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LONG PAPER

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Delving into the modeling and operation of energy communities as epicenters for systemic transformations

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Abstract
With the emergence of energy communities, this paper explores their operationalization as a tool with which to create large and stable citizen science and education hubs focused on energy, where citizens can have the chance of exploring a first-hand approach to the energy transition. We present the rationale behind an energy community, whose purpose is to generate systemic and transformative changes in local environments. The concept of an energy community is used to reflect the legally recognized union of citizens, which is much stronger than any associative mechanism yet without such a structure. While the latter's actions and interests align with those of energy communities, its operation mode differs in terms of the priority assigned to each of them. The developed model has been submitted for feedback to three European university communities. The feedback received has highlighted the acceptability of the model and encouraged us to move forward with its implementation. Approximately 90% of the participants in the study would partake in this type of energy community in very diverse ways, which shows the capacity of the model for inclusiveness and universal access to energy experiences. The barriers and drivers expressed by the participants of the study were analyzed to identify the aspects that foster or prevent citizens' participation. This approach will allow us to define a more responsible action plan when turning these models into reality.

Keywords Energy communities · Modeling · Citizen science · Energy transition · Drivers and barriers · Behavioral change

1 Introduction

Energy is essential for powering both the economy and the global society. It is a basic human need, and its use is usually considered an indicator of the standard of living. Consequently, the concern shown by citizens with regard to energy transition matters is understandable, as they recognize how energy affects their daily lives and the environment in which they live. The cost of energy can be a significant burden for many households, especially for those with low incomes. Unclean energy sources can have a detrimental effect on air and water quality, resulting in illnesses and diseases, while also contributing to climate change, which in turn leads to increasingly severe weather events, natural disasters, and sea level rises. Consequently, as climate variability shaped human history, it continues to influence our society [1]. Energy security is also of concern to citizens, as dependence on a limited number of fossil fuel sources can leave countries vulnerable to supply disruptions and price volatility [2]. Minimizing the negative impacts caused by the demand and use of nonrenewable energy sources for growing demand is a challenging mission; however, as there is no single solution, it is important to foster changes toward more sustainable choices [3]. A literature review of 2000 references drawn from 37 articles and books highlighted that changing energy-related behaviors can potentially decrease energy consumption by approximately 19% (±5%) [4].

Among the different actions that can be taken to promote such transformation, this work highlights those devoted to fostering energy citizenship [5]. This approach, in which

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citizens, end users, and local communities become active protagonists in energy, is consistently sought after throughout the different decision-making and scientific committees and panels. Enabling knowledge sharing to develop new theories, methodologies, or technologies fosters innovation in different scientific disciplines while also promoting responsible citizen-centered approaches [6–8]. These approaches can be manifested in various ways, such as relying on the use of sustainable energy sources or electric vehicles for personal use, joining energy-saving groups, or promoting environmental policies at a global level. All these options allow citizens to actively participate in creating a more sustainable scenario. Additionally, community energy initiatives, i.e., ecocities, eco-villages, renewable energy cooperatives, sustainable communities, etc., reflect a growing need to find alternative ways of organizing and governing energy systems. This form of social movement allows for more participative and democratic energy processes [9]. While these processes are becoming pivotal in decarbonizing Europe, they are also seen by citizens as a path that can be used to reach energy independence, thereby smoothing the impact of energy prices, democratizing energy systems, and improving the social ecosystem. Specifically, their deployment has been rocketing in Europe since the European Union promoted two directives in 2018 and 2019 [10, 11] to foster the implementation of energy communities, which is a legal term used to describe the collective participation of citizens in a nondiscriminatory and proportional manner across a whole spectrum of energy activities (generation, storage, supply, aggregation, sharing, consumption, etc.). Many member states have not yet adapted the directives into their national legislation, thus limiting the creation and implementation of energy communities to a mere continuation of the traditional concept of community energy[1] (self-consumption or trading). However, despite these limitations, the reality is that energy communities are progressively transforming passive consumers into active citizens in the energy system, empowering individuals and promoting behavioral changes toward more sustainable energy attitudes. As of December 2022, the European Union estimated the number of energy communities to be 9000 [12].

