 924–945. https://doi.org/10.1007/s13132-022-00896-0.

Müller, A. (2015): Energy demand assessment for space conditioning and domestic hot water : a case study for the Austrian building stock, TU Wien (Ed.).

Newman, D. K.; Day, D. (1975): The American energy consumer. Cambridge, Mass.: Ballinger. ISBN: 0884103390.

Newmark, N. L.; Thompson, P. J. (1977): Self, Space, and Shelter: An Introduction to Housing. Canfield Press. Available at https://books.google.de/books?id=YRdiQgAACAAJ.

Nezlek, J. B. (2012): Multilevel Modeling and Cross-Cultural Research. In: Matsumoto, D.; van de Vijver, F. J. R. (Eds.): Cross-Cultural Research Methods in Psychology. Cambridge University Press, pp. 299–345. https://doi.org/10.1017/CBO9780511779381.015.

O'Brien, W.; Yazdani Aliabadi, F. (2020): Does telecommuting save energy? A critical review of quantitative studies and their research methods. In: Energy and Buildings, 225, p. 110298. https://doi.org/10.1016/j.enbuild.2020.110298.

ODPM (2005): Sustainable Communities. People, Places and Prosperity. A Five Year Plan from the Office of the Deputy Prime Minister. Available at https://www.bipsolutions.com/docstore/pdf/9450.pdf.

Odyssee-Mure (2020): Household energy consumption by energy in the EU. Available at https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/energy-consumption-eu.html, accessed 15.03.2023.

Odyssee-Mure (2023a): Odyssee database. Available at https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html.

Odyssee-Mure (2023b): Sectoral profiles - households. Available at https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/heating-consumption-per-m2.html.

OECD (2021): Brick by Brick. https://doi.org/10.1787/b453b043-en.

OECD (2022): Housing Taxation in OECD Countries. OECD. https://doi.org/10.1787/03dfe007-en.

OECD (2023): Confronting the energy crisis: changing behaviours to reduce energy consumption. Available at https://www.oecd-ilibrary.org/docserver/5664e8a9-en.pdf?expires=1700665516&id=id&accname=ocid49022016&checksum=9E421A836FF3FDC045EB3E2710C584DE.

OECD Time Use Database (2016): OECD Time Use 2009-2016. Available at https://stats.oecd.org/Index.aspx?DataSetCode=TIME_USE, accessed 09.03.2023.

Ohler, A.; Loomis, D. G.; Marquis, Y. (2022): The Household Appliance Stock, Income, and Electricity Demand Elasticity. In: The Energy Journal, 43 (1), pp. 241–262. https://doi.org/10.5547/01956574.43.1.aohl.

Oliveira, G. M.; Vidal, D. G.; Ferraz, M. P. (2020): Urban Lifestyles and Consumption Patterns. In: Leal Filho, W.; Marisa Azul, A.; Brandli, L.; Gökçin Özuyar, P.; Wall, T. (Eds.): Sustainable Cities and Communities. Cham: Springer International Publishing, pp. 851–860. https://doi.org/10.1007/978-3-319-95717-3_54.

Oreg, S.; Bayazit, M.; Vakola, M.; Arciniega, L.; Armenakis, A.; Barkauskiene, R.; Bozionelos, N.; Fujimoto, Y.; González, L.; Han, J.; Hrebícková, M.; Jimmieson, N.; Kordacová, J.; Mitsuhashi, H.; Mlacic, B.; Feric, I.; Topic, M. K.; Ohly, S.; Saksvik, P. O.; Hetland, H.; Saksvik, I.; van Dam, K. (2008): Dispositional resistance to change: measurement equivalence and the link to personal values across 17 nations. In: The Journal of applied psychology, 93 (4), pp. 935–944. https://doi.org/10.1037/0021-9010.93.4.935.

Ott, L.; Weber, S. (2022): How effective is carbon taxation on residential heating demand? A household-level analysis. In: Energy Policy, 160, p. 112698. https://doi.org/10.1016/j.enpol.2021.112698.

