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RESEARCH ARTICLE

Using citizen science for the energy transition: Research on the tenant electricity model in Germany

[version 1; peer review: 1 approved, 2 approved with reservations, 1 not approved]

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Abstract

Background

The research within the Citizen Science (CS) project on tenant electricity focused on an inclusive research approach by involving actors such as citizen scientists (CSs), 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 CSs by being involved in local electricity production and consumption.

Methods

The CS project adopted a mixed-method approach, combining qualitative data analysis from workshops with quantitative data from an energy consumption monitoring scheme and a panel survey on energy-related practices.

Results and conclusions: Identified barriers for the tenant electricity model encompassing both structural (e.g. model complexity) and inherent challenges (lack of information). Drivers for scaling up include the reduction of the complexity and bureaucratic hurdles of the model as well as regulations and financial incentives and targeted information to relevant actors.

The main motivation for participating in tenant electricity was sustainability and local production of electricity, while the electricity price played a minor role. Regarding changes in energy culture, the participation in tenant electricity led to a stronger exchange among neighbours about further sustainability options and to a higher

Open Peer Review

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interest in sustainability or society engagement.

Feedback on regular consumption data was perceived by almost all participants as useful for further measures to save electricity. Electricity data collected from installed meters showed, on average, a reduction in consumption for more than half of the households compared to the start month of the research period.

Further, a cluster analysis was conducted to identify different profiles and gain deeper understanding of the characteristics of CSs. In total five clusters were identified, with differences in energy consumption patterns, energy efficient appliances, knowledge about energy consumption, and changes in energy practices.

Keywords
Renewable energy, citizen science, tenant electricity model, energy transition, neighbourhood energy sharing

H2020 This article is included in the Horizon 2020 gateway.

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Introduction

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). Nevertheless, 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.* (2020) 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 sustainable development goals (SDGs) were born of the same moment" (Wuebben *et al.*, 2020, p. 3), it becomes intriguing to consider which SDGs are addressed through Citizen Science projects. Wuebben *et al.* (2020) conducted a literature analysis showing that out of 127 Citizen Science projects in Germany, most tackled SDG 15 "Life on Land" and SDG 4 "Quality Education", while none addressed SDG 7 "Affordable and Clean Energy".

As renewable forms of energy bear the potential to make energy more accessible and inclusive to people and communities, which is also known under the term "democratization of energy", it offers a paradigm change where citizen science can play a pivotal role for gaining new results.

Our research on clean energy applying a citizen science approach was conducted within the EU-funded *Step Change Project* (https://stepchangeproject.eu/), which 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. More precisely the research focused on the under-exploited potential of photovoltaic systems on multi-family buildings in Germany, mainly implemented through the so-called *tenant electricity* model. This model provides the opportunity for neighborhood-based electricity sharing with the sale of electricity generated directly within multifamily buildings with reduced fees and taxes (Bundestag, 2017). As multi-family buildings accommodate around half of the German housing stock, the involvement of tenants in the production of clean electricity can be seen as key to boost the urban energy transition (Moser *et al.*, 2021).

But realising that the tenant electricity 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 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.

In addition to the barriers and drivers for the tenant electricity model, the motivations of the citizen scientists (CSs) to participate in the tenant electricity model were examined. Furthermore, the initiative examined behavioural changes of the citizen scientists (based on the *energy culture* concept) due to their involvement in local electricity production and consumption. In detail, the five research questions are:

1. What are the *barriers and drivers* for involvement in tenant electricity models, and how can we overcome these barriers and accelerate drivers?
2. What *motivations* do citizen scientists have in participating in tenant electricity?
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 Citizen Science Project* has an impact on energy-related lifestyles and energy culture (e.g., energy-efficacy)?

Methods

We have chosen the framework of *Energy Cultures* to analyze and understand the motivations behind changes in energy efficiency behaviors by attending to behavioral drivers (Stephenson *et al.*, 2010). The Energy Cultures framework was developed as an integrating model highlighting explanations of behavioral change or resistance to change and consequent solutions nudging the transformations of consumer habits. The three main pillars that characterize the Energy Cultures framework – norms, material culture, and energy practices– interact and influence each other (Figure 1, Figure 2). For example, one's socialization (norms) affects technological preferences (material culture) and activities (energy practices). External circumstances also play an important role (e.g. price shocks) 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).