The research focus of this work is on exploring the foundation for universal access to energy education experiences that promote a change toward more sustainable and efficient personal energy behaviors. The research focus is based on the establishment of educational energy hubs through energy communities that enable people to observe, analyze, and learn about energy-related topics as citizen researchers. In fact, public outreach, problem framing, data gathering, and policymaking associated with energy communities can be considered citizen science actions; currently, some authors claim that energy communities should be better aligned with the methods and goals of citizen science [13, 14]. However, challenges related to creating and managing energy communities can raise doubts about whether this approach of promoting ad hoc energy communities as a tool with which to operationalize citizen science hubs is worth pursuing. This research work has identified two reasons to pursue this idea.

First, anyone working in the field of citizen science is aware of the difficulty of building and maintaining an actively engaged community [15, 16]. Establishing energy community hubs and formalizing them with an institutionalized structure can provide several benefits to achieve the ultimate goal of promoting sustainable choices. Citizens' commitment to such a hub can be strengthened by their investment in the energy community through their time, money and knowledge. Furthermore, such establishment creates an energy infrastructure that facilitates data collection, observation, and learning that would otherwise be challenging. Last, this collaborative effort opens the door to incorporating external factors that influence behavior, such as feedback from peers, experts, or authorities.

The second reason for driving citizen science and education hubs through a "legal structure," such as an energy community, lies in the opportunity created by the current global energy crisis and the democratization of the energy system by energy communities. This opportunity can drive citizen science actions within the energy sector, which is just beginning to recognize the benefits of involving citizens in data collection, analysis, and scientific research [17]. If citizens are willing to be proactive in the energy sector and to participate in energy communities, then this is an opportunity for citizen science deployment in the energy sector.

However, the operational status of most energy communities does not demonstrate the expected level of citizen engagement, and local actors' involvement is not considered necessary or a mandatory element for their establishment [18, 19]. In most energy communities, the initiative is promoted by external stakeholders; citizens take part just because they can directly benefit from a lower energy price, thereby considering the energy community as a mere energy trader. In fact, the New European Bauhaus initiative highlights the urgent need for community-led projects that offer open-source learning opportunities for community members, use participatory design methods and tools, and draw on cross-disciplinary competencies and, inherently, behavioral changes [20]. Thus, the actual scenario presents a challenge in transforming existing energy communities into citizen science and educational hubs, as their original purpose may not align with this goal, and their inherent design may not

[1] For several decades, Europe has implemented the concept of "energy communities." Recent European directives promote these communities by emphasizing their social impact and encouraging the related citizens to engage in a full spectrum of energy-related activities.

provide a suitable framework for it. The authors believe that energy communities have the potential to serve as educational and citizen science hubs; however, new energy community models that are driven by this shared interest are necessary.

This paper presents a way to establish energy communities that operate as citizen science and educational hubs. It proposes a method for implementing such energy communities, i.e., leading citizens' hubs to transform local ecosystems into a system where any local citizen can have real first-hand experiences with sustainable energy, thereby enabling collective and behavioral changes. The paper presents the basis, design, and critical factors necessary to create such hubs and analyzes the feedback received by tentative members of pilot communities. Section 2 outlines the research methodology. Section 3 presents the results by first identifying the critical design principles for an energy community acting as a citizen science hub. Then, it introduces an operational rationale for technical university communities and provides feedback on this model from members of four communities. In Sect. 4, the obtained results are analyzed; finally, in Sect. 5, the conclusions, limitations, and future work are presented.

2 Methods

The focus of this research is on creating energy communities that will serve as educational and citizen science centers. Nonetheless, the methodology is not centered on developing a conventional energy community and motivating their members to participate in citizen science actions; instead, it aims to leverage existing large social communities and transform them into energy communities, thereby enabling the achievement of sustainability and enduring citizen science and educational centers.

To achieve this objective, the starting point consisted of conducting research on relevant literature to identify critical factors that could influence the rationale of this approach. Based on these principles, a specific framework was developed for the establishment of energy communities as citizen science and educational hubs. Then, this scheme was adapted to a larger social community, specifically the university campus of technological universities. This represents an important step, given that the citizen science activities proposed within the operation were planned according to the skills and interests of such communities (technology, digitalization, internet, etc.). Subsequently, four technical universities were chosen in Denmark, Portugal, Slovenia, and Spain to assess the acceptance of the concept while also seeking to enhance the rationale before its implementation. During a period of six months, the concept of creating an energy community within the different communities was presented by explaining how it would operate as a citizen energy hub. Following the presentation, feedback was gathered from the attendees through a survey (described in Appendix 1). Attendees were also invited to express their potential interest in participating in the energy community, to identify the ways that would ensure universal access to this educational hub. Questions included in the survey were prepared after a bibliographic review of the drivers and barriers already observed in other energy communities and then adapted to the model. The main drivers and barriers are presented in Tables 1 and 2.