Özinal, D.; Erman, O. (2021): Housing flexibility in terms of changes, opportunities, and sustainability of goals and values. In: Journal of Design for Resilience in Architecture and Planning, 2 (2), pp. 187–205. https://doi.org/10.47818/DRArch.2021.v2i2019.

Packard, V. O. (1972): A nation of strangers. Richmond Hill, Ont.: Simon & Schuster of Canada. ISBN: 0671786628.

Panda, S.; Chakraborty, M.; Misra, S. K. (2016): Assessment of social sustainable development in urban India by a composite index. In: International Journal of Sustainable Built Environment, 5 (2), pp. 435–450. https://doi.org/10.1016/j.ijsbe.2016.08.001.

Pauliuk, S.; Sjöstrand, K.; Müller, D. B. (2013): Transforming the Norwegian Dwelling Stock to Reach the 2 Degrees Celsius Climate Target. In: Journal of Industrial Ecology, 17 (4), pp. 542–554. https://doi.org/10.1111/j.1530-9290.2012.00571.x.

Pérez-Sánchez, L. À.; Velasco-Fernández, R.; Giampietro, M. (2022): Factors and actions for the sustainability of the residential sector. The nexus of energy, materials, space, and time use. In: Renewable and Sustainable Energy Reviews, 161, p. 112388. https://doi.org/10.1016/j.rser.2022.112388.

Pike, G. R. (2008): Using Weighting Adjustments to Compensate for Survey Nonresponse. In: Research in Higher Education, 49 (2), pp. 153–171. https://doi.org/10.1007/s11162-007-9069-0.

Priest, J.; Carter, S.; Statt, D. A. (2013): Consumer Behaviour. Available at https://ebs.online.hw.ac.uk/EBS/media/EBS/PDFs/Consumer-Behaviour-Course-Taster.pdf.

Princen, T. (2005): The Logic of Sufficiency. Massachusetts Institute of Technology. ISBN: 9780262661904.

ProPotsdam (2023): Was ist der Wohnflächenbonus? Available at https://www.propotsdam-hilft.de/was-ist-der-wohnflaechenbonus/, accessed 01.04.2024.

Prothero, A.; Dobscha, S.; Freund, J.; Kilbourne, W. E.; Luchs, M. G. (2011): Sustainable consumption: Opportunities for consumer research and public policy. In: Journal of Public Policy and Marketing, (30 (1)), pp. 31–38.

pwc (2015): Sharing or paring?: Growth of the sharing economy.

Rädiker, S.; Kuckartz, U. (2020): Focused analysis of qualitative interviews with MAXQDA. Step by step. Berlin: MAXQDA Press. ISBN: 978-3-948768-03-4.

Rasyid, L. A.; Andayani, S. (2018): Review on Clustering Algorithms Based on Data Type: Towards the Method for Data Combined of Numeric-Fuzzy Linguistics. In: Journal of Physics: Conference Series, 1097, p. 12082. https://doi.org/10.1088/1742-6596/1097/1/012082.

Redclift, M. (2005): Sustainable development (1987-2005): an oxymoron comes of age. In: Sustainable Development, 13 (4), pp. 212–227. https://doi.org/10.1002/sd.281.

Reusswig, F.; Lotze-Campen, H.; Gerlinger, K. (2003): Changing Global Lifestyle and Consumption Patterns: The Case of Energy and Food. Available at https://www.populationenvironmentresearch.org/pern_files/papers/Lotze-Campen_Reusswig_Paper.pdf.

Rohde, C.; Dütschke, E.; Gigli, M.; Bles, M. (2012): Behavioural climate change mitigation options. Domain Report housing. Available at https://publica.fraunhofer.de/handle/publica/296066.

Rotmans, J.; van Asselt, M. B. (2000): Towards an integrated approach for sustainable city planning. In: Journal of Multi-Criteria Decision Analysis, 9 (1-3), pp. 110–124. https://doi.org/10.1002/1099-1360(200001/05)9:1/3%3C110::AID-MCDA270%3E3.0.CO;2-F.

Rukmana, D. (2014): Quota Sampling. In: Michalos, A. C. (Ed.): Encyclopedia of Quality of Life and Well-Being Research. Dordrecht: Springer Netherlands, pp. 5382–5384. https://doi.org/10.1007/978-94-007-0753-5_2393.

