CSI ON ENERGY COMMUNITIES IN GERMANY

RESEARCH REPORT: ACTIVITIES AND RESULTS

Step Change

wecf
Women Engage for a Common Future

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006386

CSI on energy communities in Germany

D4.3 Research Report: Activities and Results

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Deliverable description.

Detailed description of the research activities and results

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Index.

Summary

The research within the Citizen Science Initiative on energy communities in Germany focused on an inclusive research approach by involving multiple actors such as citizen scientists, scientists, policymakers, and the private sector. The main objective was to jointly explore the barriers and drivers for and motivations to participate in the *tenant electricity model* in Germany, and to identify behavioural changes (based on the *energy culture* concept) of the citizen scientists by being involved in local electricity production and consumption.

The research allowed us to identify **barriers** for the *tenant electricity model* encompassing both structural and inherent challenges. Structural barriers include a lack of (former) political will to promote the model, resulting in the complexity of the model, and low economic incentives to implement the model on a broader scale. In addition to these structural barriers, inherent barriers to the model include a lack of *information* about the model at all levels and a lack of *initiators* who are able to drive the implementation of the model at the local level. **Drivers** for scaling up the model include the reduction of the complexity and bureaucratic hurdles of the model[1] as well as regulations (e.g., mandatory PV for new buildings) and financial incentives to foster the expansion of tenant electricity. Targeted information for residents should be provided by local authorities as well as energy supply actors, while residents can use a bottom-up approach by promoting tenant electricity at owner´s assemblies.

The main motivation for participating in tenant electricity was sustainability and local production of electricity, while the price of electricity played only a minor role. However, for almost a fifth of the participants availability and promotion of the model in the house was the main reason to participate. This means that a certain proportion of tenants can be mobilized without having sustainability as a major concern or being sensitive to low prices.

Changes in energy culture were examined from *participation in tenant electricity* projects, receiving *feedback on regular consumption data*, and through *the participation in this Citizen Science Initiative.* Overall, results show *tenant electricity* has led to a stronger exchange among

[1] The federal cabinet approved the "Solarpaket" on 16th of August 2023 with improvements on tenant electricity model and introduction of community supply within multi-family buildings. Source: https://www.bundesregierung.de/breg-de/aktuelles/solarpaket-2213726, accessed August 24, 2023

neighbours about further sustainability options in the building and to a higher interest in sustainability or engagement in society. F*eedback on regular consumption data* was perceived by almost all participants as useful for further measures to save electricity. Energy data collected from installed intelligent meters showed, on average, a reduction in electricity consumption for more than half of the households compared to the start month of the research period. *Participation in the Step Change project* prompted about half of the citizen scientists to start tracking their electricity consumption regularly, and around 40% reported improved energy behaviour. Around a third of participants became more aware of energy efficient devices and around one quarter made changes related to energy-intensive activities (e.g., mobility, reducing flights).

A detailed cluster analysis has been conducted to find different profiles and gain a deeper understanding of the characteristics of the citizen scientists. In total 5 clusters were identified, with differences in energy consumption patterns, energy efficient appliances, knowledge about energy consumption, and changes in energy practices due to participation in tenant electricity and the research project.

1 Introduction

The EU-funded Step Change Project has implemented five research initiatives, called *Citizen Science Initiatives* (CSIs), in the fields of health, energy, and environment. Overall, the Step Change project builds on the assumption that citizen science can play an important future role by adding value to science and changing the way society views research. The overall objective of the project is to explore the potential of citizen science in the above-mentioned areas and formulate recommendations for better integrating this approach within R&I processes and institutions. The CSI on energy communities in Germany focuses on the under-exploited potential of photovoltaic systems on multi-family buildings, mainly implemented through the so-called *tenant electricity model*. As multi-family buildings accommodate around half of the German housing stock, the involvement of tenants in the production of clean electricity is key to boost the urban energy transition (Moser, et al., 2021). In addition to the barriers and drivers for the tenant electricity model, the motivations of the citizen scientists (CSs) to participate in the model are examined. Furthermore, the initiative examines behavioural changes of the citizen scientists (based on the *energy culture* concept) due to their involvement in local electricity production and consumption. The research report is structured as follows: Section 2 presents the research objectives and detailed research questions, while section 3 refers to the conceptual framework used in the implementation of the CSI. The section provides insights of the integration of citizen science into energy research and about the *energy culture* concept as a framework to analyse energy-related behaviour. Background information on the tenant electricity model is outlined in section 4 and section 5 describes the process of the involvement of citizen scientists and energy sector stakeholders and step-by-step implementation of the CSI. The research process and outcomes are outlined in section 6. Qualitative data on tenant electricity, citizen science, and energy culture is presented under subsections 6.1 and 6.2. Quantitative data collected via questionnaires and intelligent metering systems are outlined and interpreted under sections 6.3 and 6.4. Section 7 provides an overview of the main research results, conclusions, and further research opportunities.

2 Research objectives and questions

The research conducted within the Citizen Science Initiative (CSI) addresses four overarching aims. These aims cover the generation of new knowledge on local energy production opportunities, the role of digitalization in consumption metering, the relevance of citizen science in the energy field, and the identification of possible changes in energy cultures[2]. In detail, the overall aims are as follows:

1. *Generating new knowledge and increasing understanding on the importance of actively involving citizens in the energy transition, informing and engaging them in local production opportunities, as well as their own energy consumption and behavior.*
2. *Proving the relevance of tenant electricity models and intelligent meters*
3. *Proving the relevance of citizen science in conducting research that reflects local realities, builds new social connections to jointly thrive for social innovation regarding a just energy transition. This aims to close the gap between different actors and levels of energy research, citizens, enterprises, and policy makers.*
4. *Identifying the components of energy cultures and which of them are more conducive to a decentralized energy transition.*

To guide the research process and align it with the overall research aims, five concise research questions are outlined. Further understanding and research on the importance of actively involving citizens in the energy transition (overall aim one) are integrated as a cross-cutting theme in all five research questions. Additionally, to accelerate the energy transition and strive for social innovation through the tenant electricity model (overall aim three), it is essential to identify the barriers and drivers for applying the model, as well as understanding the motivation behind the participation as a key driver for change:

1. *What are the **barriers and drivers** for involvement in tenant electricity models (receiving tenant electricity and investing in tenant electricity projects), and how can we overcome these barriers and accelerate drivers?*
2. *What **motivations** do citizen scientists have in participating in tenant electricity?*

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[2] For a detailed explanation of the concept of "energy culture" see chapter 3 "The Stepchange Conceptual framework"

The following three research question addresses overall aim four and examine the change of energy culture resulting from participation in tenant electricity projects, by feedback on regular consumption data (overall aim two) and engagement in this Citizen Science Initiative (CSI) (overall aim three).

3. *Does participation in **tenant electricity projects** have an impact on **energy-related lifestyles** and **energy culture** (e.g., self-efficacy: becoming more active in contributing to the energy transition, combating climate change)?*

4. *Does **regular data observation** about energy consumption have an impact on **energy-related lifestyles** and **energy culture** (e.g., energy-efficacy)?*

5. *Does **participation in this CSI** has an impact on **energy-related lifestyles** and **energy culture** (e.g., energy-efficacy)?*

After describing the research objectives and questions, the conceptual framework of the CSI is introduced in the next chapter, which is based on the citizen science approach and the energy culture framework.

3 The Step Change conceptual framework

Citizen Science describes a phenomenon with a long tradition in scientific inquiry – the voluntary involvement of people not formally educated in the specific area of research, operating especially in data collection related to biodiversity and the environment. The stream of scientific research has been named “Citizen Science” in the 1990s and gained popularity and recognition by science and policy in the last decades (Tweddle, et al., 2012). Its main characteristics involve the active engagement of the general public in scientific research tasks, fostering collaboration between scientists and citizens to generate new knowledge for the benefit of science and society (Vohland, et al., 2021). Further, the European Citizen Science Association (ECSA) has defined its approach towards Citizen Science across five sections: (1) core concepts; (2) disciplinary aspects; (3) leadership and participation; (4) financial aspects; and (5) data and knowledge (Haklay, et al., 2020). In order to define the respective scientific inquiry as Citizen Science, the following questions must be clarified at the beginning and continuously evaluated during the project duration:
What do the participants consider as science? What forms of participation are planned for the projects? How is the generation, dissemination and analysis of data expected to proceed? Etc.

(ibid.; (Kieslinger, et al., 2018). If fulfilling the main success criteria, citizen science works towards democratizing knowledge (Wuebben, et al., 2020).

To emphasize the innovative potential of our Citizen Science Initiative it is important to highlight the scarcity of citizen science initiatives in the realm of renewable and decentralized energy generation. Regarding the context of the development of Citizen Science, Wuebben et al. highlight that one of the prominent representatives of citizen science research, Alan Irwin, developed the terminology and concept with respect to the 1987 UN Report "Our Common Future" (Brundtland, 1987), where the idea of 'sustainable development' evolved (Wuebben, et al., 2020). Given that "Citizen science and the SDGs were born of the same moment" (Wuebben, et al., 2020, p. 3), it becomes intriguing to consider which Sustainable Development Goals (SDGs) are addressed through CSIs. Wuebben et al. conducted a literature analysis showing that out of 127 CSIs in Germany, most tackled SDG 15 "Life on Land" and SDG 4 "Quality Education", while none addressed SDG 7 "Affordable and Clean Energy." (p. 4).

The Citizen Science project Step Change, funded under the Horizon 2020 programme[3], has two citizen science initiatives (CSIs) bringing together Citizen Science and Clean Energy to enhance energy literacy of our society and promoting prosumer solutions in decentralized energy systems. Our CSI specifically collects energy data through citizen engagement and involves citizens in discussions with various stakeholders in the German Tenant Electricity system, aiming to collectively formulate policy recommendations that facilitate a participatory and just energy transformation aligned with SDG 7. Citizen Science in energy research thus bears the potential to promote scientific and energy literacy at the same time through participation, knowledge sharing, expertise exchange, and co-creation, thereby "supporting the co-evolution of social and technical aspects" (Bonney, et al., 2009).

To provide our results with a frame, our CSI has chosen the framework of **Energy Cultures**, which was introduced to analyze and understand the motivations behind changes in energy efficiency behaviors by attending to behavioral drivers (Stephenson, et al., 2010). The context in which the framework was developed was dominated by the situation that although policymakers worldwide were advocating strongly for increased consumer energy efficiency, the outcome was rather disappointing as people were tightly holding on to inefficient practices. To understand this resistance to changing behaviour that often counteracts to what researchers

[3] Whilst governing bodies have shown increasing support for citizen science, its priority status was further indicated in the H2020 funding program objective Science with and for Society (SwafS) (Wuebben, et al., 2020, p. 4).

are calling “rational economic choices” (Stephenson, et al., 2010, p. 2) a multidisciplinary approach was needed. An approach that acknowledges the heterogeneity of energy users and their individual, sometimes seemingly counter-intuitive, responses to state and economic interventions and functions as an “interpretive lens, an organizing principal, or as a detailed analytical instrument” (Klaniecki, et al., 2020). The **Energy Cultures framework** was thus developed as an integrating model highlighting explanations of behavioral change or resistance to change and consequent solutions nudging the transformations of consumer habits. Its development was based on an intensive literature analysis of energy behavior conducted by an interdisciplinary team as well as several pilot studies in New Zealand. Its focus lays on working against the notion of a homogenous pre-defined group as the target group of efficiency interventions and argues for the importance of understanding the notion of ‘cultures’ as bringing forward “the role of the individual or group and their socio-culturally influenced behaviours in both resisting change and causing change.” (Stephenson, et al., 2010, p. 6123). The three main pillars that characterize the Energy Cultures framework – norms, material culture, and energy practices – interact and influence each other. E.g., one’s socialization (norms) affects technological preferences (material culture) and ethical considerations (energy practices). External circumstances also play an important role in influencing energy behaviour alongside cognitive norms, material culture, and energy practices (Stephenson, et al., 2015). The framework's core hypothesis is “that stabilization of behaviour occurs, where norms, practices and technologies are aligned – that is, where the dynamics between the three components are self-reinforcing. Potential for behaviour change arises when one of these components becomes misaligned or shifts […].” (Stephenson, et al., 2010, p. 6125).

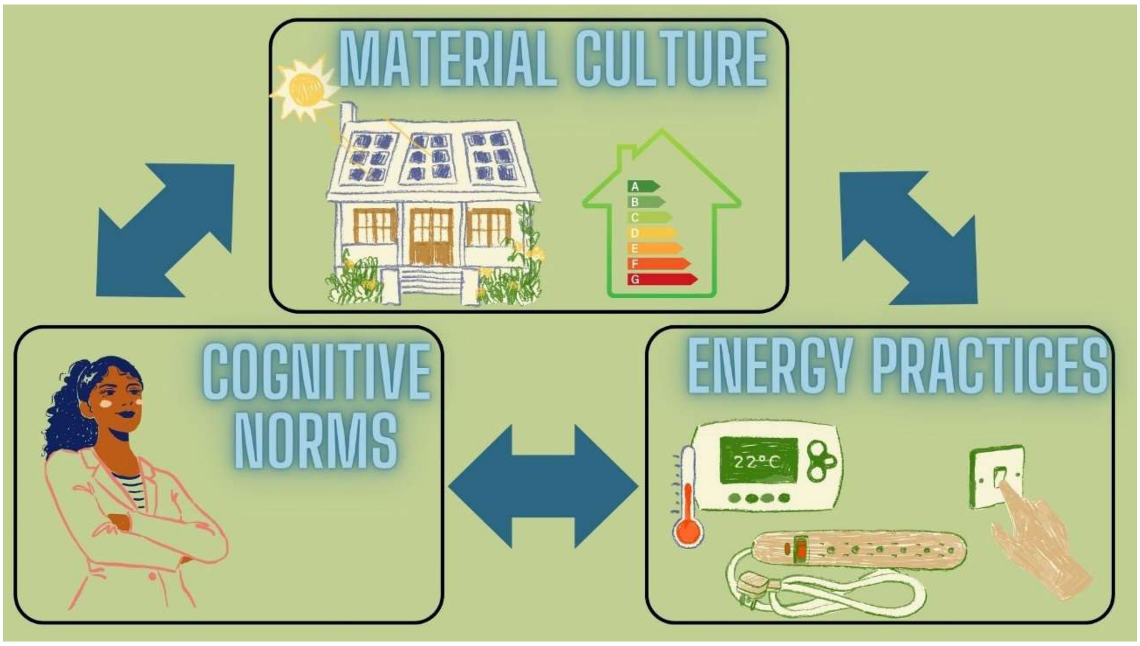

Figure 1 The three main pillars of Energy Cultures (image created by authors)