The research design of our Citizen Science project consisted of five main stages starting with stakeholder mapping and recruitment, elaborating the methodological design, conducting data collection and analyses and dissemination of recommendations, as shown in Figure 3.

After recruiting 37 citizen scientist households, the core research team collectively designed the data collection tools and protocols. The citizen science initiative adopted a mixed-method approach, combining qualitative data analysis

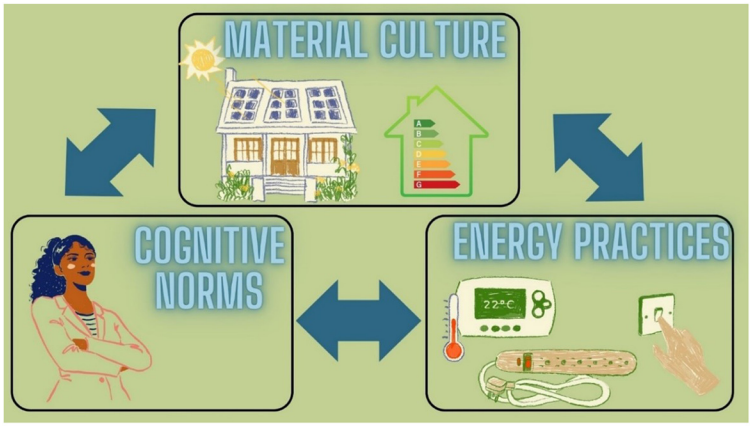

Figure 1. The three main pillars of Energy Cultures (image created by authors) adapted from: Stephenson *et al.*, 2010.

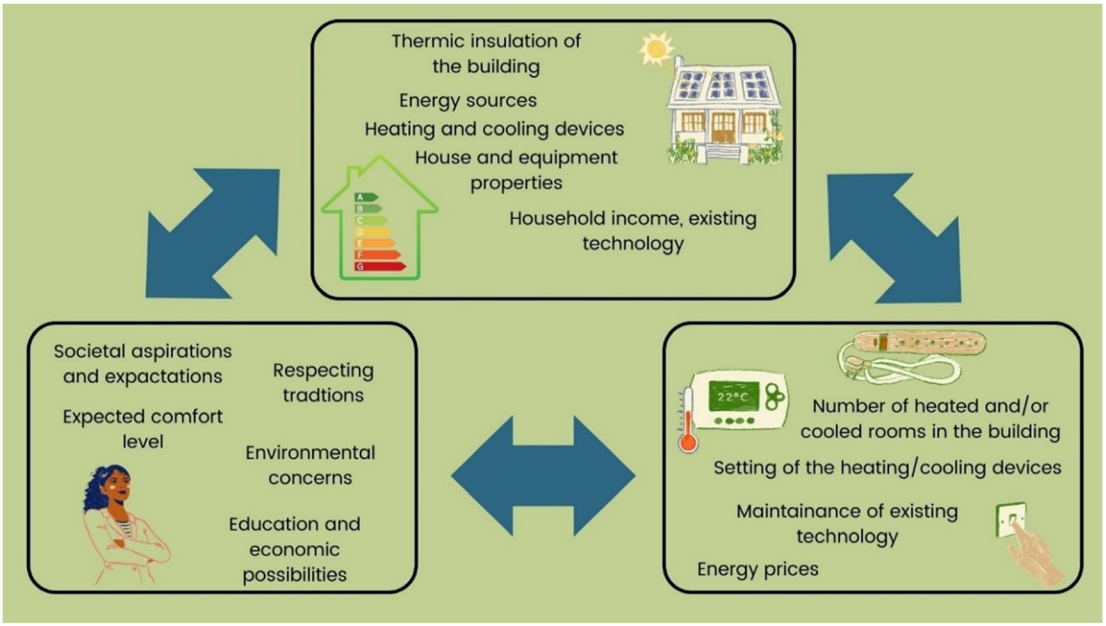

Figure 2. Examples of three main pillars of Energy Cultures (created by authors) adapted from: Stephenson *et al.*, 2010.