Sach, T.; Beyschlag, L.; Bruhin, A.; Kerres, P.; Lotz, B.; Oppermann, L. (2021): Klimaschutz in Zahlen. Available at https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutz_zahlen_20.

Said, M.; Tahlyan, D.; Stathopoulos, A.; Mahmassani, H.; Walker, J.; Shaheen, S. (2023): In-person, pick up or delivery? Evolving patterns of household spending behavior through the early reopening phase of the COVID-19 pandemic. In: Travel behaviour & society, 31, pp. 295–311. https://doi.org/10.1016/j.tbs.2023.01.003.

SALAMA, A. M. (2011): Trans-Disciplinary Knowledge for Affordable Housing. In: Open House International, 36 (3), pp. 7–15. https://doi.org/10.1108/OHI-03-2011-B0002.

Saleem, S. B.; Ali, Y. (2019): Effect of lifestyle changes and consumption patterns on environmental impact: a comparison study of Pakistan and China. In: Chinese Journal of Population Resources and Environment, 17 (2), pp. 113–122. https://doi.org/10.1080/10042857.2019.1574454.

Samadi, S.; Gröne, M.-C.; Schneidewind, U.; Luhmann, H.-J.; Venjakob, J.; Best, B. (2017): Sufficiency in energy scenario studies: Taking the potential benefits of lifestyle changes into account. In: Technological Forecasting and Social Change, 124, pp. 126–134. https://doi.org/10.1016/j.techfore.2016.09.013.

Savills (2019): Das sind die größten Wohnungseigentümer in Deutschland. Available at https://www.savills.de/research_articles/260049/291330-0.

Schmidt III, R.; Austin, S. (2016): Adaptable Architecture. Routledge. https://doi.org/10.4324/9781315722931.

Schneider, W.; Stahl, K.; Struyk, R. J. (2013): Residential Mobility in the United States and the Federal Republic of Germany. In: Stahl, K.; Struyk, R. J. (Eds.): U.S. and West German Housing Markets. Comparative Economic Analyses. Berlin: Springer Berlin, pp. 23–54. https://doi.org/10.1007/978-3-662-10649-5_2.

Schneidewind, U.; Zahrnt, A. (2013): Damit gutes Leben einfacher wird : Perspektiven einer Suffizienzpolitik. München: Oekom-Verl. Available at http://d-nb.info/1034600281/04 ; http://www.oekom.de/nc/buecher/gesamtprogramm/buch/damit-gutes-leben-einfacher-wird.html.

Seabold, S.; Perktold, J. (2010): Statsmodels: Econometric and Statistical Modeling with Python. In: Proceedings of the 9th Python in Science Conference (Python in Science Conference), June 28 - July 3 2010, Austin, Texas, pp. 92–96. https://doi.org/10.25080/Majora-92bf1922-011.

Sejm of the Republic of Poland (2022): Act of December 15, 2022 on special protection of certain consumers of gaseous fuels in 2023 due to the situation on the gas market. (Ustawa z dnia 15 grudnia 2022 r. o szczególnej ochronie niektórych odbiorców paliw gazowych w 2023 r. w związku z sytuacją na rynku gazu) (Dz.U. 2022, poz. 2687). Available at https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20220002687/T/D20222687L.pdf.

Sen, A. (1988): Freedom of Choice: Concept and Content. In: European Economic Review, 32.

Sen, A. (1999): Development as freedom. In: International Journal of Epidemiology, 30 (4), pp. 907–908. https://doi.org/10.1093/ije/30.4.907-a.

Sennett, R. (1999): The corrosion of character. The personal consequences of work in the new capitalism. New York: W.W. Norton. ISBN: 0393319873.

Shamas, u. D.; Sadaf, F. (2023): European Energy Crises, Climate Action and Emerging Market of Carbon-Neutral LNG. In: Journal of European Studies (JES), 39 (1), p. 33. https://doi.org/10.56384/jes.v39i1.287.

Silburn, R. (1999): Neighbourhood images in Nottingham. Social cohesion and neighbourhood change. York: YPS. ISBN: 1902633318.