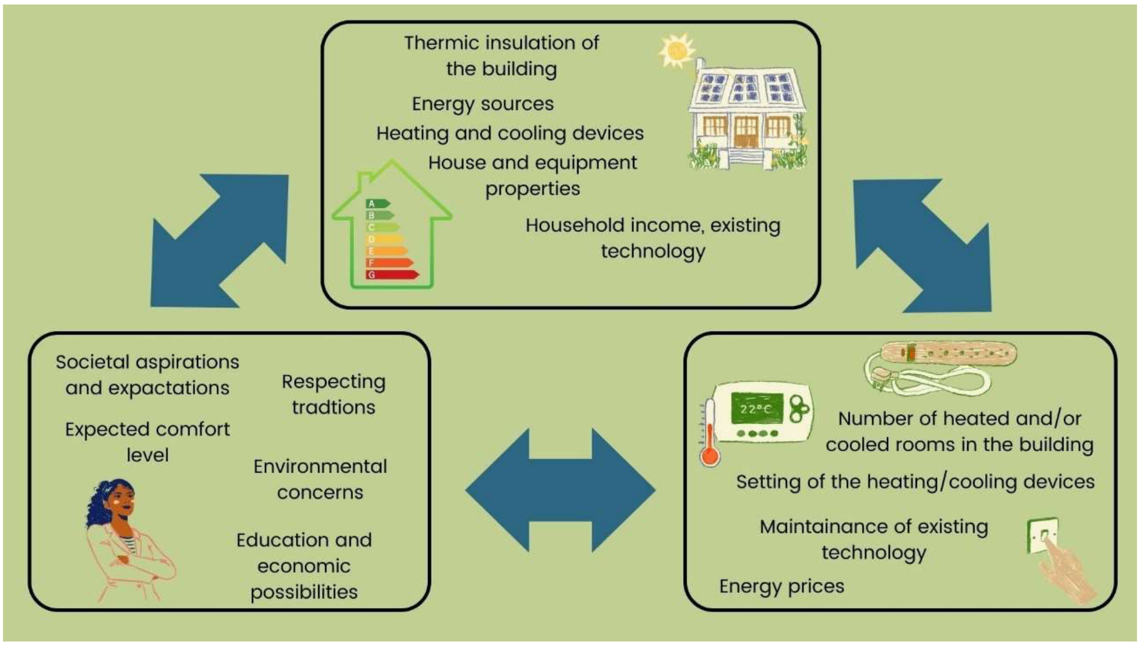

Figure 2 Examples of three main pillars of Energy Cultures (image created by authors)

The main pillars mentioned make the framework highly adaptable to specific, local situations and the concept can be applied in order to provide energy suppliers and policymakers with context and place specific information on how to influence behaviour through clustering of actual behaviours and barriers to change (Stephenson, et al., 2010, pp. 6124-6125). Since its introduction, the framework has been applied to various contexts, including diverging scales and sectors. One example focuses on energy cultures in rural regions under transition in Transylvania, Romania, as they have a different set of values, motivations, technological possibilities and practices than urban centers (Klaniecki, et al., 2020). To be more specific, Transylvania´s rural population's main focus does not concentrate on decreasing high consumption but on increasing local income generation, security and independence of the centralized energy system (ibid., p. 2). Another study accompanied 20 homes in their pre- and post-retrofit energy use in Ireland in order to show that "retrofitting initiatives need to extend their current emphasis on technical-material changes to include an equally strong focus on researching and potentially changing the energy-related expectations, aspirations, and actual activities of those who inhabit and use these buildings." (Rau, et al., March 2020, p. 1).The avoidance of monocausal explanations for energy use bears the possibility to steer behaviour change and avoid rebound effects (ibid., p. 2).

To collect information about the three main pillars constituting energy cultures and the influencing backdrop, different methodological approaches are chosen. Context and case study dependent quantitative surveys are carried out (Klaniecki, et al., 2020) (Ishak, 2017), focus groups are created (Ambrosio-Albalá, et al., 2019) (Sweeney, et al., 2013), and interviews are conducted (Hopkins, 2016) (Hopkins & Stephenson, 2016); (Johnson, et al., 2019). A frequent technique of analyzing the collected information is to cluster the data in order to, e.g., examine types of energy consumption on the household level (Lawson & Williams, 2012) (Stephenson, et al., 2015) or different types of mobility practices (Hopkins, 2016).

4 Background information on tenant electricity

Our Citizen Science Initiative in Step Change is based on the analysis of the various opportunities for a decentralized energy transition offered by the **Tenant Electricity Act** (Bundestag, 2017)**,** introduced by the German government in 2017, and the untapped potential found on the rooftops of multifamily buildings (MFB). The Tenant Electricity Act provides the opportunity for neighborhood-based electricity sharing with the sale of electricity generated directly within multifamily buildings with reduced fees and taxes. Surplus electricity generated can be sold and fed into the power grid. In addition, it is possible to provide incentives for residents and tenants to increase self-consumption, adjust their energy consumption behavior, and contribute to CO_2 mitigation.

To understand the legal background of this concept, it is essential to look at international and national frameworks. The EU directive on the **promotion of the use of energy from renewable sources** (European Parliament, 2018), introduced in 2001 and recast in 2018, sets a target for at least 32% of consumed energy in the EU from renewable sources. **The Renewable Energy Sources Act** (*Erneuerbare-Energien-Gesetz* **-** *EEG*) (Bundestag, 2000) is the national implementation of the RED II (Renewable Energy Directive) in Germany. In 2023, new amendments came into effect and the main goal of the 2023 EEG was to expand renewable energy, aiming for emission neutrality in all electricity generated and consumed in Germany by 2050, and an 80% share of renewable energy in electricity generation by 2030. Some new incentives were also introduced for the tenant electricity model. For example, the remuneration was increased from 2.1 cents/kWh (10 kWp system) in 2019 to 2.67 cents/kWh (10 kWp system) in 2023 (Bundestag, 2000, §48a).

Although MFB makes up 53% of the German apartment stock and the number of tenant households in Germany with good conditions for solar tenant electricity is 3.8 million, only 1% of the annual budget has been claimed since 2017 (Moser, et al., 2021). Realising that the model falls short of expectations and lacks broad citizen acceptance, interest arose in understanding the drivers and challenges of the tenant electricity concept. As part of the concepts 'pushing' for prosumer[4] empowerment (as is the energy communities movement), the tenant electricity concept is dependent on the constant adjustments to its prosumer's needs and criticism. To actively participate in these adjustment processes and serve as mediators and advocates for tenants, landlords, and political decision-makers, we decided to directly engage citizens as scientists. Our CSI made the potentials, barriers, and motivation for participating in tenant electricity visible, highlighting the important roles played by energy cultures and literacy in prosumption, consumption behaviour, and behavioural changes.

Through energy consumption monitoring schemes and protocols, lifestyle/panel questionnaires, workshops, interviews and comparative analysis, citizen scientists had the chance to engage in the research tool preparation, data analysis, and interpretation. Through this engagement and unraveling of motivational factors behind decentralized energy transition concepts, the overall aim of involving more citizens in tenant electricity research was achieved.

5 Activities of the CSI

It is increasingly recognized that involving citizens in energy research can be a powerful tool to increase the acceptance of energy transition and understanding of the societal challenges it poses. Therefore, moving beyond conventional energy consumption research, Step Change's

[4] Prosumer stands for **pro**ducer and con**sumer** of energy.

Citizen Science Initiative on tenant electricity in Germany aims to generate knowledge on the potential and challenges for scaling up of the tenant electricity model. This is achieved by actively involving citizens in research and collecting data on how participation in tenant electricity has influenced their everyday energy-related practices.

The CSI is based on the idea that the energy transition cannot be seen only as a technical process aimed at developing and providing low-carbon technologies. Rather, it must integrate social and cultural dimensions to understand how a new technology or energy supply model, such as the tenant electricity model, addresses the needs and expectations of people while aligning with their social and financial realities. In other words, the CSI acknowledges and builds on the role of energy culture in transforming energy systems.

5.1 Involving citizens and energy sector stakeholders in the CSI implementation

The implementation of the citizen science initiative started with the identification and mapping of key actors who, on the one hand, contributed to the CSI with their expertise and, on the other hand, played a crucial role in recruiting, engaging, and involving citizen scientists (CSs). This process led to the inclusion of three researchers and one representative from the community energy sector in the core team of the initiative (Table 1). The core team was supported by a group of experts in the fields of citizen energy, social innovation, housing policy, and citizen participation, whose contributions and insights were crucial for the research design and methodology.

Table 1: Participating researchers and experts in the Step Change core team

Participant	**Organisation**	**Role/ research field**
Hölsgens Henricus	Technical University of Dortmund	Researcher in the field of social innovation
Iris Behr	Darmstadt University of Applied Sciences	Researcher in the field of tenant electricity
Anna Nora Freier	University of Wuppertal	Researcher in the field of citizen participation
Malte Zieher	German Citizen Energy Alliance (Bündnis Bürgerenergie e.V.)	Expert in community energy

In addition, the citizen science initiative gained the interest and support of various stakeholders from private (5 SMEs), public (5 authorities and 5 political actors), and non-profit (3 NGOs, 2 energy cooperatives and 2 housing cooperatives) sectors. Those are referred hereafter as *engaged stakeholders*.

The recruitment of citizen scientists took place mainly through the energy cooperatives and small and medium-sized enterprises (SMEs) linked to the initiative. Since the initiative had a specific target group (people participating or investing in tenant electricity), recruitment actions focused on a narrow population. This stage constituted a significant challenge for developing the initiative's activities. Initially, it was planned to develop the activities of the CSI in the City of Munich and its surroundings. However, due to low levels of recruitment in the targeted area and the gain of a strategic partner in the tenant electricity sector, the geographical scope was extended to include the customers of prosumergy GmbH, a tenant electricity provider with operations mainly based in the States of Hesse and Saxony-Anhalt.

The citizen science initiative thus succeeded in engaging citizens from Frankfurt, Darmstadt (State of Hesse), Munich, and Münsing (Bavaria). Figure 3 provides an overview of the geographical distribution of citizen scientists, engaged stakeholders and members of the core team.

Figure 3 Map of CSI on Tenant Electricity (own elaboration of the authors)

One of the stated aims of the CSI's recruitment strategy was to involve a diverse range of citizens in terms of gender, age, and socio-economic status. During the recruitment phase, the CSI only collected information on gender and geographic location. Based on this data, the initial group of citizens consisted of 64% men and 36% women. During the implementation of the citizen science initiative, there were four dropouts, representing 10.8% of the group. Additional demographic information about the citizen scientists was collected through a survey (see Section 6).

5.2 The step-by-step implementation of the CSI

The research design of the CSI consisted of five stages, illustrated in Figure 4.

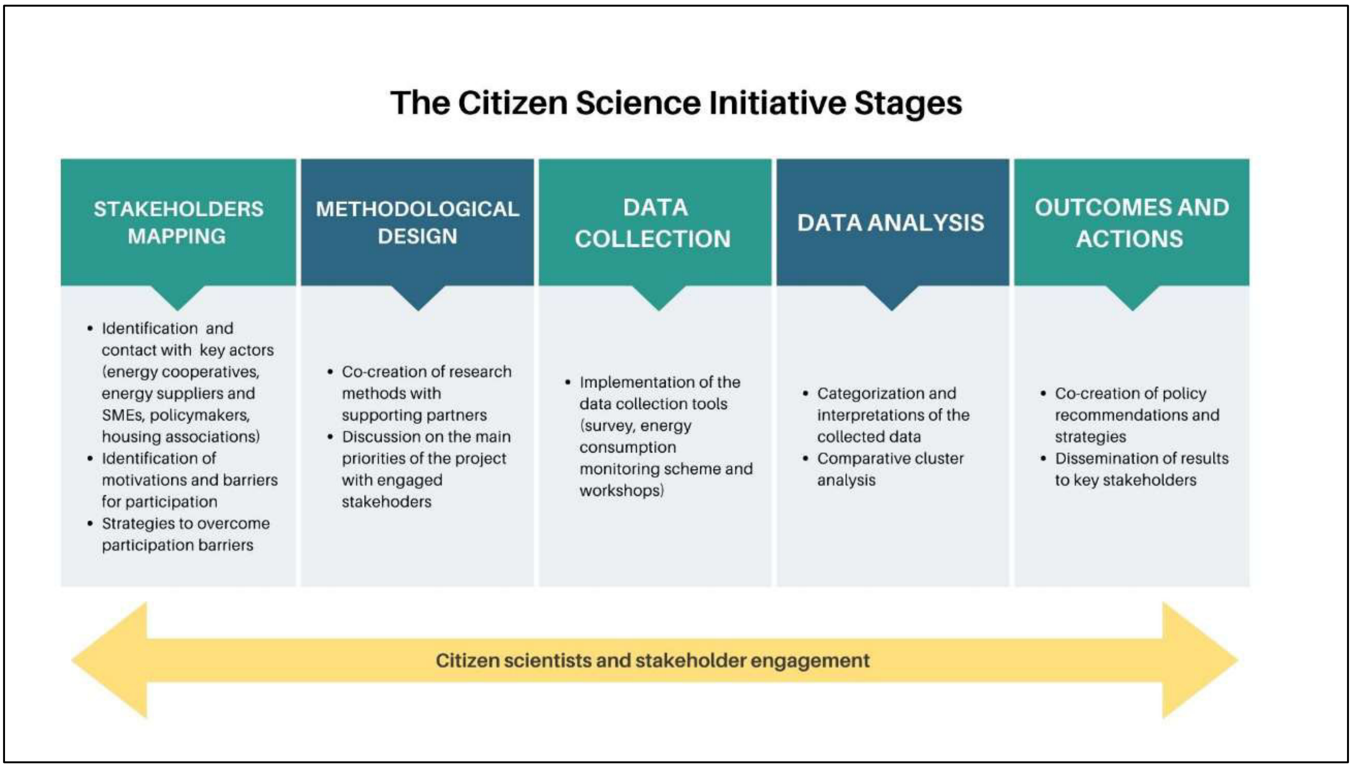

Figure 4 Stages of the citizen science initiative on tenant electricity (own elaboration of the authors)

After recruiting citizen scientist households, the core team collectively designed the data collection tools and protocols. The citizen science initiative adopted a mixed-method approach, combining qualitative data analysis from three workshops and quantitative data from an energy consumption monitoring scheme and a panel survey on energy-related practices.

Before starting the data collection phase, citizen scientists received either access to software for monitoring energy consumption or intelligent meters were installed in their homes. Citizens were trained in the use of the software and intelligent meters through an online workshop. In addition, two virtual meetings (CSI Kick-off meetings) were held to inform citizens about the CSI's objectives, methodologies, and opportunities for contributions beyond home data collection.

The active data collection phase was launched with the distribution of the first of three surveys, forming the baseline for analyzing changes in practices, attitudes, and motivations at home. Upon concluding the first round of surveys, the first online workshop aimed to deepen the understanding of perceptions of and experiences with the tenant electricity model. Concurrently, the collection and reporting of household energy consumption started. Participants were asked to report only their monthly total consumption via an online platform. However, the software installed in the framework of the citizen science initiative allowed them to track other consumption statistics such as hourly and daily consumption. Citizen scientists were encouraged to track those as well.

This structure (conducting a workshop after each round of surveys) was carried out three times in total. The workshops offered a platform to share the preliminary results of the survey with citizens, to delve deeper into issues of interest (thus increasing energy literacy), and to generate discussion on the various challenges and barriers encountered by the tenant electricity model and community energy more broadly within the local and national context. Figure 5 provides additional information on the data collection tools.