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 (Kick-off meetings) were held to inform citizens about the project 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

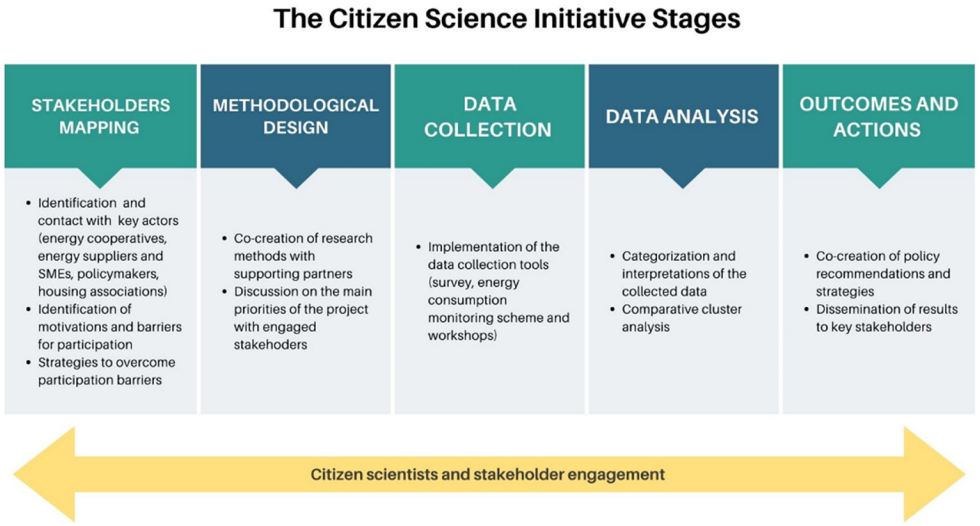

Figure 3. Stages of the citizen science initiative on tenant electricity (Authors' own elaboration).

science initiative allowed them to track other consumption statistics such as hourly and daily energy consumption.

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 4 provides additional information on the data collection tools.

All research methods were applied between September 2022 and May 2023. After each workshop, the core research team analyzed the collected data, compiling thematic summaries with the most salient information. Together with the preliminary results of the survey, these results were shared and discussed with citizen scientists, experts, politicians and the private sector. 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.

Results and discussion

Barriers 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. We identified a number of barriers which encompassed both structural and inherent challenges. Structural barriers were:

- Lack of (former) political willingness to promote the model
- Complexity of the model
- Low economic incentives to implement the model on a broader scale

While the inherent barriers were:

- Lack of *information* about the model on all levels and
- Lack of *initiators* who are able to drive the implementation of the model at the local level.

Strategies for overcoming barriers

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 in Germany 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). Moreover, the new strategy considers the introduction of community supply within a building

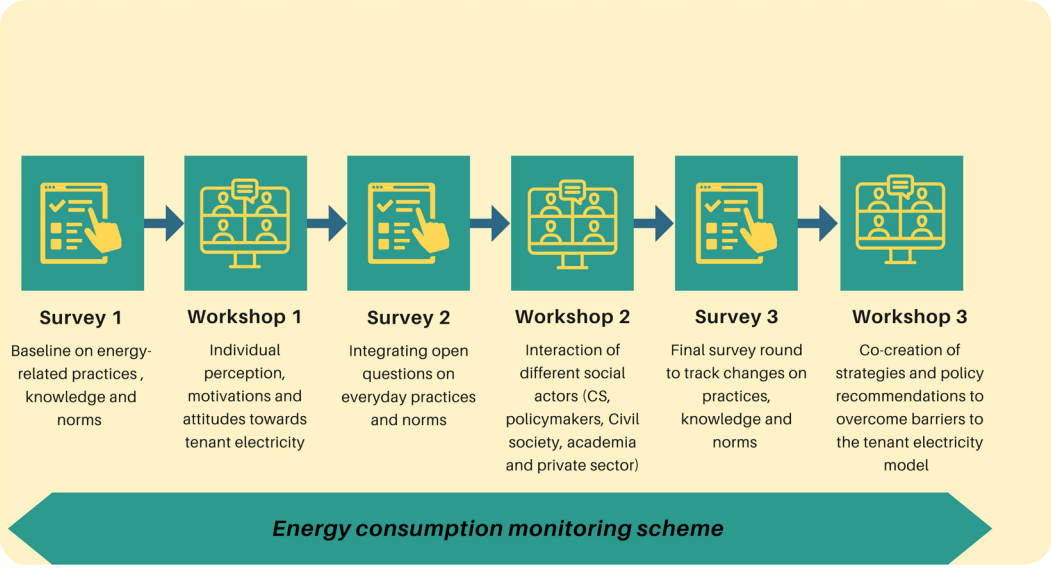

Figure 4. Data collection methods (authors' own elaboration).