Sirgy, M. J. (2002): The psychology of quality of life. Dordrecht: Kluwer Academic Publishers. https://doi.org/10.1007/978-94-007-4405-9.

Smelser, N. J.; Swedberg, R. (2005): The handbook of economic sociology. Princeton, N.J.: Russell Sage Foundation. ISBN: 9780691121260.

Sociology (2019): Family Structure - Sociology of Family - iResearchNet. Available at https://sociology.iresearchnet.com/sociology-of-family/family-structure/, accessed 09.11.2023.

Sorge, P. (2023): Germany Saved Too Little Gas in Recent Weeks, Regulator Warns. Available at https://www.bnnbloomberg.ca/germany-saved-too-little-gas-in-recent-weeks-regulator-warns-1.1878864.

Sovacool, B. K.; Demski, C.; Noel, L. (2021): Beyond climate, culture and comfort in European preferences for low-carbon heat. In: Global Environmental Change, 66, p. 102200. https://doi.org/10.1016/j.gloenvcha.2020.102200.

Spangenberg, J.; Omann, I. (2006): Assessing social sustainability: Social sustainability and its multicriteria assessment in a sustainability scenario for Germany. In: Int. J. Innovation & Sustainable Development, 1, pp. 318–348. https://doi.org/10.1504/IJISD.2006.013734.

SRU (2024): Suffizienz als „Strategie des Genug“: Eine Einladung zur Diskussion. Available at https://www.umweltrat.de/SharedDocs/Downloads/DE/04_Stellungnahmen/2020_2024/2024_03_Suffizienz.pdf?__blob=publicationFile&v=11).

Stadt Frankfurt am Main (2024): Umzugsprämie. Available at https://frankfurt.de/themen/planen-bauen-und-wohnen/wohnen/vermittlung-von-gefoerderten-wohnungen-und-fehlbelegungsabgabe/wohnungssuche---wohnungsvermittlung/umzugspraemie, accessed 01.04.2024.

Stadt Zürich (2024): Mietbedingungen für städtische Wohnungen - Stadt Zürich. Available at https://www.stadt-zuerich.ch/fd/de/index/wohnen-und-gewerbe/vermietungen/mietbedingungen.html, accessed 17.03.2024.

statista (2021): Raumwärme - Verteilung der Energieträger in deutschen Haushalten 2019. Available at https://de.statista.com/statistik/daten/studie/250403/umfrage/raumwaermebereitstellun.

statista (2022): Hungary: daily time spent in home office 2021 | Statista. Available at https://www.statista.com/statistics/1246273/hungary-daily-time-spent-in-home-office/, accessed 21.03.2023.

Statista Global Consumer Survey (2022): Statista Global Consumer Survey, 2022. Household appliances in Europe. Available at https://www.statista.com/topics/7043/household-appliances-in-europe/#topicOverview.

Stazi, F.; Naspi, F.; D'Orazio, M. (2017): A literature review on driving factors and contextual events influencing occupants' behaviours in buildings. In: Building and Environment, 118, pp. 40–66. https://doi.org/10.1016/j.buildenv.2017.03.021.

Stefan, V.; van Herpen, E.; Tudoran, A. A.; Lähteenmäki, L. (2013): Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. In: Food Quality and Preference, 28 (1), pp. 375–381. https://doi.org/10.1016/j.foodqual.2012.11.001.

Stewart, C. T. (2006): Gross national accumulation. In: Business Horizons, 49 (2), pp. 105–113. https://doi.org/10.1016/j.bushor.2005.06.008.

Tado (2023): 80 % der deutschen Haushalte haben im Winter 2022 die Heizung heruntergedreht. Available at https://www.tado.com/de-de/pressemitteilungen/Heating_Winter_2022, accessed 06.02.2023.

Tauschwohnung (2024): Wohnungstausch in Düsseldorf. Available at https://www.wohnungstauschduesseldorf.de/.

Thomas, P. (2019): Are Britain’s Houses Getting Smaller? (New Data). Available at https://www.labcwarranty.co.uk/news-blog/are-britain-s-houses-getting-smaller-new-data, accessed 02.03.2023.