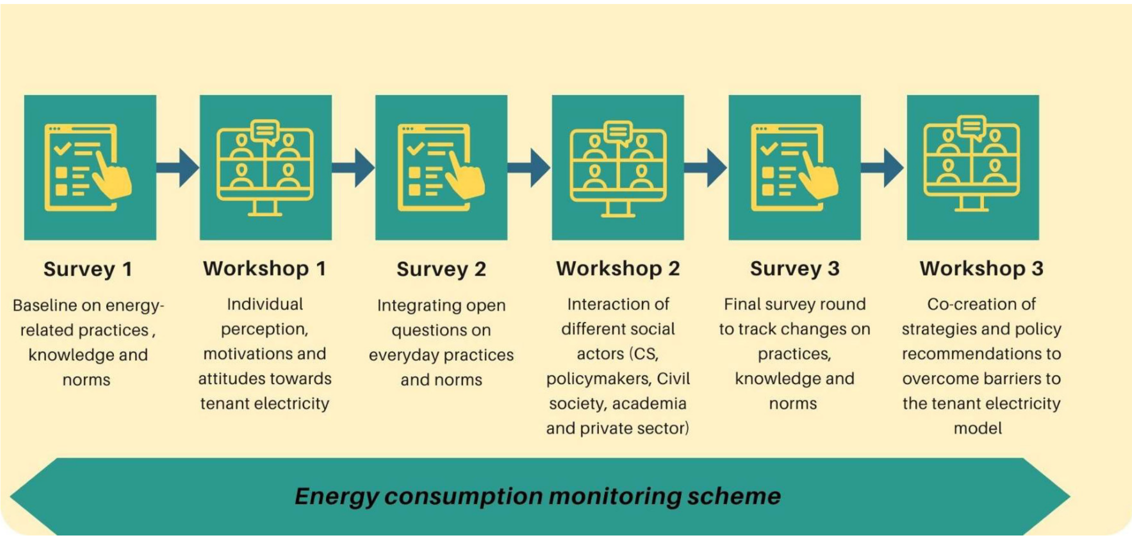

Figure 5 Data collection methods (own elaboration)

All research methods were applied between September 2022 and May 2023. After each workshop, the core team analyzed the collected data, compiling thematic summaries with the most salient information (see Chapter 6.2). Together with the preliminary results of the survey, these results were shared and discussed with the engaged stakeholders. This activity also allowed to gather information about their perceptions and expectations regarding the citizen science initiative and its impact.

Upon completion of the third survey round, the analysis stage continued with a comparative analysis and hierarchical clustering, aiming at identifying how the energy culture of the citizen group changed during the citizen science initiative and creating consumer profiles (see chapter 6.4).

6 Research process and outcomes

This section presents the main findings of the CSI´s research. The analysis of the collected data is divided into four subsections. Sections 6.1 and 6.2 provide insights on the observations from citizen scientists and energy experts collected during the three workshops and analyzed them using the conceptual energy culture framework. The surveys and the electricity consumption protocol are analyzed in section 6.3 and behavioural profiles are described in section 6.4, applying the hierarchical cluster analyses.

6.1. The tenant electricity in Germany: observations from citizens and energy experts

This section describes the synthesis and evaluation of the qualitative data collected in the workshops and meetings. Within the framework of the CSI, workshops were designed to foster interaction and knowledge sharing among citizen scientists, serving as a method to gather reliable and valid data. This is based on the idea that workshops, as a participatory research method, strengthen dialogue among the participants by considering their various perspectives and diverse knowledge and academic backgrounds. As mentioned above, a total of three workshops were conducted with the involved citizen scientists’ group. The contents and methodologies of the workshops were interconnected and followed a sequential approach, allowing the collection of data on individual perceptions and the formulation of collaborative strategies and recommendations.

The first workshop relied on previous studies on tenant electricity and on the preliminary results of the baseline survey to generate a debate about individual motivations, possible drivers, and barriers of the tenant electricity model. The workshop was divided into three sessions: 1) input from the core team of the citizen science initiative on the current situation of tenant electricity in Germany and the preliminary results of the first survey round; 2) a discussion with the CSs on their individual experiences and motivations concerning tenant electricity, along with their perceptions on the advantages, disadvantages, and challenges of the model; 3) a discussion with a community energy expert on the opportunities for accelerating the uptake of the model.

During the discussion of individual experiences with the tenant electricity model, some common themes or categories emerged. Although positive perceptions predominated in the group's opinions, some expressed doubt about the actual benefits (compared to other forms of energy provision), and the complexity of the model. Positive perceptions were reported regarding the price, the contributions to sustainability and the regional economy. Conversely, from the perspective of participants who were property owners, the model is complex and fails to offer real incentives to them for implementing a tenant electricity system.

In the second part, the discussion focused on the motivation and the process of participating in a tenant electricity project. A common view among the participants is that to start the model within a given community, having an informed initiator who guides tenants and provides information is essential. For example, one participant remarked, "*in existing properties, it is almost impossible to implement tenant electricity if there are no people who deal with it. It needs people who invest time and energy in it*".

Another highlight of this workshop session relates to the decision-making process within the buildings, especially within housing associations. The decision to implement the tenant electricity model was made at the general assembly and therefore required a majority of votes in favour of the tenant electricity model. However, in some cases, participants stated that they did not know how the decision on the energy provider was made. Other participants stated that the decision had been made prior to their involvement in the housing project and therefore did not participate in it. Regarding the role of energy prices in the decision to participate in tenant electricity, two divergent discourses emerged. On the one hand, some participants indicated that their priority is focused not so much on price but on obtaining energy from green sources and through companies/cooperatives that benefit the local economy. On the other hand, those who expressed a higher sensitivity to the price stated that as the electricity price continues to be burdened with surcharges and cost, tenant electricity is not the most efficient way to provide energy.

Finally, the third session focused on deliberating strategies for getting more people involved in the tenant electricity model. Communication and information challenges were particularly prominent in this session. Most of the participants agreed that knowledge about the model is scarce, and therefore, both providers and local authorities should work on communication and marketing strategies to reach more people and explain its benefits. Concerning the legal framework, participants emphasized the importance of simplifying the model's complexity and formulating policies that provide real incentives to property owners and tenants to participate in tenant electricity.

The second workshop focused on the concept of energy cultures, particularly on the social construction of energy-related norms and practices and their relationship with tenant electricity and energy consumption. The central activity of the workshop was a roundtable discussion that brought together actors from the public sector, academia, and civil society. The session aimed to discuss the views of the different actors on how energy cultures change due to social innovations, technological or political changes, and within the current context of the energy crisis.

The discussion provided interesting insights, especially into the diverse ways in which policies and national frameworks influence people's behaviours and decisions regarding energy. In this regard, the discussants reflected on how existing regulations in Germany have either motivated or constrained the adoption of renewable energy and, consequently, the energy transition. These viewpoints were particularly prominent in relation to highly complex regulatory frameworks such as the tenant electricity law (2017 and later amendments). A consensus among the discussants was that despite the relevance of citizens' engagement and bottom-up approaches towards renewable and decentralised energy, the development of enabling policy frameworks and structures is fundamental.

A second central theme related to the role of information and knowledge emerged from the analysis. Providing reliable information was seen as an important step in achieving changes in energy cultures, increasing the acceptance of renewable and decentralised energy, and counteracting the influence of those who defend the prolonged use of fossil fuels and centralised energy systems. Knowledge was also mentioned in relation to the intersection between digitalisation and the energy transition.

The third and last workshop of the citizen science initiative built on the discussion from the second workshop and offered citizen scientists a more private atmosphere to express their opinions and viewpoints. Therefore, the last workshop of the citizen science initiative was exclusively designed for citizen scientists. Since part of the workshop was held in the form of “breakout rooms”, the core team was able to step back, enabling citizen scientists to collaborate and discuss exclusively among themselves. This self-reliant conversation format at the end of the workshop spotlighted the citizen scientists’ expertise in the area of tenant electricity, energy literacy, and potential drivers for increasing the efficiency of tenant electricity and energy literacy initiatives. The main drawback that they identified was the lack of a consistent and compelling communication strategy. They concluded that it is crucial to inform different stakeholders about the importance of expanding the tenant electricity system while providing practical tips to increase energy literacy in the whole society, thereby promoting energy efficiency. The overall notion that citizen scientists brought forward was the need for the German State to take responsibility for building up ‘unbiased’ information centres to avoid reinforcing power imbalances between tenants and landlords. Additionally, information on the system and understanding energy usage needs to be provided to a bigger part of the society. This could be done, for instance, by developing informative television formats that air during prominent time slots and using inclusive and accessible language to reach and inform targeted groups (a detailed description of proposed strategies will be included in policy recommendation Deliverable 4.4).

Overall, the third workshop brought the opportunity for the citizen science initiative to highlight the importance of citizen scientists’ knowledge and the urgency of knowledge as well as energy sharing to overcome energy illiteracy and its associated inefficient consumption behaviour. The space, which was opened by the citizen science initiative core team but not systematically controlled by them, offered the opportunity for citizen scientists to 1) engage in discussions to enhance existing mechanisms and propose new ideas around tenant electricity and energy literacy, and 2) give feedback on the CSI as such and the methodology of data collection in particular, and openly address criticism of organizational structures and statements regarding the necessity of energy saving.

Taken together, the workshops results indicate that the barriers for a larger scale implementation of the tenant electricity model in Germany are mainly at the political level, as the legislation regulating the model creates important blockages and does not provide sufficient incentives to citizens, tenants, landlords and other stakeholders. In addition, the citizen scientists and experts highlighted the fundamental role of information, target group-specific language, and marketing around the model – aspects that have been neglected so far.

Regarding strategies to address these barriers, the workshops allowed us to identify potential actions at various levels that could be developed by different stakeholders. These stakeholders can be divided into three main groups:

- Building-related actors: This category includes residents and property owners as well as representatives of housing cooperatives.
- Energy supply actors: This group includes (tenant) electricity companies, energy cooperatives, and network and metering operators.
- Public actors: This group includes authorities, politicians, and decision-makers at the local, regional and national levels.

Figure 6 summarizes the potential measures to scale up the tenant electricity model in Germany, resulting from the data analysis of the citizen science initiative's workshops.

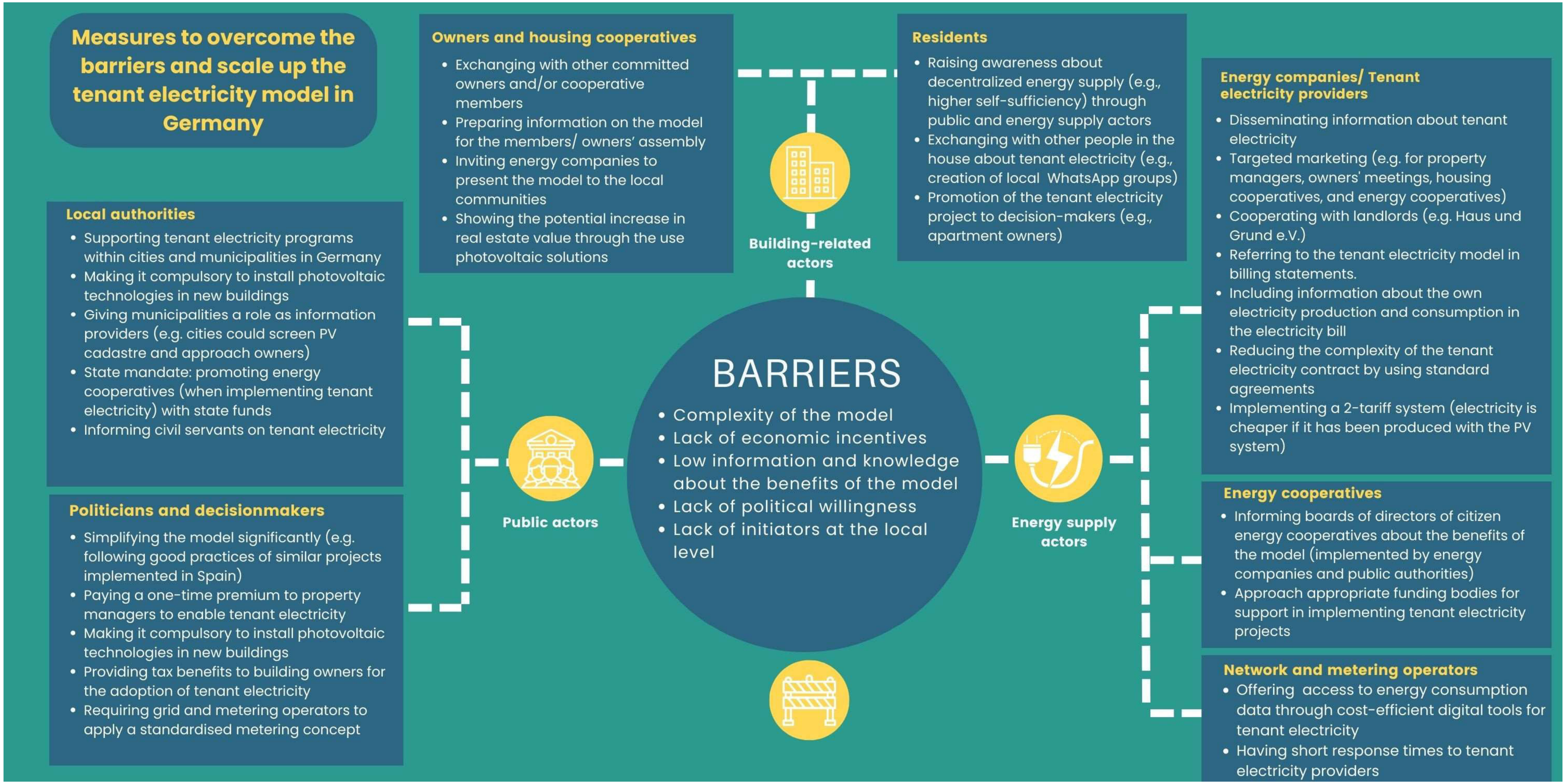

Figure 6 Measures to overcome barriers and scale up the tenant electricity model in Germany

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006386

6.2. *Energy cultures, tenant electricity and Citizen Science*

The qualitative data collected during the workshops also allowed us to analyse how energy cultures shape energy-related behaviours and outcomes and are key to a shift towards a clean energy system (SDG 7). As expressed in Section 3, the energy cultures framework states that decisions, behaviours and changes in energy consumption at home result from the interaction and mutually reinforcing relationship among norms, material culture, and practices. This is further influenced by external factors (Stephenson, et al., 2010).

According to Stephenson et al. (2015), the concept of energy cultures can be applied across many scales, including individuals, households, or on a larger scale, at the national level. In the case of our CSI, we are examining the concept within a group of households that share certain characteristics in terms of norms, practices, and material culture. Initially, a growing concern for sustainability and environmental protection has changed the social norms of energy consumption in Germany, consequently increasing the desirability and acceptance of renewable energies and decentralised energy systems. Secondly, regarding material culture, the group of citizens shares two main characteristics: they are recipients of tenant electricity (photovoltaic systems installed on the building's roof) and have access to intelligent metering systems[5]. Thirdly, practices related to energy use are expected to align with the sustainability concern, thus shifting towards energy saving and the pursuit of energy efficiency. These pillars of energy culture within the Step Change CSI are presented in Figure 7.

In addition, during the citizen science initiative's implementation, several significant external factors strongly influenced the citizens' energy culture. These factors are:

- the effects of the COVID-19 pandemic, originating in 2019, leading to changes in behaviours and energy consumption at home, e.g. increased energy demand due to more people working from home.
- the impacts of Russia's invasion of Ukraine, resulting in, among other dramatic and inhumane consequences, an energy crisis in central Europe and in rising energy prices.

[5] Further aspects of the material culture of the households, such as those related to the available devices at home, were explored through a survey. The results are presented in Section 6.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006386

- changing energy regulations at national and European levels, such as the issue of the REPowerEU Plan in December 2022.