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

Motivation and sustainability awareness of citizen scientists

Another objective of our research 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 (see Figure 5).

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 research project. The participation in tenant electricity has

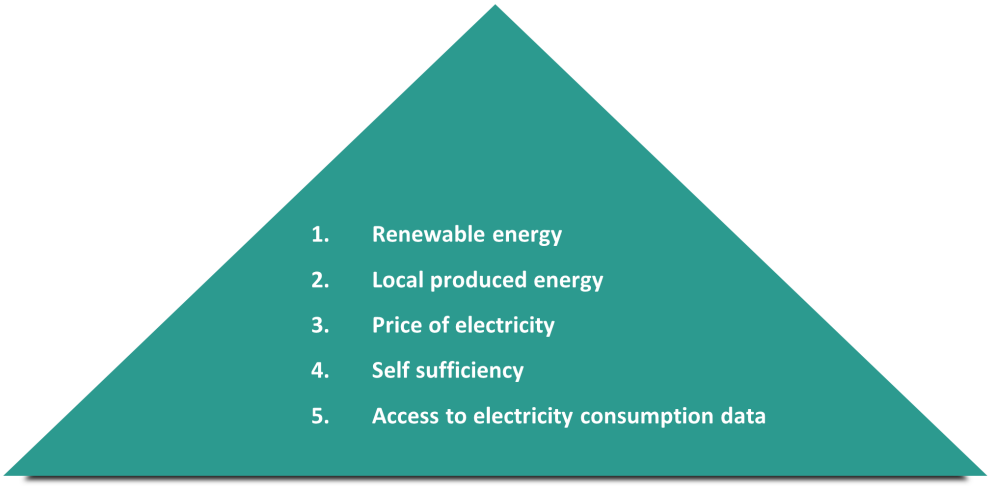

Figure 5. Ranking of important aspects for the Citizen Scientists (own source).

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.

A detailed cluster analysis was 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 (Figure 6).

Especially one cluster 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 participants' 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.

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. Only six households used more electricity during the data collection phase, but it must be acknowledged that five of these households still used less energy than an average comparable German household.

Additional information about the type of electricity available - solar from the roof or from the grid - and the ability to compare with other households ("gamification") 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 project and its impact on energy culture

The final research question related to the impact of participation in a citizen science project on energy culture. In this regard, we 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.

Conclusion

Within our research, we were able to shed light on each research question. While the barriers are mainly of structural