Thomas, S.; Thema, J.; Brischke, L.-A.; Leuser, L.; Kopatz, M.; Spitzner, M. (2019): Energy sufficiency policy for residential electricity use and per-capita dwelling size. In: Energy Efficiency, 12 (5), pp. 1123–1149. https://doi.org/10.1007/s12053-018-9727-4.

TNS Nipo (2022): Netherlands: share of households with a bathtub 2007-2016 | Statista. Available at https://www.statista.com/statistics/786177/share-of-households-with-a-bathtub-in-the-netherlands/, accessed 14.03.2023.

Toffler, A. (1970): Future shock. London: The Bodley Head. ISBN: 0370013018.

Tröger, J.; Toulouse, E.; Alexander-Haw, A.; Dütschke, E.; Marignac, Y.; Preuß, S.; Toledano, A. (2022): Refinement of research design. FULFILL Deliverable D 2.3. Available at https://fulfill-sufficiency.eu/wp-content/uploads/2022/08/FULFILL_Research_Design_202208_submitted.pdf.

Tübingen Universitätsstadt (2019): Haben Sie noch Platz? Available at https://www.tuebingen.de/29884.html#/31049.

TUMI (2020): COVID-19 and Sustainable Mobility. Observations and documentation of frst developments. Available at https://www.transformative-mobility.org/wp-content/uploads/2023/03/2020_05_TUMI_COVID-19-and-Sustainable-Mobility-sMtB7P.pdf.

Turčínek, P.; Stastny, J.; Motycka, A. (2012): Usage of cluster analysis in consumer behavior research. In: Advances in Applied Information Science, pp. 172–177.

UBA (2022): Richtiges Heizen schützt das Klima und den Geldbeutel. Available at https://www.umweltbundesamt.de/umwelttipps-fuer-den-alltag/heizen-bauen/heizen-raumtemperatur#unsere-tipps.

UK Government (2013): Local authorities and advisers: removal of the spare room subsidy. Available at https://www.gov.uk/government/collections/local-authorities-removal-of-the-spare-room-subsidy.

Umweltbundesamt (Ed.) (2020). *Treibhausgasemissionen sinken 2020 um 8,7 Prozent.* Available at https://www.umweltbundesamt.de/presse/pressemitteilungen/treibhausgasemissionensinken-.

Umweltbundesamt (2023a): Bevölkerungsentwicklung und Struktur privater Haushalte. Available at https://www.umweltbundesamt.de/daten/private-haushalte-konsum/strukturdaten-privater-haushalte/bevoelkerungsentwicklung-struktur-privater#843-millionen-menschen.

Umweltbundesamt (2023b): Wohnfläche. Available at https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/wohnflaeche#zahl-der-wohnungen-gestiegen.

Umweltbundesamt (2024a): Bodenversiegelung. Available at https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/boden/bodenversiegelung#was-ist-bodenversiegelung.

Umweltbundesamt (2024b): Siedlungs- und Verkehrsfläche. Available at https://www.umweltbundesamt.de/daten/flaeche-boden-land-oekosysteme/flaeche/siedlungs-verkehrsflaeche#anhaltender-flachenverbrauch-fur-siedlungs-und-verkehrszwecke-.

United Nations (2015): General Assembly Resolution A/RES/70/1. Transforming Our World, the 2030 Agenda for Sustainable Development. Transforming Our World, the 2030 Agenda

for Sustainable Development. Available at https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E, accessed 22.04.2020.

United Nations (2018): World Urbanization Prospects: The 2018 Revision.

United Nations, Human Rights Council (2022): Towards a just transformation: climate crisis and the right to housing. Report of the Special Rapporteur on adequate housing as a component of the right to an adequate standard of living, and on the right to nondiscrimination in this context, Balakrishnan Rajagopal. A/HRC/52/28 (23 December 2022). Available at undocs.org/A/HRC/52/28.

Unwin, A. (2010): Exploratory Data Analysis. In: : International Encyclopedia of Education. Elsevier, pp. 156–161. https://doi.org/10.1016/B978-0-08-044894-7.01327-0.

Unwin, R. (2014): Nothing gained by overcrowding. With an introduction by Dr Mervyn Miller. London: Routledge. ISBN: 9780415644983.