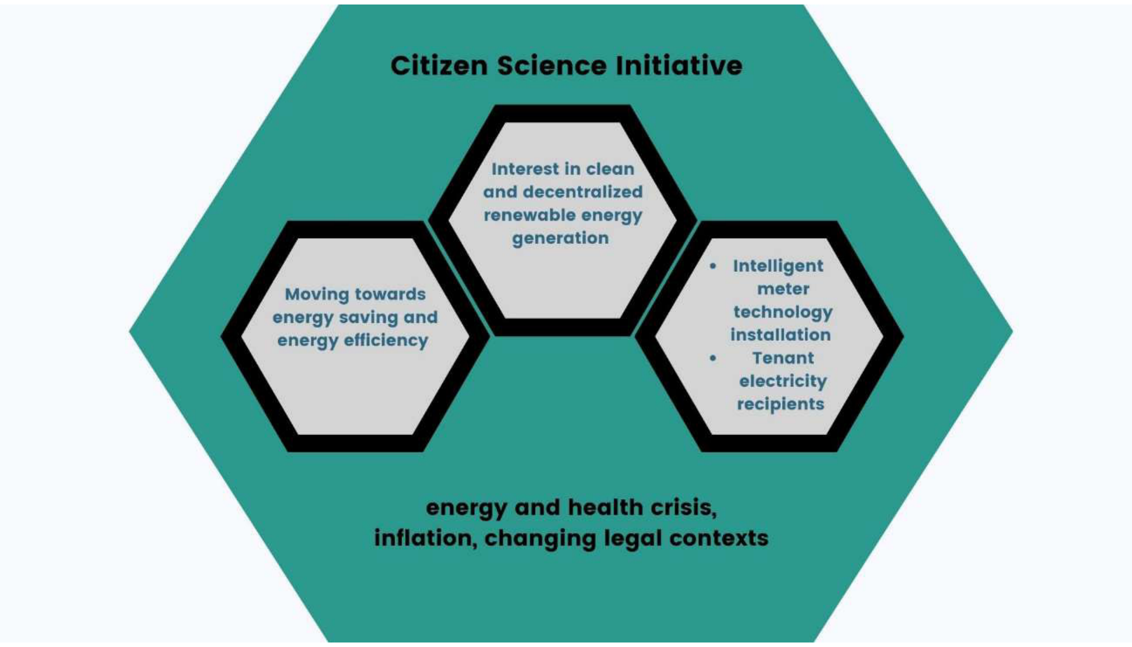

Figure 7: Pillars of Energy Cultures in Step Change CSI (image created by the authors)

By using the energy cultures framework, the CSI's core team aimed to gain a better understanding of the energy behaviour of our CSs and how changes in norms (e.g., growing environmental awareness and concern), material culture (e.g., the introduction of intelligent metering systems), and practices associated with receiving solar energy through tenant electricity impact energy transition-friendly behaviours. Furthermore, the framework allowed us to identify the type of actions and interventions that our CSs perceive as most effective in promoting societal behaviour change.

The collected data confirmed the significance of changing social norms towards more sustainable forms of energy consumption. Interest in sustainability was highlighted in the workshops (and surveys) as one of the main drivers for change. According to the energy experts who participated in our second workshop, it is evident that there is a high level of public commitment to renewable energy despite existing regulatory barriers. In this regard, it is essential to promote knowledge and education on energy and decentralisation issues. This could have positive impacts, not only on the take-up and acceptance of renewable energies, but also on setting up more democratic and socially just energy systems.

Citizen science, as a way of involving citizens in a practical way in research and connecting them with different social actors, can play a key role in the promotion and communication of knowledge. In our citizen science initiative, the activities were also seen as a way to increase energy literacy in a wide range of issues, including the tenant electricity model itself and the use of energy consumption track systems. Our approach was therefore based on the assumption that by actively involving citizens in the research process and making energy consumption visible through using intelligent meter technologies, the awareness of the involved citizen scientists will increase and might have a transformative effect on energy consumption behavior.

Regarding changes in energy-related practices at home, the data from the workshops showed that concerns about environmental issues and the provision of solar energy have translated into certain energy-saving practices. These practices include the installation of devices to control appliances running on standby or using energy-intensive appliances (such as washing machines or dishwashers) during peak hours of solar energy production. In addition, these changes are seen as a personal contribution to the well-being of society and the environment.

Further data on the energy culture components of the citizen scientists was collected through surveys and the monthly electricity consumption protocol, so that we could analyse the connections between citizen scientists' self-assessment and their reported energy consumption data. This will be elaborated on in the following chapter.

6.3. Energy cultures in the CSI: Everyday energy-related practices and norms

This section is divided into four parts. In the first part, the demographic data of the citizen scientists is presented to gain insights into knowledge about the composition of the sample. The second part analyses the questionnaire results, focusing on possible changes in the answers of citizen scientists in each of the three energy culture dimensions: material culture, knowledge and norms, and energy practices. The third section analyses possible changes in energy consumption-patterns based on energy data collected from November 2022 to April 2023. In the last section, the results of both previous sections are connected, contributing to answering research questions 3 to 5 (see chapter 2), which investigate the change of energy culture and energy lifestyle. Overall, descriptive statistics are applied to present and organize data clearly while using tables, graphs, and key figures.

6.3.1. Demographic data

At the beginning of the active research phase, 33 of the 37 initially recruited citizen scientists (CS) were involved in the project. The age distribution of the sample was relatively homogenous with most CS older than 60 years (n=9) followed by the 30- to 39-year-old (n=8) and 40- to 49-year-old CSs (n=8). 6 persons were building the group of the 50- to 59-year-old CSs, while the 18- to 29-year-old category consisted only of one person and one person did not respond at all. Figure 8 gives an impression of the age distribution.

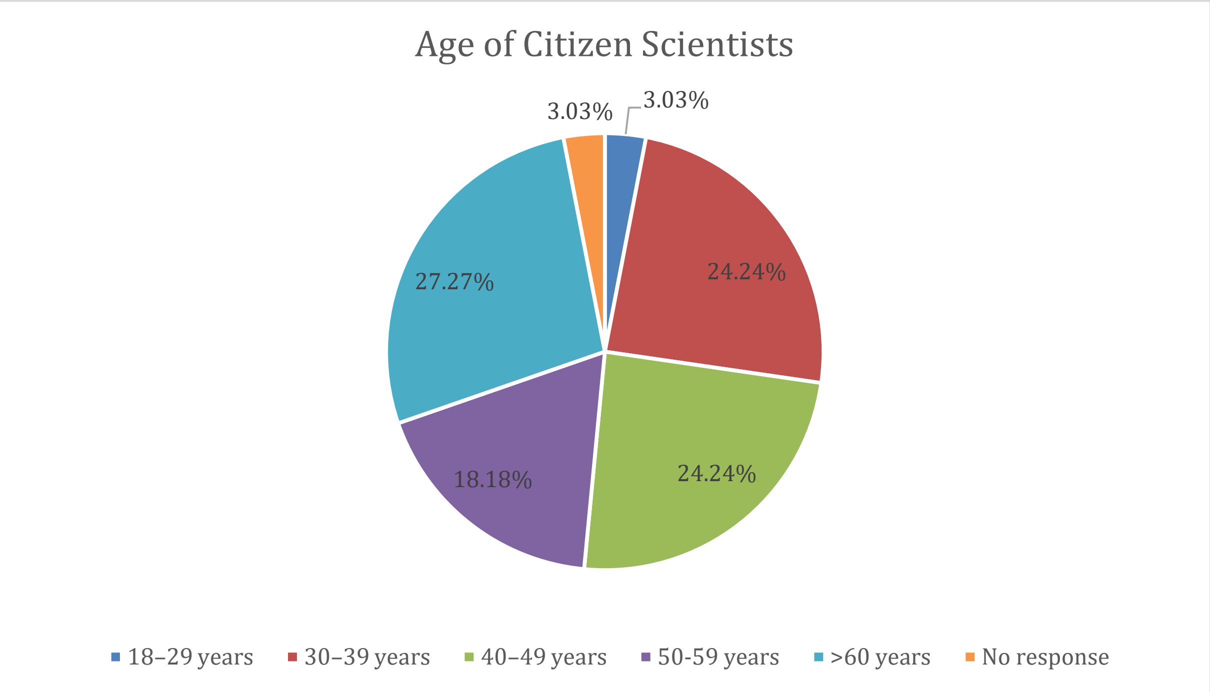

Figure 8: Age distribution of Citizen Scientists (n=33) (own source)

One objective of the recruitment strategy consisted in having a gender-balanced group composition. In the end, the group composition resulted in 64% men (n=21) and 36% women (n=12). Figure 9 shows the gender composition of the citizen scientists.

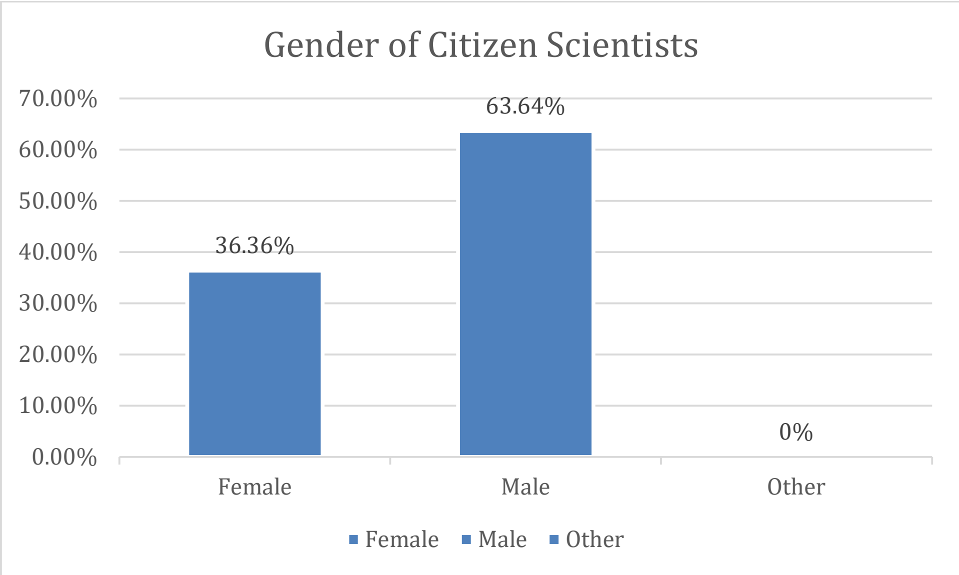

Figure 9: Gender of Citizen Scientists (own source)

Figure 10 shows the relatively homogenous monthly income distribution among the participating households.[6] The highest number of participants fell within the 1,501€ to 2,500€ range, as well as the above 4,500€ range (n=8 for each range). Runner up is the 2,501 to 3,500€ range (n=7), followed by the 3,501€ to 4,500€ range (n=5). Two households receive a monthly net income between 0€ and 1,500€ (n=2), and two citizen scientists did not answer the question.

[6] Net income per month per household or per person (if single household or in a shared apartment)

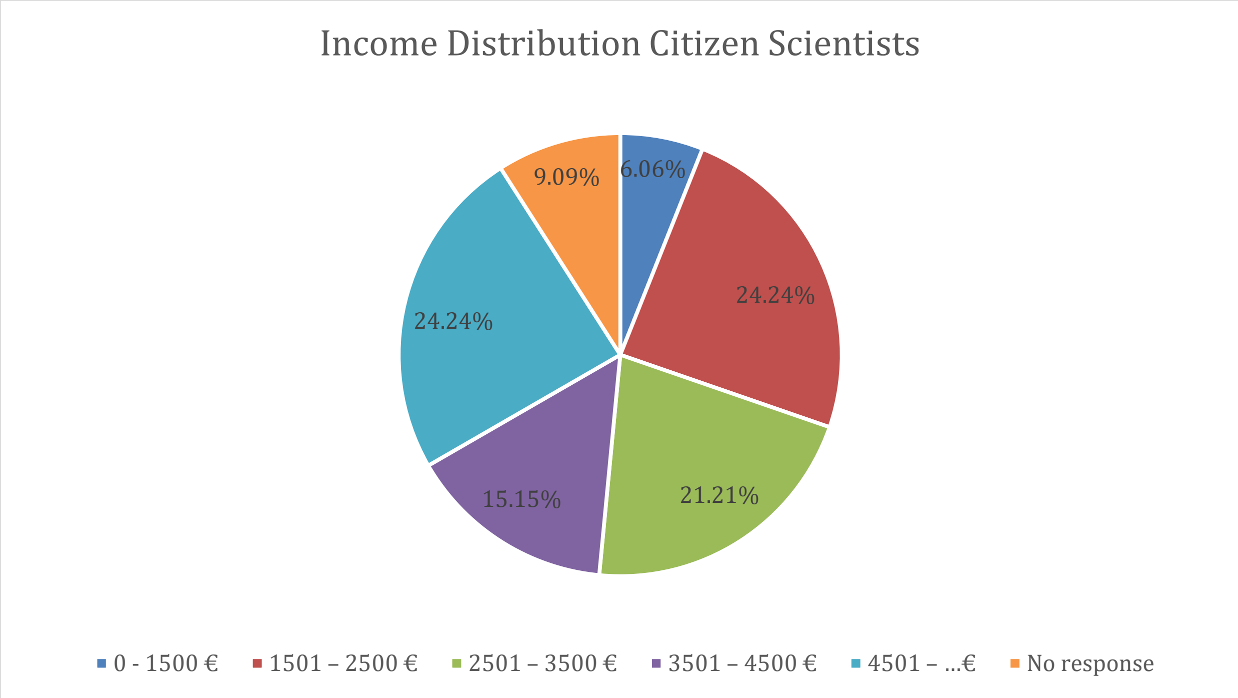

Figure 10: Income Distribution of Citizen Scientists (own source)

The housing situation of the citizen scientists is dominated by apartments within a housing association, accounting for 69.7% (n=23). Further participants are living either in an owner-occupied apartment or as tenants with 15.15% (n=5) respectively.

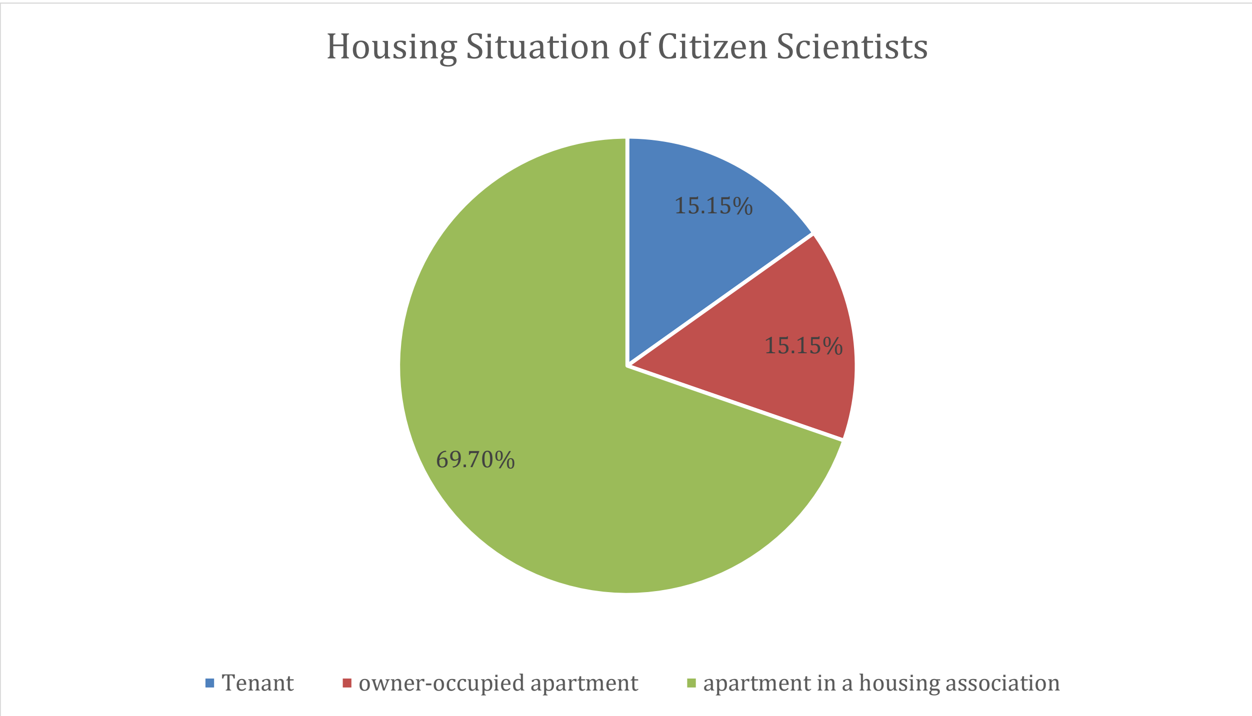

Figure 11: Housing Situation of Citizen Scientists (own source)

6.3.2. *Quantitative analyses of panel questionnaire*

The panel questionnaire was sent three times to the citizen scientists, one at the beginning, one mid-term, and one at the end of the active research phase. The first dispatchment started in August 2022, resulting in 33 answers. In January 2023, the midterm collection started, and 26 answers were recorded, out of which one answer was not valid due to missing data. With the last dispatchment in April 2023, 24 valid answers were collected. In conclusion, the comparison of results over the period is limited to 24 households.