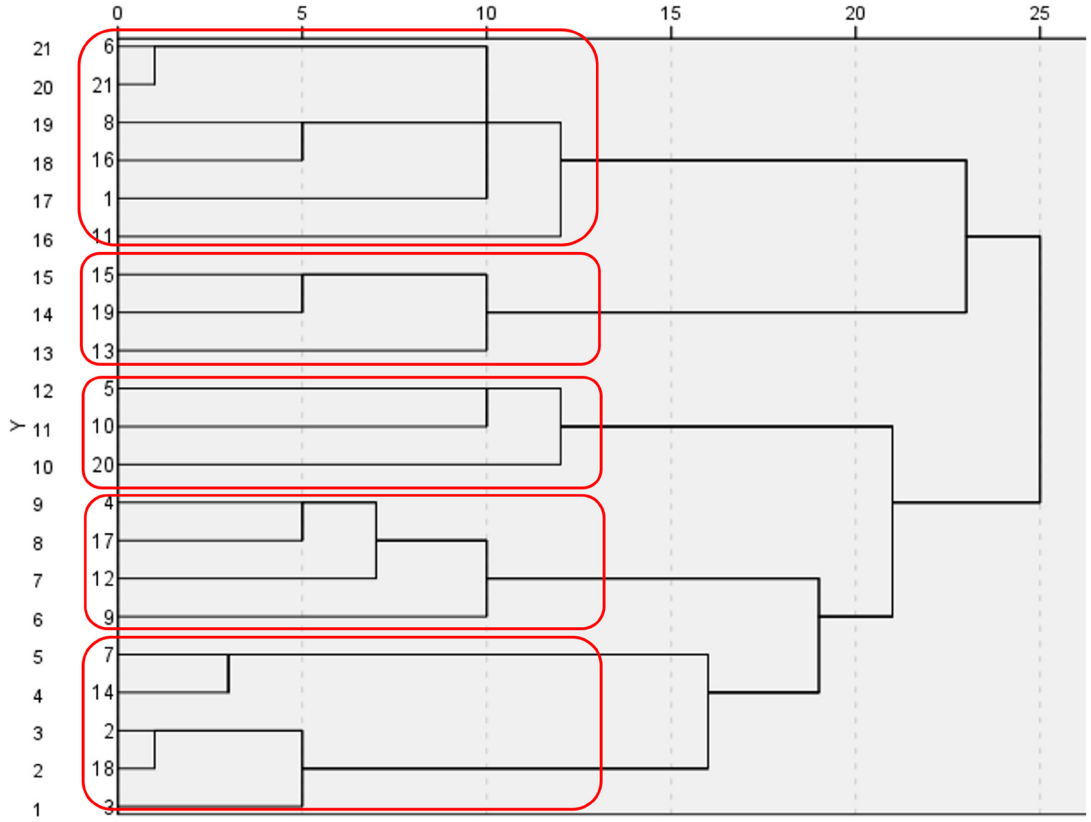

Figure 6. Dendrogram of clustering process with 5 clusters. The clusters represent different sub-energy cultures by showing differences in energy consumption patterns, energy efficient appliances, knowledge about energy consumption, and changes in energy practices (own source).

nature it was surprising that knowledge and information about the tenant electricity model is lacking on multiple levels. Targeted information campaigns could solve the latter while political efforts must be made to overcome the structural barriers. Surprisingly, the main motivation for participating in tenant electricity was sustainability and local production of electricity while the price of electricity played a minor role. The influence on energy related lifestyles and energy culture was multidimensional and resulted from the participation in tenant electricity projects (e.g. exchange with neighbours about sustainability options in the building), the feedback on electricity consumption data (leading to a reduction in electricity consumption), and the participation in our citizen science project (e.g. getting access to the intelligent metering system, getting aware of energy efficient appliances).

The cluster analysis also provided interesting research opportunities, as each of the five elaborated clusters had 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. Our findings show that 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 the conducted research can be seen as a pioneer project on the implementation of a Citizen Science project in the area of sustainable goals 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.

We find ourselves in a dynamic phase with fundamental legal, bureaucratic, and financial changes and development of the tenant electricity model through the current government, which brings further research opportunities regarding the model. Since the motivation to participate in tenant electricity 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.

Ethics and consent

In accordance with the ethical and data protection principles agreed upon for the Step Change project, we provide the following statement on participant consent:

Consent type and justification. The study utilizes data that were collected as part of an earlier research phase within the Step Change project. During this initial phase, participants provided written consent for the collection, use, and analysis of their data, with the understanding that any data shared or published would be anonymized. As such, explicit consent for this particular publication was not separately obtained, as it falls within the scope of the original consent provided by participants.

Ethical approval. Ethics approval was received from the WECF Ethics Committee, led by Dr. Anke Stock, responsible for overseeing the Step Change project on 1st April 2022. The committee confirmed on 15th July 2024 that the publication adheres to the ethical standards and data protection principles established for the project. After careful consideration, the management team, in consultation with the ethics officer, determined that additional consent from participants was not required for this publication. This decision was based on the fact that the data used in this study is anonymized and participants had already agreed to such usage in their original consent.

Ethics committee review. The decision to waive the need for additional consent was reviewed and approved by the ethics officer overseeing the project. The officer supported this approach, recognizing that the original consent covered the anonymized use of data for future analyses and dissemination within academic and analytical contexts.

Should you have any further questions regarding the ethical considerations or consent procedures for this study, please contact the project's ethics officer, Dr. Anke Stock, at anke.stock@wecf.org

Data availability

Restrictions on the data

The energy consumption data collected from participating households is considered highly sensitive. To ensure the privacy and confidentiality of participants, access to the raw data has been restricted exclusively to the researchers from WECF involved in this study. As a result, only aggregated data will be available for external use.

The study, including its data management, was reviewed by the WECF ethics officer. The WECF Ethics officer emphasized the importance of protecting participants' privacy and endorsed the decision to limit data access to aggregated datasets only. They also supported the case-by-case evaluation of requests for data access, ensuring that any sharing of data aligns with ethical standards.