Vallance, S.; Perkins, H. C.; Dixon, J. E. (2011): What is social sustainability? A clarification of concepts. In: Geoforum, 42 (3), pp. 342–348. https://doi.org/10.1016/j.geoforum.2011.01.002.

van den Broek, K. L.; Walker, I.; Klöckner, C. A. (2019): Drivers of energy saving behaviour: The relative influence of intentional, normative, situational and habitual processes. In: Energy Policy, 132, pp. 811–819. https://doi.org/10.1016/j.enpol.2019.06.048.

van Dender, K.; Elgouacem, A.; Garsous, G.; Belgroun, H.; Mateo, M.; Prentice, A. C. (2022): Why governments should target support amidst high energy prices. OECD.

van Kessel, R.; Kyriopoulos, I.; Wong, B. L. H.; Mossialos, E. (2023): The Effect of the COVID-19 Pandemic on Digital Health-Seeking Behavior: Big Data Interrupted Time-Series Analysis of Google Trends. In: Journal of medical Internet research, 25, e42401. https://doi.org/10.2196/42401.

Veljkovic, A.; Pohoryles, D. A.; Bournas, D. A. (2023): Heating energy demand estimation of the EU building stock: Combining building physics and artificial neural networks. In: Energy and Buildings, 298, p. 113474. https://doi.org/10.1016/j.enbuild.2023.113474.

Vita, G.; Hertwich, E. G.; Stadler, K.; Wood, R. (2019a): Connecting global emissions to fundamental human needs and their satisfaction. In: Environmental Research Letters, 14 (1), p. 14002. https://doi.org/10.1088/1748-9326/aae6e0.

Vita, G.; Lundström, J. R.; Hertwich, E. G.; Quist, J.; Ivanova, D.; Stadler, K.; Wood, R. (2019b): The Environmental Impact of Green Consumption and Sufficiency Lifestyles Scenarios in Europe: Connecting Local Sustainability Visions to Global Consequences. In: Ecological Economics, 164, p. 106322. https://doi.org/10.1016/j.ecolecon.2019.05.002.

Walters, G. D. (2006): Lifestyle theory. Past, present, and future. New York: Nova Science.

WCED (1987): Report of the World Commission on Environment and Development: our common future. Available at http://digitallibrary.un.org/record/139811.

Węgrzyn, J.; Kania, K. (2024): Heterogeneous preferences for sustainable housing: evidence from Poland. In: Journal of Housing and the Built Environment. https://doi.org/10.1007/s10901-023-10101-6.

Wei, S.; Jones, R.; Wilde, P. de (2014): Driving factors for occupant-controlled space heating in residential buildings. In: Energy and Buildings, 70, pp. 36–44. https://doi.org/10.1016/j.enbuild.2013.11.001.

Weingaertner, C.; Moberg, Å. (2014): Exploring Social Sustainability: Learning from Perspectives on Urban Development and Companies and Products. In: Sustainable Development, 22 (2), pp. 122–133. https://doi.org/10.1002/sd.536.

Westin, S. (2021): Un-homing with words: economic discourse and displacement as alienation. In: cultural geographies, 28 (2), pp. 239–254. https://doi.org/10.1177/1474474020970251.

Wilhite, H.; Nakagami, H.; Masuda, T.; Yamaga, Y.; Haneda, H. (1996): A cross-cultural analysis of household energy use behaviour in Japan and Norway. In: Energy Policy, 24 (9), pp. 795–803. https://doi.org/10.1016/0301-4215(96)00061-4.

Wilkinson, T. M. (2013): Nudging and Manipulation. In: Political Studies, 61 (2), pp. 341–355. https://doi.org/10.1111/j.1467-9248.2012.00974.x.

Williams, K. (2009): Space per person in the UK: A review of densities, trends, experiences and optimum levels. In: Land Use Policy, 26, S83-S92. https://doi.org/10.1016/j.landusepol.2009.08.024.