The quantitative evaluation of the questionnaire was done in several steps to find major changes within the sample. First, data preparation involved comparing questionnaire responses in an Excel sheet to track changes in selected sections. Identified peculiarities in the data were reviewed in detail, interpreted, and subsequently outlined.

The first section of the questionnaire explores the *material culture* of the participant households. Specifically, questions focused on the characteristics, availability, and use of (high energy consuming) devices at home to assess their energy efficiency. The energy efficiency assessment was based on the EU energy label and included the categories *very efficient*, *average efficient* and *not efficient*. Lighting was categorised as *predominantly LED* (>70%) or *predominantly not LED* (<70%). Considering that most of the included devices are durable goods with high upfront costs only minor changes were expected for the second and third survey rounds.

Table 2: Equipment of households with lighting (own source)

Lighting	Predominatly LED (>70%)	Predominantly not LED (<70%)	Non knowledge
Survey 1	82%	15%	3%
Survey 2	87%	13%	0%
Survey 3	82%	18%	0%

Table 2 shows the equipment of households with lighting, and it can be seen an overall high LED equipment in place. Data variations in survey 2 arise from an additional answer indicating "mainly LED", otherwise numbers would remain unchanged.

Regarding different household devices, Table 3 provides an overview of various household devices across all three surveys. For each device, the efficiency category was specified by the citizen scientists and there were two more answering options: "none" for not used devices and "not aware of the score" for unfamiliarity with energy efficiency. Examination of table 3 reveals efficiency gains from survey 1 to survey 3 for the category *Fridge/freezer* and *Dish washer*. An efficiency decrease can be seen for category *Washing machine* and category *Stove.* Nonetheless, data should be interpreted carefully, because also the interpretation of energy labels must be done carefully to assess the efficiency categories of the survey. Furthermore, different data could be inserted over time although there was no change in equipment. Nevertheless, overall, only minor changes in the answers were noticed, which confirms our assumption of long-lasting devices which are not often exchanged due to their long-expected lifetime and high upfront costs.

Table 3: Material Culture - Household Devices (own source)

Device	Energy efficiency	Survey 1	Survey 2	Survey 3
Washing machine	high efficiency	26%	27%	18%
	average efficiency	26%	36%	41%
	low efficiency	9%	5%	9%
	none	26%	23%	23%
	not aware of the score	13%	9%	9%
Dryer	high efficiency	13%	14%	13%
	average efficiency	17%	14%	9%
	low efficiency	4%	-	
	none	65%	73%	70%
	not aware of the score	-	-	9%
Fridge/freezer	high efficiency	35%	35%	43%
	average efficiency	52%	57%	43%
	low efficiency	13%	4%	13%
	none		-	-
	not aware of the score		4%	-
Dish washer	high efficiency	30%	30%	43%
	average efficiency	39%	52%	35%
	low efficiency	9%	9%	13%
	none	9%	4%	9%
	not aware of the score	13%	4%	-
Stove	high efficiency (induction)	48%	52%	43%
	lower efficiency (ceran)	52%	48%	57%

Information on multimedia devices was also collected in this part of the questionnaire. Collecting data on the use of multimedia appliances is of great importance given their high impact on annual household electricity consumption. For instance, a daily 4-hour use of a PC results in a yearly energy consumption of 87 kWh. The use of a gaming PC is even higher with 130 kWh in consumption, whereas the use of a notebook is estimated at 22 kWh per year[7]. Similar assumptions can be made for televisions, where technology/efficiency and screen size are critical parameters. For example, a very efficient 50-inch screen consumes approximately 60 kWh per year, whereas a 65-inch screen with equal energy efficiency results in about 80 kWh per year[8].

The overall change in multimedia devices over the research period is displayed in the following table, considering the result of the first survey as a baseline.

Table 4: Changes of multimedia devices (own source)

Device	Number Devices Survey 1	Change Survey 2 to Survey 1	Change Survey 3 to Survey 1
PC	11	-5	-4
Gaming/Multimedia PC	8	-1	-5
Notebook	25	-2	+4
Notebook with external monitor	20	-1	+2
TV < 50 inches younger generation (< 5 years)	4	-2	+/- 0
TV < 50 inches older generation	9	+1	+/- 0
TV > 50 inches younger generation (< 5 years)	2	+/- 0	+/- 0
TV > 50 inches older generation	4	+/- 0	-1

[7] Bundesministerium für Wirtschaft und Klimaschutz.
[8] Bundesministerium für Wirtschaft und Klimaschutz. https://www.energiewechsel.de/KAENEF/Redaktion/DE/Standardartikel/Dossier/A-tv.html

At a first glance at the absolute number of devices from survey 1, it can be seen that households are dominated by notebooks and notebooks extended with external monitors. PCs and gaming/multimedia PCs play minor roles in the computer setting. This overall tendency aligns with the average German household, which typically owns 0.54 stationary PCs and 1.12 notebooks[9]. However, the surveyed ratios of 0.79 stationary PCs and 1.88 notebooks per household are notably higher than the German average. This can be explained by the high number of households with three or more persons (n=16) in the survey. Particularly noticeable is the decrease of stationary PCs and gaming/multimedia computers and the final increase of notebooks and notebooks with external screens at the end of the research phase. In detail, four citizen scientists switched from stationary PCs to notebooks/notebooks with external monitors. The sharp decrease in gaming/multimedia computers is attributed to one citizen scientist giving away six computers of this kind.

In contrast, the number of televisions remains relatively stable throughout the research phase. Compared to the national household average with 1.68 televisions, the surveyed 0.79 ratio appears comparatively low. Moreover, a positive impact on energy consumption is anticipated due to the prevalence of televisions with screen sizes below 50 inches.

The second section of the questionnaire focuses on *knowledge and norms.* Three questions cover the knowledge about own energy consumption and the tenant electricity model, while seven additional questions explore attitudes towards sustainability and the energy transition.

The knowledge about own energy consumption changed significantly during the research phase, from 57% in the first survey to 91% in the last survey[10]. This can be explained by the installation of intelligent meters in the participant homes and the subsequent completion of the monthly energy consumption monitoring scheme. When comparing themselves to other households, around half of the citizen scientists assumed to use less energy than the average household. This number was nearly constant during the whole research period. This means that some households did not know their energy consumption in the beginning but assessed it as below average. Further on, the knowledge about the tenant electricity model steadily increased over time, with 20% of the citizen scientists initially having no knowledge about the model,

[9] Statistisches Bundesamt 2022 https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Ausstattung-Gebrauchsgueter/Publikationen/Downloads-Ausstattung/ausstattung-privater-haushalte-2150200227004.pdf?__blob=publicationFile, page 15

[10] In the questionnaire was asked, if cititzen scientist can estimate their monthly electricity consumption on average.

decreasing to only 5% at the end of the research phase. This trend could be attributed to the conscious dealing with the fundamentals of the model during workshops and discussions.

Analysis of attitudes towards sustainability and the energy transition reveals that around 75% of the citizen scientists are not price sensitive. They would opt for electricity through the tenant electricity model even if it were 5 to 10% more expensive than the average electricity price. Despite the sharp rising electricity prices due to the war against Ukraine, price sensitivity did not change for the citizen scientists over time.
Respondents also ranked important aspects of their energy supply, whereby a positive attitude towards sustainability was visible. On average, the most important aspect is the supply of renewable energy, followed by locally produced electricity. The price of electricity ranked in the middle, whereas energy self-sufficiency and access to electricity consumption data made it respectively on the penultimate and last position (see figure 12).

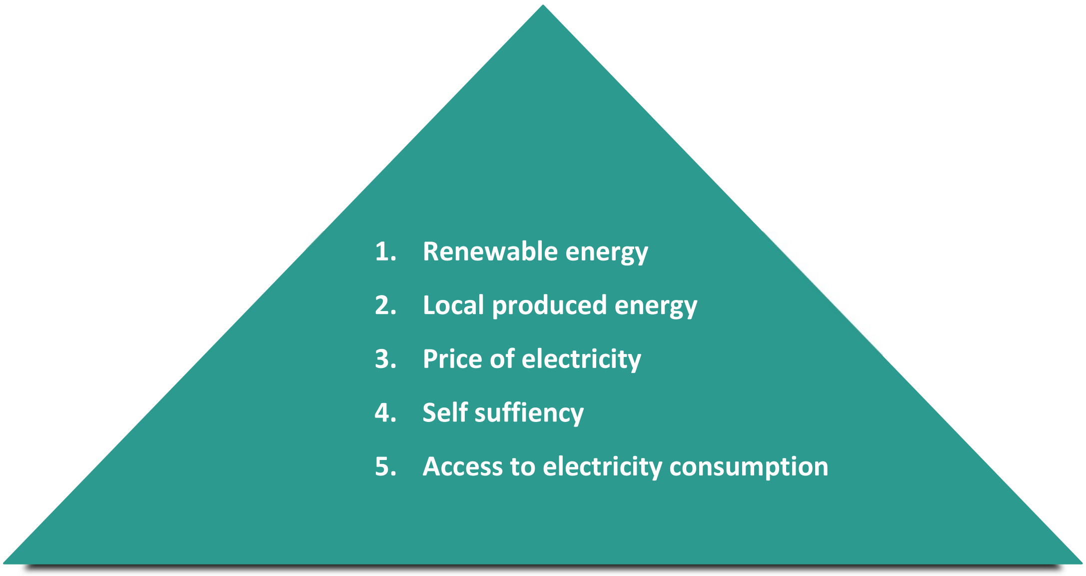

Figure 12: Ranking of important aspects for the Cititzen Scientists (own source)

A further question with an open response option asking for the main reasons for using tenant electricity confirms the sustainable attitude of the participants.[11] Table 5 shows the results of this open question, revealing that around half of all answers in both surveys indicate sustainability and local production as main reasons. The lower price of electricity is not the

[11] This open question was included in survey 2 and survey 3, the first survey was without the possibility to answer openly.

predominant argument for tenant electricity, accounting for around 13% and 9% of all answers, respectively. The availability and promotion of tenant electricity within the house also play an important role, comprising 17.5% and 13% of all answers, respectively. This indicates that a certain proportion of tenants can be mobilized without strong convictions about sustainability or low sensitivity to pricing. Tracking one's own energy consumption and pursuing self-sufficiency only became relevant in the last survey. This change could be caused by the participants engaging with the energy consumption metering software and heightened sensitivity to energy dependencies due to the war against Ukraine.

Table 5: Main reason for tenant electricity (own source)

	Main reason for tenant electricity – Survey 2	Main reason for tenant electricity – Survey 3
Sustainability and locally produced electricity	52%	48%
Tenant electricity was available and promoted in the house	17.5%	13%
Lower price of electricity	13%	9%
Tracking of own energy consumption	0%	13%
Energy self-sufficiency	0%	9%
Other reasons	17.5%	8%

Further confirmation for a sustainable attitude is gained through the responses to questions on the importance of climate protection in relation to economic growth, self-efficacy regarding environmental protection in the surrounding area, and the readiness to engage in the energy transition. All answers received between 80% and 95% consent ("predominantly agree" and "fully agree" on the importance of climate protection, self-efficacy and own readiness for engagement) and no major change could be seen throughout the research phase. The last question in the second section of the questionnaire pertained to the usefulness of feedback on electricity consumption to initiate further energy-efficient measurements. In the first survey, before the implementation of consumption metering and feedback, 100% of participants agreed. However, during the metering phase in the second survey, agreement decreased to 74%. In the last survey, approximately 95% expressed agreement regarding the usefulness of feedback. The decline in the second survey could be attributed to participants adjusting to newly introduced feedback on energy consumption, requiring time to get familiar with the regular consumption feedback. A further open question on this topic asked for additional information they would like to gain. Information about the type of electricity available – solar electricity from the roof or electricity from the grid – and comparison with other households were most relevant. Both answers indicate attitudes favouring sustainability, as this additional information would promote energy saving and the use of local renewable energy.

The last section of the questionnaire focuses on *energy practices.* The first question focuses on the implementation of possible sustainability actions that were motivated *through the participation in tenant electricity*, whereas the second question focuses on possible energy-saving actions resulting from participation *as citizen scientist in this Step Change initiative*. The third question addresses the use of an ecological footprint calculator since joining the Step Change initiative. The last question targets sustainability actions conducted due to the regular consumption metering.

Participation in tenant electricity fostered increased exchange among neighbours regarding further sustainability options within the multi family building. This finding was consistent across all surveys, with 40% to 45% of participants confirming such interactions. Furtheron, the participation in tenant electricity increases interest in becoming a member of an energy cooperative, with 40% to 50% of citizen scientists expressing interest. By the end of the research phase, 8% to 13% had signed up for membership. Through participating in tenant electricity, 22% to 38% displayed no interest in implementing sustainability activities at their workplaces, while 40% to 45% are either interested or have implemented sustainability activities. Similarly, interest in participating in associations focused on sustainability was not an option for 33% to 40%, but 32% to 44% of citizen scientists gained interest in participation, although only a minor stake of 3% to 8% signed up. Despite common sustainability actions with friends and family were done by nearly half of the citizen scientists before participating in tenant electricity, further 35% to 43% are either interested or have begun implementing sustainability actions since participating in tenant electricity.

Participation as a citizen scientist in the Step Change initiative yielded notable changes in tracking energy consumption. A substantial 69% reinforced their interest in the first survey, and in the subsequent surveys, 50% and 45% respectively engaged in energy consumption tracking. Even though 61% of the respondents had already changed their behavior to save energy before the project started, 39% stated a change in their energy-saving behaviour due to project participation in the last survey – compared to 4% in the first survey. Further on, while many citizen scientists were already aware of buying energy-efficient devices before joining the project (48% to 61%), 35% have changed their opinion or made such purchases as a result of their participation. A change due to the project participation can also be seen in considering other options or changes related to energy-intensive activities (e.g., mobility, reducing flights), with 26% of citizen scientists reflecting on this in the last survey. A smaller change is present in reducing time playing video games or streaming videos, with 13% in the last survey.

The use of an ecological footprint calculator was done by only 22% of the participants before the project started. By the end of the research phase (survey 3), an additional 30% had used a footprint calculator due to their participation in the project, while 17% remained uninterested at all in gaining information about their ecological footprint.