Applying for data access

Researchers or reviewers interested in accessing further aggregated data may contact the project manager, Johannes Baumann, at johannes.baumann@wecf.org. Applications for data access should include a detailed explanation of the legitimate interest in the data and how it will be used. The project manager and ethical officer will assess each request individually, considering the relevance and purpose of the research. If approved, access will be granted under specific conditions, which may include agreements on data usage, confidentiality, and publication rights.

Acknowledgements

The success of our Citizen Science Initiative would not have been possible without the support and involvement of our citizen scientists. We are immensely grateful for the dedication of the following Citizen Scientists (and other Citizen Scientists whose names are not disclosed in this publication):

Marie-Sophie Adeoso, Florian Hetterich, Gisela Schill, Jan Kordes, Thomas Roth, Bernd Simonis, Simon Noggler, Björn Roch

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Anna Nora Freier, University of Wuppertal

Iris Behr, Darmstadt University of Applied Sciences

Malte Zieher, German Citizen Energy Alliance (Bündnis Bürgerenergie e.V.)

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Publisher Full Text

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Current Peer Review Status: ? ? ✗ ✓

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Reviewer Report 05 March 2025

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✓ **Bożena Ryszawska**
Wroclaw University of Economics, Wroclaw, Poland

It seems interesting to me to include citizens scientists in energy transition research. The choice of a research approach using citizen science highlights the roles of citizens and not just consumers in the energy transition. Current European Union policy focuses on the market and on two actors: the producer and the consumer. People are reduced to the role of consumer, they are assigned consumer standards of behaviour and motivation, e.g. energy is a commodity, cost reduction, low price, and access to the grid.
The positive results of research using citizen science are related to:

- empowering citizens in the study,
- giving them an important role as co-researchers,
- noticing their expertise in the subject,
- through workshops making information and research results available to them on an ongoing basis.

The conclusions of the research are very interesting: structural (e.g. model complexity) and inherent challenges (lack of information). These conclusions are confirmed by many other studies. Citizens as transformation actors are placed on the market in a complex model and are confronted with the necessity of professional knowledge in management, finance and law as well as engineering. They are forced to compete with other energy producers and consumers (large energy corporations, manufacturing companies, etc.). The market structure, regulations, financial tools, access to information, support from local government are not adapted to the needs of citizens. Therefore, the authors advocate the reduction of the complexity and bureaucratic hurdles of the model as well as regulations and financial incentives and targeted information to relevant actors.

The value of the research is to draw attention to energy culture. Because in reality, energy for citizens is not just a commodity, it is also a natural resource, a social necessity and even a common good. Therefore, it emerged in the motivations of the respondents that price reduction is not the most important motivation. What the research participants pointed out was: participation in tenant electricity led to a stronger exchange among neighbours about further sustainability

options and to a higher interest in sustainability or society engagement.

An important element of the research was the observation that: multi-family buildings accommodate around half of the German housing stock, the involvement of tenants in the production of clean electricity can be seen as key to boost the urban energy transition'. To date, the energy transition has been designed more with single-family homes in mind, often meaning support for wealthier individuals rather than energy justice for all.

I suggest to the authors that the study should be complemented by a context of citizens and indicate that citizens are not systematically supported in the energy transformation process.

Is the work clearly and accurately presented and does it engage with the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

Are all the source data and materials underlying the results available?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Not applicable

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Sustainability transition, citizens energy transition, green economy, sustainable finance

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 03 March 2025

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Silvia Tomasi

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The research idea is interesting, but the paper requires major revisions to meet scientific quality standards. To begin with, the background literature review is insufficient: several key concepts are introduced without proper references, and their connections are presented in a confusing manner. This suggests a lack of a comprehensive literature review, which needs to be addressed to strengthen the paper's theoretical foundation. Scientific references and explanations of key concept of the research are misplaced in the methods and results sections.

Overall, the study sets too many objectives (and possibly employs too many data collection methods), resulting in superficiality and confusion in the findings. The research design could have been structured into three distinct papers, each with a clear focus: one examining changes in consumption behaviors resulting from participation in tenant electricity programs, another identifying barriers and drivers of participation through workshops with diverse stakeholders, and a third exploring the impact of citizen science projects on energy consumption behaviors. This approach would allow for a more in-depth and coherent analysis of each topic.