Wirtz, R.-W. (2013): Beitrag gemeinnütziger Wohnbaugenossenschaften zur Steigerung ihres Marktanteils am Mietwohnungsbestand in der Stadt Zürich. Available at https://www.curem.uzh.ch/static/abschlussarbeiten/2013/Wirtz_RolfWerner_MT_2013.pdf.

World Bank (2022): Europäische Union: Urbanisierungsgrad in den Mitgliedstaaten im Jahr 2021. Available at https://de.statista.com/statistik/daten/studie/249029/umfrage/urbanisierung-in-den-eu-laendern/.

World Health Organization (2018): WHO housing and health guidelines. [Geneva, Switzerland]: World Health Organization. Available at https://www.ncbi.nlm.nih.gov/books/NBK535293/.

Wronski, I. (2023): Wellbeing through sufficiency. Available at https://www.eceee.org/all-news/columns/wellbeing-through-sufficiency/.

Wulff, M.; Healy, E.; Reynolds, M. (2004): Why don't small households live in small dwellings? Disentangling a planning dilemma. In: People and Place, 12.

Xie, L.; Yan, H.; Zhang, S.; Wei, C. (2020): Does urbanization increase residential energy use? Evidence from the Chinese residential energy consumption survey 2012. In: China Economic Review, 59, p. 101374. https://doi.org/10.1016/j.chieco.2019.101374.

Yadav, J.; Sharma, M. (2013): A Review of K-mean Algorithm. In: International Journal of Engineering Trends and Technology, 4 (7), pp. 2972–2976.

Yiftachel, O.; Hedgcock, D. (1993): Urban social sustainability. In: Cities, 10 (2), pp. 139–157. https://doi.org/10.1016/0264-2751(93)90045-K.

Yong, W. T. L.; Thien, V. Y.; Rupert, R.; Rodrigues, K. F. (2022): Seaweed: A potential climate change solution. In: Renewable and Sustainable Energy Reviews, 159, p. 112222. https://doi.org/10.1016/j.rser.2022.112222.

Yougov (2021): Wie oft duschen Sie ungefähr in der Woche? Available at https://yougov.de/topics/society/survey-results/daily/2021/11/07/118a4/2, accessed 14.03.2023.

Zangheri, P.; Armani, R.; Pietrobon, M.; Pagliano, L.; Boneta, M.; Müller, A.; Kockat, J.; Rohde, C. (2014): Heating and cooling energy demand and loads for building types in different countries of the EU. Available at https://api.semanticscholar.org/CorpusID:158045588.

Zangheri, P.; Serrenho, T.; Bertoldi, P. (2019): Energy Savings from Feedback Systems: A Meta-Studies' Review. In: Energies, 12 (19), p. 3788. https://doi.org/10.3390/en12193788.

Zell-Ziegler, C.; Best, B.; Thema, J.; Wiese, F.; Vogel, B.; Cordroch, L. (2022): European Sufficiency Policy Database [Data set]. Available at https://energysufficiency.de/policy-database/.

Zell-Ziegler, C.; Förster, H. (2018): Mit Suffizienz mehr Klimaschutz modellieren.

Zell-Ziegler, C.; Thema, J.; Best, B.; Wiese, F. (2021a): Sufficiency in transport policy : an analysis of EU countries' national energy and climate plans and long-term strategies. In: A new reality : ECEEE 2021 Summer Study ; 7-11 June 2021, digital event ; proceedings. Stockholm, pp. 723–730. Available at https://nbn-resolving.org/urn:nbn:de:bsz:wup4-opus-78495.

Zell-Ziegler, C.; Thema, J.; Best, B.; Wiese, F.; Lage, J.; Schmidt, A.; …; Stagl, S. (2021b): Enough? The role of sufficiency in European energy and climate plans. In: Energy Policy, (157), p. 112483.

Zhong, X.; Hu, M.; Deetman, S.; Steubing, B.; Lin, H. X.; Hernandez, G. A.; Harpprecht, C.; Zhang, C.; Tukker, A.; Behrens, P. (2021): Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060. In: Nature communications, 12 (1), p. 6126. https://doi.org/10.1038/s41467-021-26212-z.

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. In: Journal of Cleaner Production, 201, pp. 169–177. https://doi.org/10.1016/j.jclepro.2018.08.027.