The regular review of energy use through the metering software resulted in the reduction of energy consumption due to changes in behaviour for 26% of the citizen scientists in the preultimate and last surveys. One possible energy-saving action entailed turning off the Wi-Fi-router during nighttime. In the first survey, only 22% of citizen scientists did this, compared to 43% in the last survey. When it comes to the procurement of new energy-efficient devices, around 4% to 8% stated the procurement due to the feedback on energy consumption.

6.4. *Quantitative analyses of collected* **energy data**

This section analyses possible changes in the energy consumption-pattern based on energy data collected from November 2022 to April 2023. In total, regular data was collected for 21 households. First, a short overview of the average consumption for each household in relation to average consumption patterns in Germany is introduced in table 6.

Table 6: Overview of household consumption in relation to average consumption patterns in Germany (own source)

Nr.	Average monthly energy consumption from November 2022 to April 2023 in [kWh]	House-hold size	Household situation	Projected yearly energy consumption in [kWh]	German average electricity consumption in [kWh][12]	Relation between projected yearly energy consumption and german average electricity consumption
1	52.87	1	Single household	634.46	1400	-55%
2	144.88	1	Single household	1738.54	1400	24%
3	71.91	1	Single household	862.86	1400	-38%
4	82.49	1	Single household	989.82	1400	-29%
5	104.52	2	Single parent	1254.24	2000	-37%
6	172.08	2	2-person household (adults)	2065.00	2000	3%
7	131.16	2	2-person household (adults)	1573.96	2000	-21%
8	235.50	2	2-person household (adults)	2826.00	2000	41%
9	97.63	2	2-person household (adults)	1171.58	2000	-41%
10	71.00	3	Family (3 persons)	852.00	2600	-67%
11	114.83	3	Family (3 persons)	1378.00	2600	-47%
12	210.98	3	Family (3 persons)	2531.80	2600	-3%
13	144.69	3	Family (3 persons)	1736.24	2600	-33%
14	159.66	3	Family (3 persons)	1915.90	2600	-26%
15	134.68	3	Family (3 persons)	1616.16	2600	-38%
16	159.06	4	Family (4 persons)	1908.74	2900	-34%
17	156.16	4	Family (4 persons)	1873.96	2900	-35%
18	194.29	4	Family (4 persons)	2331.50	2900	-20%
19	202.71	4	Family (4 persons)	2432.54	2900	-16%
20	156.27	5	Family (5 persons)	1875.26	3000	-37%
21	106.59	5	Family (5 persons)	1279.11	3000	-57%

The average monthly energy consumption during our research phase was projected to a yearly basis and set into relation to the German energy electricity consumption for the relevant household size. It can be shown that all families use less energy than the German average with values from -3% to -67%. As only one single household and one two-person household uses significantly more energy than the average with 24% and 41% respectively, it can be summarized

[12] Average yearly consumption in German multi family buildings, where electricity is not used for heating.
Source: https://www.stromspiegel.de/stromverbrauch-verstehen/stromverbrauch-im-haushalt/

that the sample of households is overall taking actions to significantly reduce their energy consumption.

To get a better understanding of the development of energy consumption during the research period, the energy consumption data of each household was fixed in the first month of data collection (mostly November) as base month, with a value of 1.00. The change of consumption data over the following months in table 7 is exclusively referring to the first month of reporting. Each row at the table represents one household.

Table 7: Change of consumption data of citizen scientists. First month as base month with a value of 1.00 (own source)

Nr.	Nov 2022	Dez 2022	Jan 2023	Feb 2023	March 2023	April 2023	Average
1	1.00	1.01	0.68	0.67	0.67	0.69	**0.79**
2	n.a.	1.00	1.01	0.76	n.a.	0.51	**0.82**
3	1.00	n.a.	1.00	0.78	n.a.	0.73	**0.88**
4	1.00	0.99	1.01	0.78	0.83	0.66	**0.88**
5	1.00	0.80	0.80	0.86	1.07	0.78	**0.88**
6	1.00	0.92	1.05	0.93	0.94	0.60	**0.91**
7	1.00	1.03	0.96	0.95	0.93	0.59	**0.91**
8	1.00	0.92	0.97	0.77	0.95	0.91	**0.92**
9	1.00	1.21	0.82	0.81	0.82	0.87	**0.92**
10	1.00	1.15	1.11	0.87	0.77	n.a.	**0.98**
11	1.00	1.08	1.07	0.96	1.17	0.68	**0.99**
12	1.00	1.13	1.01	0.92	1.09	0.82	**1.00**
13	1.00	0.89	1.07	1.35	0.91	0.91	**1.02**
14	1.00	0.58	0.96	1.07	1.38	1.16	**1.03**
15	1.00	1.11	0.96	1.28	0.93	0.96	**1.04**
16	1.00	1.07	1.12	1.64	1.11	0.81	**1.13**
17	1.00	1.06	1.11	1.09	1.35	1.23	**1.14**
18	1.00	0.91	1.01	1.23	1.55	1.17	**1.15**
19	1.00	1.27	1.43	1.43	1.14	0.79	**1.18**
20	1.00	1.27	1.32	1.36	1.30	0.98	**1.20**
21	1.00	1.15	1.49	1.49	1.23	0.95	**1.22**

Table 7 shows an average monthly reduction in electricity consumption over the entire period for 11 households and an average monthly increase of consumption for 9 households. For deeper analysis, two further things must be considered:

First, the electricity consumption is not equally distributed throughout the year and must be adjusted according to the monthly consumption pattern. Therefore, allocation data from *Bundesverband der Energie- und Wasserwirtschaft e.V. (BDEW)* is used for adapting the monthly consumption values[13]. The following table shows the monthly distribution of 100 kWh electricity over one year. It is visible that consumption in the months of January, February, December, and March are higher than in November whereas only April is below November consumption.

Table 8: Monthly electricity load profiles for households. (Source: own calculation based on data of BDEW)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec
10.17%	8.93%	9.33%	8.31%	7.83%	7.02%	6.72%	7.14%	7.33%	8.33%	8.69%	9.98%

The second aspect to consider is the assumption that electricity saving for households is getting more difficult when consumption is already relatively low and there is no big range left to save more energy. One explanation is the lack of change of household devices which are used for several years before they will be replaced (see section *material culture* above). The following table includes the monthly consumption adaptation for each month, setting the first month (primarily November) as the base month with a value of 1. Additionally, the relation between projected annual energy consumption and German average electricity consumption is included to indicate the range of energy saving possibilities.

[13] In this case dynamic loadprofiles for household are used and calculated for the respective month. Source of data: https://www.bdew.de/energie/standardlastprofile-strom/

Table 9: Change of adapted consumption data of citizen scientists. First month as base month with the value of 1. (own source)

Nr.	Nov 22	Dec 22 adapted	Jan 23 adapted	Feb 23 adapted	Mar23 adapted	April 23 adapted	Average	Relation between projected yearly energy consumption and german average electricity consumption
1	1	0.88	0.58	0.65	0.62	0.72	**0.74**	41%
2	1	n.a.	0.99	0.85	n.a.	0.61	**0.81**	-57%
3	1	0.87	0.86	0.76	0.78	0.70	**0.83**	3%
4	1	0.70	0.69	0.83	0.99	0.82	**0.84**	-26%
5	n.a.	1	0.85	0.76	n.a.	0.76	**0.84**	-67%
6	1	0.80	0.90	0.91	0.87	0.63	**0.85**	-41%
7	1	0.89	0.82	0.92	0.86	0.62	**0.85**	-34%
8	1	1.06	0.70	0.79	0.76	0.90	**0.87**	-3%
9	1	0.80	0.83	0.75	0.89	0.95	**0.87**	-21%
10	1	1.00	0.95	0.85	0.72	n.a.	**0.90**	-37%
11	1	0.94	0.91	0.94	1.09	0.71	**0.93**	-35%
12	1	0.98	0.87	0.89	1.02	0.86	**0.94**	-38%
13	1	0.78	0.92	1.31	0.84	0.96	**0.97**	-33%
14	1	0.54	0.88	1.05	1.29	1.22	**1.00**	-47%
15	1	0.97	0.88	1.25	0.87	1.01	**1.00**	-38%
16	1	0.94	0.96	1.59	1.03	0.85	**1.06**	-16%
17	1	0.93	0.95	1.06	1.26	1.28	**1.08**	-55%
18	1	0.80	0.87	1.20	1.44	1.23	**1.09**	-37%
19	1	1.11	1.22	1.39	1.06	0.82	**1.10**	-20%
20	1	1.11	1.13	1.32	1.21	1.03	**1.13**	-29%
21	1	1.00	1.27	1.45	1.14	0.99	**1.14**	24%

Analyzing the data in table 9 allows for a final classification of the changes in energy consumption. 13 households used less energy on average during the research period (average values below 1), from which two households used 41% and 3% more electricity than the average comparable German households and therefore had sufficient saving potential. Two households experienced no change on average since November 2022, whereas 6 households used more electricity during the data collection phase (average values above 1). It must be acknowledged that 5 of these households use between 16% to 55% less energy than the average comparable German household which could impede further energy savings. Only one household used 14% more energy on average since November and uses 24% more energy than a comparable German household on average.

6.4. *Behavioral profiles of citizen scientists: a hierarchical cluster analysis of energy-related knowledge, practices, and norms in the CSI*

In this section, a hierarchical cluster analysis is conducted on selected characteristics to identify homogeneous clusters and help to gain a deeper understanding of the properties that determine energy-related lifestyles, energy culture, and the use of tenant electricity. The analysis utilizes variables from the questionnaire, categorized into material culture, norms (including knowledge), and practices. Further on, categorized energy data and changes in energy consumption are incorporated. A variable would be considered irrelevant in terms of content if it does conceptually not fit for the clustering process. A formal irrelevance is prevalent when there is a large proportion of the same values for a variable (Schendera, 2010, pp. 11-13). Therefore, the following relevant variables have been taken into consideration, as they have not large portions of same values:

Table 10: Relevant categories and variables for the cluster analysis (Source: own elaboration)

Category	**Variables**			
Material culture	Fridge/freezer	Dish washer	Stove	
Norms and knowledge	Estimation of own consumption	Consumption comparison estimation with average households	Conviction of tenant electricity	
Practice	Community engagement	Sustainability actions	Monitoring/ action nexus	Consumption development

The next step involves assessing whether scale conversions or standardization are necessary. The subsequent determination of the similarity or dissimilarity of objects is carried out by using a proximity measure (ibid.). For this survey, ordinal variables are used and converted into a dichotomous scale. Table 11 shows the metric conversion scale for the ordinal variables:

Table 11: Metric conversion scale for ordinal variables (own source)

Category	Ordinary scale	Dichotomous scale
Practice	Yes	1
	Not yet done, but interested	1
	No, I have done it before	0
	No, I am not interested	0
	No	0
Norms & Knowledge	Right estimation regarding consumption data	1
	Wrong estimation regarding consumption data	0
	Rank 1 to 2 (most and second most important)	1
	Rank 3 to 5 (average and not important)	0

Since the energy consumption data of the citizen scientists is included into the clustering process, categories are established, and a convertion from metric to a dichotomic scale is applied. Table 12 gives insight into the categories and dichotomous conversation of energy data.

Table 12: Relevant categories and variables for cluster analysis (own source)

Category	Metric scale	Dichotomous scale
Consumption data related to average comparable households* *mean at -26%	-26% to -xx%	1
	-25.99% to xx%	0
Consumption data - monthly development over research phase	0.xx to 0.999	1
	1 to 1.xx	0

After data preparation, the clustering process is conducted applying the *complete-linkage method* and uses *simple matching* as proximity measure. Figure 13 displays the dendrogram of the clustering process, showing 5 clusters. These clusters are analyzed more in detail by connecting them with additional demographic information such as gender, income, and household size to receive specific profiles. Crossing data of clusters with demographic information will make it possible to get a deeper understanding of properties, which are related to different profiles.

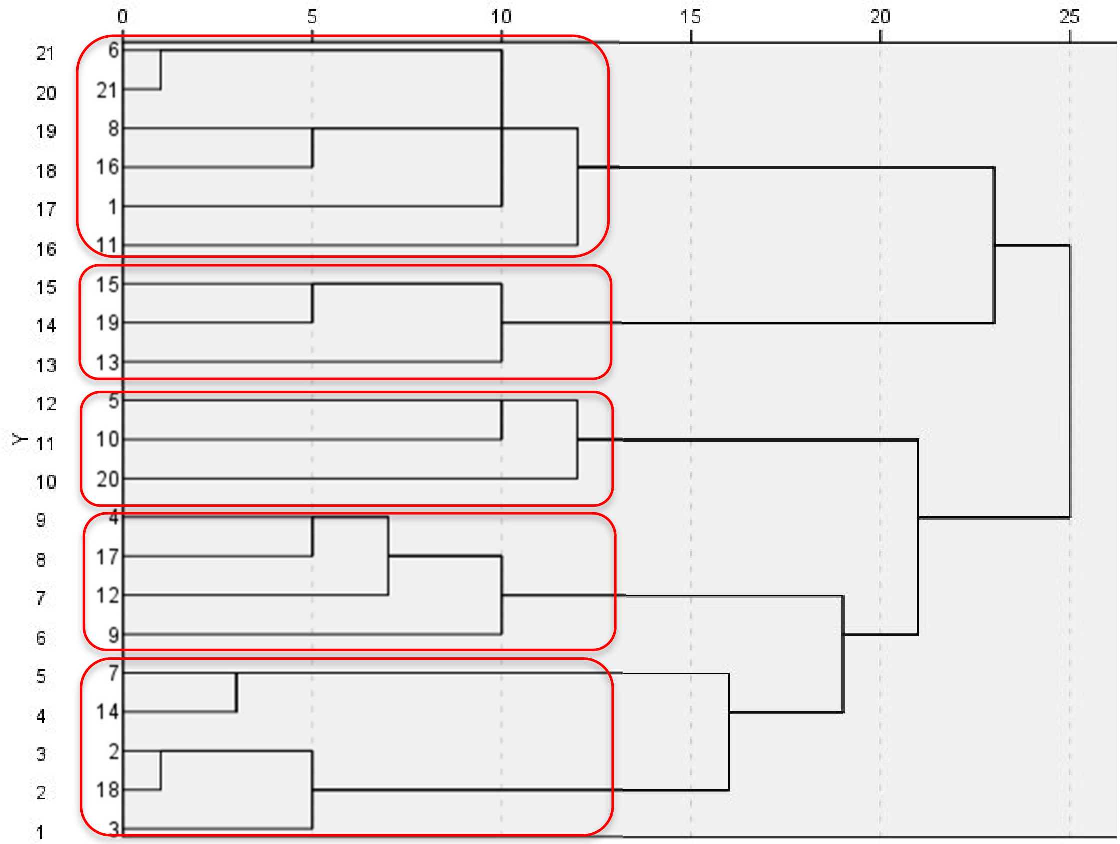

Figure 13: Dendrogram of clustering process with 5 clusters (own source)

A detailed analysis of the 5 clusters yields the following insights:

Cluster 1

The first cluster consists of 6 persons, including 2 women and 4 men. The household income is on the higher end, with 4 households earning at least 4,500 €, and 2 households having an average income of 2,500 to 4,500 €. Nearly all individuals live in family households, with only one person living in a single household. Characteristically, this group exhibits lower *energy consumption* compared to the average consumption patterns of comparable households in Germany. Despite this low consumption, 5 households achieved an average monthly reduction of electricity consumption during the research period. One pillar of low consumption is the use of very energy-efficient household devices (material culture). The *knowledge* regarding accurate estimation of consumption data is relatively low. Only one person is able to estimate the own monthly electricity consumption correctly, and only half of the group can estimate their energy consumption correctly in relation to other comparable households.