Finally, the most worrying aspect is that while the data collection methods are mentioned (though not comprehensively—see my comment below in the dedicated section), the authors do not explain the methods used to analyze the collected data. This omission not only hinders the reproducibility of the study but also raises concerns about the reliability and validity of the results.

Hereafter are some specific revisions. I stopped before completing the *Results and Discussion* section because the study contains too many flaws.

Abstract:
The abstract has to be deeply reviewed.
The first paragraph of the abstract is oddly structured. Please, first provide the context for the study, and the main research gap in addresses. Then clarify the aim of the study. In the first paragraph of the abstract there is also a reference to the concept of energy culture, please integrate a brief definition of it.

Results in the abstract are too synthetic and thus not fully comprehensible (e.g. what is meant with tenant electricity model? The energy consumption scheme citizens are involved in?).

Introduction:
Include a reference (there is plenty in the literature) for the paragraph stating "As renewable forms of energy bear the potential to make energy more accessible and inclusive to people and communities…". You can further elaborate on this step in your narrative by strengthening the connection between the concept of citizen science and that of energy democracy.

Be consistent with terminology: either you chose to use the term "renewable energy" or "clean energy".

The following statement needs to be referenced: "But realizing that the tenant electricity model falls short of expectations and lacks broad citizen acceptance". This is a gap in the literature that your research aims to address, and it needs a strong foundation in the existing literature.

The following sentence is not clear: “As part of the concepts ‘pushing’ for prosumer empowerment (as is the energy communities movement), the tenant electricity concept is dependent on the constant adjustments to its prosumer’s needs and criticism.” You introduce two different concepts (prosumer empowerment and energy communities) without any scientific reference and without explaining how they are connected to the tenant electricity concept (you state this last is part of the former two…). Moreover, the syntax of your statement needs to be revised to enhance clarity and readability.

The citizen scientists you engaged are the same citizens involved in the tenant electricity model? All of them or just some of them?

The introduction of the concept of energy culture needs both scientific references and a short explanation of what it entails. Such description and reference is reported later in the Methods section, please move it to the Introduction section.
This section in general lacks information about existing literature (and there is plenty) concerning barriers and drivers for citizens involvement in prosumers schemes (what you call tenant electricity model, which I would be interested to understand if it is called like that just in Germany and what are the difference with other citizens engagement approaches in prosumers schemes), motivation leading to citizens involvement in tenant electricity models (which form my point of view overlaps with the drivers mentioned before, I urge you to explain which is the difference), effects of participation in the model and energy data observation on energy consumption behaviors. Finally I do not fully understand the difference between RQ 3 and 5: not all citizens participating in the tenant electricity project (seek for consistence between the different terminology you use: tenant electricity project and tenant electricity model) are also participating as citizen scientists in your project?

Methods:
The first paragraph concerning the energy culture framework is misplaced, should be located in the introduction where you discuss the main concepts and reference literature.
It is not entirely clear why the authors refer to citizen science and citizen scientists in their study, given that their research design primarily involves collecting household energy consumption data through software or smart meters, supplemented by surveys and workshops examining changes in consumption behavior. In this context, participants appear to be subjects of the research—whose behavioral changes are being investigated after receiving information—rather than actively contributing to shaping the research questions or methodology, as is typically expected in citizen science initiatives. Clarifying this distinction would strengthen the conceptual alignment of the study.
There is a mismatch between the text and the content of figure 4: in the text you just mention citizens as participants to the workshops, while from the figure it emerges that other stakeholders participated in some of the workshops.

There is no reference on how the data collected has been analyzed. Both the analysis of qualitative data should be thoroughly explained (e.g. thematic analysis) and also quantitative models (e.g. regression).

Results
Here too you included references to the literature which should have been placed in the introduction section (or even better in a dedicated literature review section). The results and

discussion section should first report the results of your analysis (in this case of both quantitative and qualitative data) and then discuss them in light if the existing literature.

You report your results on barriers, which if I correctly understood emerged from the discussion in one of the workshops, but you do not provide sufficient information to fully understand them: who identified these barriers? Citizens? Other stakeholders from the public and private sector? Also results concerning the engagement in citizen science are not supported by thorough explanation.