In terms of *practices*, participation in tenant electricity did not lead to further interest or engagement in sustainability actions with family, friends, or associations with sustainability focus. Only half of the group showed interest or took actions in implementing further sustainability measures with neighbours as a result of their participation in tenant electricity. This also applies to the stimulation for participating in energy cooperatives. Analyzing the changes in energy practice due to the participation in this citizen science initiative results in no changes regarding further energy intensive activities and in almost no changes regarding the decrease of energy consumption. Further on, no changes can be seen regarding the use of an ecological footprint calculator due to the participation in the citizen science initiative. Major changes can be seen in the observation of the electricity consumption, which was applicable to 4 persons. Nonetheless, did the observation of electricity consumption lead to improved energy-efficient bevaviour for only 1 person.

Table 13: Overview of cluster 1

Cluster 1	**Energy consumption**	**Material culture**	**Knowledge**	**Change in practice through participation in tenant electricity**	**Change in practice through participation in CSI**
Profile	low	efficient	low	low	low

Cluster 2

Comprising 5 individuals, this cluster is predominantly male, with one woman and four men. The household income shows a mixed picture, with 3 households earning at least 4,500 €, 1 in the middle-income range of 3,500 to 4,500 €, and 1 household falling below 1,500 €. Household compositions differ, as three persons live in family households, one person in a 2-person-household, and one person lives alone. Characteristic for this group is a higher energy consumption compared to cluster 1. Only 60% managed to use less electricity in relation to average consumption patterns among comparable German households. However, 40% of the group achieved an average monthly reduction in electricity consumption during the research period. The *material culture* can be described as average, as 40% of all considered devices are energy efficient. Regarding the *knowledge category*, only 2 persons accurately estimated their monthly electricity consumption, yet all persons managed to correctly estimate their electricity consumption relative to other comparable households.

Analysing the *practice* category, participation in tenant electricity led to further interest in sustainability actions together with neighbours for all individuals, while only one person showed further interest in sustainability actions with family and friends. Interest in participation in sustainability-focused associations and energy cooperatives due to participation in tenant electricity was expressed by 3 individuals. Through participation in this citizen science initiative, all persons observed their electricity consumption regularly. Three persons reported energy reduction due to the initiative, with two persons directly linking it to electricity consumption observation. This was not the case at all for changes regarding further energy-intensive activities. However, all persons expressed interest or even used an ecological footprint calculator due to their participation in this citizen science initiative.

Table 14: Overview of cluster 2

Cluster 2	Energy consumption	Material culture	Knowledge	Change in practice through participation in tenant electricity	Change in practice through participation in CSI
Profile	medium	Medium efficient	medium	medium	medium

Cluster 3

Comprising 4 individuals, this cluster is also predominantly male, with one woman and three men. Household income shows variation with 1 household earning at least 4,500 €, 1 in the middle-income range of 2,500 € to 3,500 €, and 2 households falling in the 1,500 € to 2,500 € range. Household compositions differ, as two persons live in 2-person households, one in a single-person household, and one person lives in a family household.

Characteristic for this group is a high electricity consumption, with three persons consuming more electricity compared to average consumption patterns among comparable German households. Only one person managed an average monthly reduction in electricity consumption during the research period.

The *material culture* can be described as low, as only 30% of all considered devices are energy-efficient. *Knowledge* regarding the correct estimation of the own monthly electricity consumption was high, with 3 persons providing accurate estimations. However, none correctly estimated their electricity consumption in relation to other comparable households. Noticeable for this group is the missing relevance of locally produced electricity for them, which was of interest in all other groups.

Analysing the *practice* category, participation in tenant electricity led to further interest or action in all areas for this cluster. All individuals expressed interest in sustainability actions together with neighbours, in participation in sustainability-focused associations, and in engagement in energy cooperatives. Three persons are interested in further sustainability actions with family and friends. Due to their participation in the CSI, all persons expressed interest in or even used an ecological footprint calculator and expressed interest in or even made changes regarding further energy intensive activities. But the participation in the citizen science initiative had no major impact on the regular observation on their electricity consumption, with a reported change for 2 persons, and with only one person reporting energy reduction.

Table 15: Overview of cluster 3

Cluster 3	Energy consumption	Material culture	Knowledge	Change in Practice through participation in tenant electricity	Change in practice through participation in CSI
Profile	high	Low	medium	high	medium

Cluster 4

This cluster consists of 3 male persons. Household income displays variability, with 1 household earning at least 4,500 €, 1 in the middle-income range, and 1 household in the range of 1,500 € to 2,500 €. Household compositions differ, as two persons live in 2-person households, and one person lives in a family household.

Characteristic for this group is above-average electricity consumption, with two persons consuming more electricity compared to average consumption patterns among comparable German households. However, all individuals managed an average monthly reduction in electricity consumption during the research period of the initiative.

The *material culture* can be described as very high, as 90% of all considered devices are energy-efficient. *Knowledge* regarding the correct estimation of the own monthly electricity consumption was high, with 2 persons providing accurate estimations, and all persons making correct estimations of their electricity consumption relative to other comparable households.

In terms of *practices*, participation in tenant electricity led all persons to further action or interest in sustainability measures together with neighbours and in further sustainability measures with family and friends. The participation in sustainability-focused associations was of interest to two persons, and one person expressed interest in engagement in energy cooperatives.

Furtheron, through the participation in the citizen science initiative, all persons expressed interest in or even used an ecological footprint calculator, and two persons expressed interest in or even made changes regarding further energy intensive activities. Two persons stated that the participation in the citizen science initiative had no major impact on the regular observation of their electricity consumption, but two persons reported energy reductions due to the observation of energy consumption data.

Table 16: Overview of cluster 4

Cluster 4	Energy consumption	Material culture	Knowledge	Change in Practice through participation in tenant electricity	Change in practice through participation in CSI
Profile	high	high	High	medium	medium

Cluster 5

The fifth cluster consists of 3 female persons with two household income in the range of 3,500 € to 4,500 € and one household income in the 1,500 € to 2,500 € range. Two individuals live in family households, and one person lives alone.

This cluster's characteristic is low electricity consumption, as all persons consume less electricity compared to average consumption patterns among comparable German households. Remarkably, two persons managed an average monthly reduction in electricity consumption during the research period of the initiative.

The *material culture* is low, as only 11% of all considered devices are energy-efficient. *Knowledge* regarding the correct estimation of the own monthly electricity consumption was high, as all individuals provided accurate estimations, and two persons made correct estimations of their consumption in relation to other comparable households.

Analysing the *practice* category, participation in tenant electricity did not lead to further action or interest in sustainability measures together with neighbour, family, or friends for any of the individuals in this cluster. The participation in associations with sustainability focus was of interest to two persons, and one person expressed interest in engagement in energy cooperatives.

Furtheron, through the participation in the citizen science initiative all persons made regular observation on their electricity consumption, but neither the observation nor the participation in the citizen science initiative had an impact on the reduction of their energy consumption. The CSI did also not lead to interest in using an ecological footprint calculator, but two individuals expressed interest in or even made changes regarding further energy-intensive activities.

Table 17: Overview of cluster 5

Cluster 5	Energy consumption	Material culture	Knowledge	Change in practice through participation in Tenant electricity	Change in practice through participation in CSI
Profile	low	Low	High	low	medium

7. Conclusion and key results

Even though the relationship between citizen science and decentralized energy systems has been scarcely explored (Wuebben, et al., 2020), there is an increasing recognition that the involvement of citizens in energy research and innovation can be a powerful tool to enhance the acceptance of the energy transition and the understanding of the societal challenges that the energy transition and the achievement of SDG7 entail. Against this background, by involving a variety of actors such as citizens, researchers, experts, enterprises, landlords, NGOs, and politicians, the Step Change initiative on energy communities in Germany sought to bridge the gap between scientific research and public engagement and to provide a more comprehensive and holistic understanding of the challenges and drivers of the tenant electricity model.

7.1. Encountered Challenges

The implementation of the Citizen Science Initiative presented the research team with a number of challenges and lessons. First, the recruitment of citizen scientists was more challenging and time-consuming than was estimated in the planning phases of the project. Despite WECF's longstanding cooperation with energy cooperatives, the interest of the members in participating in the initiative was low. In this context, the core team needed to redesign the recruitment strategy in order to increase the interest of potential citizen scientists. An adequate, long-planned recruitment phase together with an appealing design of the recruitment material and financial incentive for citizen scientists emerged as key determinants of success.

Another challenge was the different interests and stages of engagement of the citizen scientists in the project. Some citizen scientists were very familiar with renewable energy, the tenant electricity model, and engaged in discussions, while others were not. The diverse composition of the group needs to be taken into account by researchers and methods found to engage all citizen scientists. Important for this CSI were small break-out sessions in workshops, personalised emails and even bilateral phone calls on specific topics.

The WECF team has a strong commitment to integrating intersectional and gender-responsive approaches in research. Therefore, the core team sought to have a group that was gender-balanced and inclusive of diverse backgrounds. This was difficult to achieve given that in

Germany there is a higher participation of men in community energy models. Regarding the research findings, although sex-disaggregated data were collected, conclusions regarding gender differences were only considered in the cluster analyses and cannot be generalised due to the small sample size.

7.2. Key messages

Barriers and drivers of the tenant electricity model

Most of the current studies on tenant electricity often focus on barriers to the tenant electricity model resulting from regulatory frameworks that end in technical and economic barriers (e.g. Moser et al., 2021). However, a study on the acceptance of tenant electricity from the perspective of tenants (Schäfer, 2019) found that aspects related to lower costs, the provision of renewable energy, and sustainability concerns are key determinants of a tenant's decision to participate in tenant electricity. Our research builds on this study and provides new insights into the barriers identified. The identified barriers encompass both structural and inherent challenges. Structural barriers include:

I) a lack of (former) political willingness to promote the model
II) the complexity of the model and
III) low economic incentives to implement the model on a broader scale.

Next to these structural barriers, inherent barriers of the model include:

IV) lack of *information* about the model on all levels and
V) lack of *initiators* who are able to drive the implementation of the model at the local level.

Strategies for overcoming barriers

As stated in chapter 6.1, overcoming barriers implies measures and strategies from different actors such as political actors, energy supply actors and building-related actors, such as residents and building-owners.

One of the essential steps for scaling up the model is its simplification, and **political actors** are responsible for reducing the complexity of the model. There are some noticeable developments in this regard as the current Federal Government is planning to include strategies for bureaucracy reductions and further development of the existing tenant electricity model as a component of its photovoltaic strategy (Bundesministerium für Wirtschaft und Klimaschutz, 2023, pp. 18 - 22)[14]. Moreover, the new strategy considers the introduction of community supply within a building (proportionate allocation of generated pv electricity to residents resulting in a reduction of grid electricity), which would be an additional entry point for the implementation of energy sharing options in buildings.

Policymakers can also use regulations to encourage the expansion of tenant electricity, for example by requiring the installation of photovoltaic panels on new buildings and requiring grid and metering operators to apply a standardised metering concept. Economic incentives could not only be part of the model itself, but local authorities can support with special programmes and use their scope for action. This requires a proactive role for local authorities in informing and reaching out to residents, e.g. by checking the photovoltaic cadastre and approaching property owners.

Energy supply actors, such as utilities and tenant electricity providers, can contribute to faster uptake through targeted information and marketing to relevant audiences, such as property managers, housing cooperatives and energy cooperatives. Prospective customers in multi-family dwellings can be reached by advertising the tenant electricity model in their bills. In addition, energy companies have a financial control instrument if they offer a two-tariff system and provide cheaper electricity when it is produced by the PV system.

Concerning the lack of initiators at the local level, (also) residents can contribute to a faster uptake of the tenant electricity model. The exchange with interested neighbours and the promotion of the project at owners' meetings are key for a bottom-up approach. The necessary

[14] The federal cabinet approved the "Solarpaket" on 16th of August 2023 with improvements on tenant electricity model and introduction of community supply within multi-family buildings. Source: https://www.bundesregierung.de/breg-de/aktuelles/solarpaket-2213726, accessed August 24, 2023

support from apartment owners can be achieved by demonstrating the potential increase in property value by using PV systems.

Motivation and sustainability awareness of CS

Another objective of our CSI was to identify **motivation** of citizen scientists participating in tenant electricity. Data from the workshops and surveys broadly align with previous observations (e.g., Schäfer, 2019), linking participation in tenant electricity to sustainability awareness and to a lesser extent to the potential lower electricity prices.

Surprisingly, despite the general increase in electricity prices due to Russia's invasion of Ukraine, participants in the citizen science initiative still appear to have low price sensitivity. These findings provide support for the notion of *changing social norms* as a key determinant of energy behaviour and a more sustainable energy culture.

On the other hand, for almost a fifth of the participants, the main motivation for participating in tenant electricity was the availability and promotion of the model in the building. However, it should be noted that 70% of the citizen scientists live in housing cooperatives where the implementation of rental electricity was decided by a simple majority at the general assembly meeting. However, the conclusion of a tenant electricity contract is in any case voluntary. This finding indicates that, taking into account the specific composition of our group, the bottleneck in the implementation of tenant electricity is not due to a lack of demand.

Impact on energy culture

A possible change in **energy culture** was examined through the participation in tenant electricity, the feedback on regular electricity consumption data, and by the participation in this Citizen Science Initiative. The participation in tenant electricity has led to an overall stronger exchange among neighbours about further sustainability options in the building and to higher interest in sustainability actions with friends and family. In general, the citizens scientists have expressed interest in participating in social and environmental initiatives, including energy cooperatives and associations with a sustainability focus. Similarly, participation in tenant electricity also spills over in interest in conducting sustainability activities at the workplace. This indicates a general positive impact on the energy culture.

As stated in section 6.4, especially cluster 3 stands out when referring to the changes caused by the *participation in tenant electricity*. For them, participation led to further interest or action in nearly all the above-mentioned areas. This is of special interest as people of this cluster had the highest relative energy consumption of all five clusters, an overall low material culture and low knowledge about classifying the electricity consumption in regard to comparable households. As the cluster covers nearly 20% of the participating citizen scientists, it is diverse in income and household situation it can be seen as the group where tenant electricity did the most to reflect about and change their energy culture.

Feedback on regular consumption data and energy culture impacts

Analysing the *feedback on regular consumption data* regarding impacts on energy culture, most participants found it useful for further action to save electricity. According to the survey responses, the regular review of energy use through the metering software has led to a reduction in energy consumption through behavioural change for around a quarter of the citizen scientists. When it comes to purchasing new energy efficient equipment, only a small share of the citizen scientists expressed that feedback on energy consumption motivated them to change their equipment. This is in line with the results for material culture, where small changes in responses were noted for household appliances, with a slightly higher number of energy efficient appliances in the fridge/freezer, dishwasher and laptop categories. Unfortunately, the survey did not ask about the disposal of electronic equipment as a sufficiency measure, which was seen in the reduction of multimedia equipment during the research phase.

Backing up the survey results with electricity consumption data during the research period, it was visible that more than half of the households used less energy on average during the research period compared to the starting month of the research period[15]. Only 6 households used more electricity during the data collection phase, but it must be acknowledged that 5 of these households used still less energy than the average comparable German household. Similarly, positive results in electricity-saving behaviour were observed through the cluster analysis. In particular, two thirds of cluster one managed to save electricity during the research phase despite less energy use than the average comparable German household. Supportive in this case is a highly efficient material culture for this cluster. In cluster five the situation is similar to cluster one, but the material culture is not efficient, and it is even harder to save electricity

[15] Data from table 9 - change of adapted consumption data of citizen scientists

which can only be done by a very conscious use of electrical devices. In contrast, in cluster four electricity savings for all households were achieved whereas two third use more energy than the average comparable German household and the material culture is highly efficient.

Additional information about the type of electricity available - solar from the roof or from the grid - and the ability to compare with other households were seen as drivers to encourage more conscious use of electricity. This should be taken into account by tenant electricity suppliers when providing metering software to their customers.

The Citizen Science Initiative and its impact on energy culture

The final research question relates to the impact of participation in the Step Change project on energy culture. In this regard, the project initiated regular electricity tracking for about half of the citizen scientists, which can be related to higher awareness on the own consumption and foster behavioral changes in the long run. Participants also became more aware of energy efficient appliances and around a quarter reported changes in certain energy-intensive practices (e.g., mobility or flights). Similarly, the project also initiated the use of ecological footprint calculators for about one third of the citizen scientists.

7.3. Further research opportunities

We find ourselves in a dynamic phase with fundamental legal, bureaucratic, and financial changes and development of the model through the current government, which brings further research opportunities regarding the model. Since the motivation to participate in tenant electricit is highly influenced by sustainability concerns, it is relevant to conduct further research on the ways to use changing social norms towards sustainable behaviour to increase the acceptance of tenant electricity and energy sharing models.

The cluster analysis also provides interesting research opportunities, as each of the 5 elaborated cluster has their own sub-energy culture determined by energy consumption patterns, equipment with energy efficient devices, knowledge on energy consumption and energy practice changes. A better understanding of each cluster could be conducive for a more targeted interventions and nudges that encourage citizens to participate in energy sharing models and to change energy-related behaviours.

There is also a growing need for research into the social justice implications of the tenant electricity model and, more generally, of community energy and energy sharing. Citizen science has the potential to help analyse whether these models provide equal access and benefits across different demographic groups and socio-economic backgrounds, and how gaps can be addressed.

Finally, it should be noted that this report can be seen as a pioneer publication on the implementation of a CSI in the area of SDG7 (clean energy) through the analytical lens of the energy cultures framework, and that it will lay the groundwork for further citizen science and institutionalised science to expand and complement.

8. Bibliography

Ambrosio-Albalá, P., Upham, P. & Bale, C., 2019. Purely ornamental? Public perceptions of distributed energy storage in the United Kingdom. *Energy Research & Social Science,* Issue Volume 48, pp. Pages 139-150.

Bonney, R. et al., 2009. Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *Bioscience,* 01 December, https://doi.org/10.1525/bio.2009.59.11.9(Volume 59), pp. 977-984.

Brundtland, G., 1987. *Our Common Future: Report of the World Commission on Environment and Development..* A/42/427 ed. Geneva: UN-Document.

Bundesministerium für Wirtschaft und Klimaschutz, B., 2023. *Photovoltaik-Strategie.* [Online] Available at: https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/photovoltaik-stategie-2023-entwurf.pdf?__blob=publicationFile&v=14
[Accessed 01 Juli 2023].

Bundestag, 2000. *Erneuerbare Energien Gesetz (EEG).* [Online]
Available at: https://www.gesetze-im-internet.de/eeg_2014/

Bundestag, 2017. *Gesetz zur Förderung von Mieterstrom und zur Änderung weiterer Vorschriften des Erneuerbare-Energien-Gesetzes.* [Online]
Available at:
https://www.bgbl.de/xaver/bgbl/start.xav#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl117s2532.pdf%27%5D__1690455787618

European Parliament, 2018. *DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL.* [Online]
Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

Haklay, M. et al., 2020. *ECSA's Characteristics of Citizen Science.* [Online]
Available at: 10.5281/zenodo.3758668; https://zenodo.org/record/3758668

Hopkins, D., 2016. Destabilising automobility? The emergent mobilities of generation Y. *AMBIO A Journal of the Human Environment,* Issue 46(3).

Hopkins, D. & Stephenson, J., 2016. The replication and reduction of automobility: findings from Aotearoa New Zealand. *Journal of Transport Geography,* Issue 56, pp. 92-101.

Ishak, M. H., 2017. Modelling energy consumption behaviour using 'energy culture' concept for student accommodations in Malaysian public universities. *Facilities,* DOI:10.1108/F-12-2015-0084(35(3)), pp. 658-683.

Johnson, O., Gerber, V. & Muhoza, C., 2019. Gender, culture and energy transitions in rural Africa. *Energy Research & Social Science,* https://doi.org/10.1016/j.erss.2018.11.004(49), pp. 169-179.

Kieslinger, B., Schäfer, T., Heigl, F. & Dörler, D., 2018. Evaluating citizen science – Towards an open framework. In: U. Press, ed. *Citizen Science – Innovation in Open Science, Society and Policy* . s.l.:s.n., pp. pp.81-98.

Klaniecki, K. et al., 2020. Applying the energy cultures framework to understand energy systems in the context of rural sustainability transformation. *Energy Policy,* https://doi.org/10.1016/j.enpol.2019.111092(Volume 137).

Lawson, R. & Williams, J., 2012. *Understanding Energy Cultures.* [Online]
Available at: https://www.otago.ac.nz/centre-sustainability/otago055641.pdf
[Accessed 27 07 2023].

Moser, R., Xia-Bauer, C., Thema, J. & Vondung, F., 2021. Solar Prosumers in the German Energy Transition: A Multi-Level Perspective Analysis of the German 'Mieterstrom' Model. ,. *Energies,* https://doi.org/10.3390/en14041188(14, 1188).

Rau, H., Moran, P., Manton, R. & Goggins, J., March 2020. Changing energy cultures? Household energy use before and after a building energy efficiency retrofit. *Sustainable Cities and Society,* Issue Volume 54.

Schäfer, M., 2019. *Akzeptanzstudie "Mieterstrom aus Mietersicht".Eine Untersuchung verschiedener Mieterstromprojekte in NRW,* s.l.: Wuppertaler Insitut für Klima, Umwelt, Energie GmbH.

Schendera, C. F. G., 2010. *Clusteranalyse mit SPSS. Mit Faktorenanalyse..* München: Oldenbourg.

Stephenson, J. et al., 2010. Energy cultures: A framework for understanding energy behaviours. *Energy Policy ,* Volume 38, pp. 6120-6129.

Stephenson, J. et al., 2015. The Energy Cultures Framework: Exploring the Role of Norms, Practices and Material Culture in Shaping Energy Behaviour in New Zealand. *Energy Research & Social Science,* Issue Volume 7, pp. pp. 117-123..

Sweeney, J. et al., 2013. Energy saving behaviours: Development of a practice-based model. *Energy Policy,* Issue Volume 61, pp. Pages 371-381.

Tweddle, J., Robinson, , L., Pocock, M. & Roy, H., 2012. *Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK.* [Online]
Available at: www.ukeof.org.uk

Vohland, K. et al., 2021. *The science of citizen science..* s.l.:Springer Nature.

Wuebben, D., Romero-Luis, J. & Gertrudix, M., 2020. Citizen Science and Citizen Energy Communities: A Systematic Review and Potential Alliances for SDGs. *Sustainability 2020,* Issue 12(23).

Annex 1: Energy Lifestyle Questionnaire

Section 1 – General information

1.1. Age range

- ☐ 18–29 years old
- ☐ 30–39 years old
- ☐ 40–49 years old
- ☐ 50-59 years old
- ☐ >60 years old

1.2. Gender:

- ☐ Female
- ☐ Male
- ☐ diverse

1.3 Employment status:

- ☐ Full-time employee
- ☐ Part-time employee
- ☐ Self-employee/freelance
- ☐ Retired
- ☐ Unemployed and looking for work
- ☐ Homemaker/caregiver (e.g., children, elderly)
- ☐ Student

1.4 Household size:

- ☐ Single household
- ☐ Single parent (+1 Child)
- ☐ Single parent (+2 Children)
- ☐ Single parent (+3 Children or more)
- ☐ 2 persons (adults)
- ☐ Family (3 Persons)
- ☐ Family (4 Persons)
- ☐ Family (5 Persons and more)
- ☐ Shared apartment/commune with 3 persons
- ☐ Shared apartment/commune with 4 persons and more

1.5 Household /(person, if single or shared apartment) *net* income per month:

- ☐ 0 - 1500 €
- ☐ 1501 – 2500 €
- ☐ 2501 – 3500 €
- ☐ 3501 – 4500 €
- ☐ 4501 - …
- ☐ No answer

1.7 Which of the following categories best defines your housing situation and tenant electricity situation?

- ☐ Tenant
- ☐ Flat Inhabitant of a condominium
- ☐ Inhabitant of a flat in a housing cooperative
- ☐ Other: _______________

1.8 Which of the following categories best defines your situation regarding tenant electricity?

- ☐ Interested in tenant electricity, but not obtaining
- ☐ Obtaining tenant electricity
- ☐ Involved in tenant electricity (investing)
- ☐ Member of an energy cooperative
- ☐ Other: ___________________________

1.9 Are you a member or participant of any of the following initiatives/groups? (Multiple answers possible)

- ☐ Energy community
- ☐ Environmental Initiative
- ☐ A political party or group
- ☐ Professional association
- ☐ Initiative regarding sustainability at your workplace
- ☐ None

Section 2 Material Culture

2.1. How large is your living space?

- ☐ 0-30 m^2
- ☐ 31-60 m^2
- ☐ 61 -80 m^2
- ☐ 81 - 100 m^2
- ☐ 101 - 150 m^2
- ☐ > 150 m^2

Use of electrical appliances and electronic devices

Please indicate your household use of the following electrical appliances

2.2 Lightning:

What kind of light bulbs do you have in your flat?

- ☐ Mainly LED lightning (> 70%)
- ☐ Mainly non-LED lightning
- ☐ I don't know

Household devices:

2.3 What kind of the following electrical appliances do you have at home:

Device	High energy efficiency	Average energy efficiency	Low energy efficiency	I don´t know	I do not have this device
Washing machine					
Dryer					
Fridge/Freezer					
Dish Washer					

Infobutton für Labels (A+++ or (at least) C with new EU-Energy Label)

(B-D former EU Energy Label E-G with new EU-Energy Label)

2.4 Which of the following statements describes the use of the dryer in your home:

- ☐ I always use the dryer
- ☐ I regularly use the clothes dryer (>50%)
- ☐ I use the clothes dryer sometime (<50%)
- ☐ I only air-dry my clothes

2.5 What type of stove do you use for cooking?

- ☐ Induction stove
- ☐ Cooker with ceramic stove
- ☐ Gas stove
- ☐ Other stove: _______________

2.6 EDV Devices:

How many electronic devices do you have at home?

PC	Gaming/Multimedia PC	Laptop	Laptop with external Monitor

2.7 How many and what type of televisions do you have at home?

TV < 50 inch and not older than 5 years	TV < 50 inch and older than 5 years	TV > 50 inch and not older than 5 years	TV > 50 inch and older than 5 yeas	No TV at all

2.8 Which of the following statements describes the use of the Wi-Fi router in your home

- ☐ I never switch the Wi-Fi router off
- ☐ I switch the router off at night
- ☐ I do not have a Wi-Fi router

Section 3 Knowledge

3.1. Could you say how much electricity your household consumes on average per month?

- ☐ No, I have to look it up
- ☐ yes, less than 100 kWh/month
- ☐ yes, between 100 and 200 kWh/month
- ☐ yes, between 200 and 300 kWh/month
- ☐ yes, more than 300 kWh/month

3.2. Compared with the national average, do you think your household energy consumption is

- ☐ Below average
- ☐ Average
- ☐ Above average
- ☐ I don't know

3.3. Do you know how the tenant-electricity model works? (RQ1 RQ2)

- ☐ Yes, in detail
- ☐ Yes, I understand the logic but not all details
- ☐ No, I don´t know how it works

Section 4 Norms

4.1. Describe the main reasons of your participation/investment in tenant electricity?

Participation:

- ☐ It was promoted by my supplier
- ☐ It was offered by my landlord
- ☐ I want to contribute to the energy transition
- ☐ Because of the lower price of electricity

4.2. How important are the following aspects of energy supply to you? (1= not at all important, 2= Slightly important, 3= important, 4= very important)

	Not important	**Rather not important**	**Rather Important**	**Very important**
Aspect	**1**	**2**	**3**	**4**
Price of electricity				
Renewable energy				
Local generated electricity				
Digital metering				
self-sufficiency				

4.3. Would you also consume tenant electricity when it would be 5 -10 % more expensive than the average electricity price?

- ☐ Yes
- ☐ No

4.4. Indicate to what extent you agree or disagree with the following statements (1= strongly disagree; 2= rather disagree; 3= rather agree; 4= strongly agree)

	1	**2**	**3**	**4**
I see climate change as a real problem				
I consider the mitigation of climate change more relevant than economic growth				
I believe that people advocating for environmental protection have a real impact for improvement				
I believe that I can make a difference regarding environmental protection in my environment				

I would change some of your habits to protect the environment (e.g., using the bike instead of the car for small distances)				
I would engage in my community with further actions to foster the energy transition (e.g. in an energy cooperative)				

4.5. Do you think it would be useful to have feedback on your electricity consumption (e.g. for further action)?

- ☐ Yes
- ☐ No

4.6. What kind of information would you like to receive?

- ☐ I don´t need any information
- ☐ Quantitative (how many kWh am I consuming)
- ☐ Comparative (my positioning respect the average)
- ☐ Time distribution (when am I consuming which amount of energy)

Section 5—Practices

5.1. Has your participation in tenant electricity motivated any of the following actions regarding sustainability in your community?

Action	No because I am not interested	No because I was engaged before (the participation in tenant electricity has had no influence)	I have not done it yet, but I am interested	Yes
Getting a membership in an energy cooperative				
Discussing with neighbors about further sustainability options in your multifamily building				
Common actions with friends and family (e.g., planting trees, planting own food together, Citizens' Initiative)				
Implementing sustainability actions at your workplace				

participating in associations which have a sustainability focus				
other sustainability activities				

5.2 Has the participation in tenant electricity motivated some of the following actions regarding consumption (RQ3)?

Action	No because I am not interested	No because I was doing it before (the participation in Tenant Electricity has had no influence)	I have not done it yet, but I am interested	Yes
I observe my electricity consumption regularly				
I have reduced my energy consumption due to different behaviour (e.g. switching the lights off, stopped using the dryer)				
I have reduced my energy consumption due to buying efficient devices (e.g. new fridge)				
I think about further options or changes regarding energy intensive activities (e.g., mobility, flight reduction)				
I reduced the time spent on streaming videos or playing videogames				

5.3 Have you ever used an ecological footprint calculator since you have been participating in tenant electricity to know your environmental impact (e.g. carbon footprint)?

- ☐ No, because I am not interested
- ☐ No, because I was doing it before (the participation in Tenant Electricity has had no influence)
- ☐ I have not done it yet, but I am interested
- ☐ Yes

5.4 Do you use devices or apps that allow you to periodically know your energy consumption since you participate in tenant electricity (RQ4)?

- ☐ No, because I am not interested
- ☐ No, because I was doing it before (the participation in tenant electricity has had no influence)
- ☐ I have not done it yet, but I am interested
- ☐ Yes

5.5 If you monitor your energy consumption regularly, has it triggered one of the following activities? (RQ4)

	Yes	**No**
I have reduced my energy consumption due to different behaviour (e.g. switching the lights off)		
I have reduced my energy consumption due to buying efficient devices (e.g. new fridge)		
I think about further options/fields of actions (e.g. buying an electric car)		