Is the work clearly and accurately presented and does it engage with the current literature?
No

Is the study design appropriate and is the work technically sound?
No

Are sufficient details of methods and analysis provided to allow replication by others?
No

Are all the source data and materials underlying the results available?
No

If applicable, is the statistical analysis and its interpretation appropriate?
No

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental economics, applied econometrics, energy transition, energy and environmental justice, socio-ecological transformations

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 27 February 2025

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Jussi Valta

Tampere University, Tampere, Finland

Thank you for allowing me to comment on the manuscript. It is an interesting work with a mixed method approach, which allows to triangulate and find credible results. I think the results are interesting, and also partly surprising if I understood them right.
This part: *"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."*
Would be interesting to hear from you why this might be the case.

Overall, the manuscript needs a clear description of the case and the sample that participated in the study. This could include data on where the building is, what energy it uses, apartment ownership profiles, income levels/ is it a prosperous area,...)

The basic notions of the data should be described more clearly: What was asked and possibly, how many responded, what were the means, standard deviations (when applicable), what were interview questions.

In many cases, the results are not backed by numbers or quotations, which leaves the reader wondering on what kind of data are they based on and how the data was analysed.

The cluster analysis seems interesting. You could add the names and descriptions for each cluster and descriptions on the "sub-energy cultures" you mention.

The methods and data was not presented in detail it is hard to assess its reliability and validity.

The recommendations for different actors could be more towards the end. I felt that these were more based on authors' ideas and not the surveys. This division of discussion and results should be cleared.

Small notion: in the sentence *"We find ourselves in a dynamic phase with fundamental legal, bureaucratic, and financial changes..."* the word fundamental seems a strong word. Maybe back it up or change it?

For many readers, the German Tenant electricity model might be unfamiliar. Description of its principles and functions would clarify a lot. Also, there is a notion *"But realising that the tenant electricity model falls short of expectations and lacks broad citizen acceptance, interest arose in understanding the drivers and challenges of the tenant electricity concept. "* Is there some reference to this statement?

Overall, it is a nice research, but the research process should be more transparent. You could also discuss how the different research approaches complement each other.

Is the work clearly and accurately presented and does it engage with the current literature?
Partly

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

Are all the source data and materials underlying the results available?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 19 February 2025

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Ogechi Vivian Nwadiaru
University of Massachusetts, Amherst, USA

Engagement with Current Literature
The manuscript addresses a pertinent issue related to tenant electricity and citizen science, which is highly relevant to the ongoing discourse on accelerating the energy transition. However, the support from existing literature is insufficient. The introduction does not fully justify the role of citizen science in the tenant electricity model or explain how it could contribute to advancing energy democracy. Additionally, the authors should provide more context on prior research in this area and clarify how this study builds on or extends previous work.

Study Design
The study design appears appropriate. However, important details are missing, such as how citizen scientists were recruited, how engagement with the study community was facilitated, and the geographical scope of the research. Furthermore, the demographics of the participants are not clearly outlined, which limits the ability to assess the representativeness and applicability of the findings.

Replicability
The authors provide a useful figure illustrating the stages of a citizen science initiative. However, there is insufficient detail on the data collection tools, analysis methods, and thematic coding process. Several key questions remain unanswered:

- Was a codebook developed? If so, how?
- Have the citizen scientists had prior exposure to sustainability topics?
- How was the survey instrument developed?
- Can the survey instrument be included as supplementary material to help reviewers better understand the questions covered?

Additionally, references to existing literature that informed the survey design and workshop methodology should be included.

Results
The results section lacks contextualization through direct quotes from survey responses or thematic analysis. Providing evidence to support the claims in the results would enhance clarity and credibility. For instance:

- How were structural barriers identified?
- How many respondents or participants perceived model complexity as a structural barrier, and how did they define it?
- Discussing barriers and drivers would benefit from direct quotes, as is common in qualitative research.

Moreover, Figure 5 requires further explanation. What do the rankings illustrate? A brief description should be added to clarify their significance.

Overall Assessment
The manuscript would be significantly strengthened if the authors address the issues outlined above. Additionally, the research questions should be more concise, and the results section should explicitly address each question.

Furthermore, several key concepts—such as energy democracy, energy literacy, and energy cultures—are introduced without adequate explanation. The authors should clarify how these concepts relate to one another and to the tenant electricity model, using references from existing literature to support their discussion.

Is the work clearly and accurately presented and does it engage with the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

Are all the source data and materials underlying the results available?
No

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Community based participatory research, optimization, energy systems modelling and energy justice

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.