All surveys were conducted online after informed consent was obtained. The survey, which was created originally in English, was translated into each local language.

The Campus Sur of the Technical University of Madrid was chosen as the initial testing ground to gauge the solution's acceptance. This community comprises 5090 individuals, namely 4500 students, 360 professors, 60 researchers, and 170 administration and maintenance staff. During 2022, two engagement activities were conducted with the Campus Sur community. In April, multiple meetings with students were organized; in October and November, the remaining groups were targeted. Approximately 600 people participated in the different events. At this time, a presentation was made concerning the concept of creating an energy community within the campus and how it would operate as a citizen energy hub.

The rationale was also tested in other locations, namely Aarhus, Évora, and Ljubljana. In this paper, detailed results from Évora (Portugal) and Aarhus (Denmark) universities are presented. The results from Ljubljana are added as aggregated data to the final analysis due to the low number of received responses, together with 10 responses from participants who did not indicate their location.

Évora University performed communication events explaining the rationale designed by the authors. The academic community is composed of 11,524 students from 80 nationalities, 819 teachers and researchers and 566 support staff. Évora University organized a meeting with a focus group of people drawn from the academic community to promote an initial discussion about the community model and collect users' expectations. In a second stage, an Innovation Café was developed, which encouraged open participation from the community.

Aarhus University (AU) conducted similar engagement processes, where students and staff were invited to various public discussions on the community energy initiative and other energy-related discussions. AU has close to 40,000 students overall from a wide range of degree programs and 8000 full-time staff, including researchers, educators, and administrative staff. The initial public discussions were mainly attended by students and staff from the faculty of technical sciences because the topic was closely related to

Table 1 Driver categories and references

Category	Driver	References
Environmental	Environmental awareness	[18, 21–24]
	Citizen participation in energy transition	[23, 25–28]
	Mobilization to combat climate change	[18, 28]
Social	Community identity	[18, 21–24, 27–30]
	Improvement of local conditions	[21, 23, 25]
	Fighting against energy poverty	[18, 23, 28, 29]
	Citizen empowerment	[18, 28]
	Changes in social norms	[23, 28]
	Social acceptance	[21–23, 27]
	Setting an example	[21, 23]
	Contribution to self-esteem	[21]
	Transformations of individual thinking to a collective thinking	[27, 28]
Economic	Creation of local value	[18, 23, 24, 27–29, 31]
	Generation of returns to the community	[18, 22, 27, 28]
	Reduction of energy bills	[18, 21–23]
Market	Energy democracy	[22, 24, 26, 31]
	Independence of big companies	[18, 21, 23, 24]
	New energy model	[27, 29, 31]
	Change in the consumer's role	[23, 25, 28, 29, 31]
	Security supply	[21, 23]
	Renewable energy production	[18, 22]
	Formation in energy-matter	[18, 21, 23, 28]
Formation	Access to a clear and transparent information	[22, 25, 32]
	Successful examples	[21, 28, 29, 31]
	Innovation systems	[21, 28]

Table 2 Barrier categories and references

Category	Barrier	References
Institutional	Lack of regulatory framework	[28, 29]
	Changes in norms	[28, 29]
	Complexity of the administrative procedures	[29]
Economic	Difficult access to financing	[24, 26, 29]
	Dependency on subsidies	[28, 29]
Organizational	Volunteer work	[26, 28]
	Lack of resources	[24, 28, 33]
	Communication problems	[26, 28, 34]
Behavioral	Lack of interest and awareness	[24–26, 28, 34]
	Lack of information and training	[24, 31]
	Local opposition to renewables	[25, 28]
	Internal group conflicts	[32]
Market	High grid connection costs	[26, 28]
	Centralized energy model	[26, 28]
	Natural monopoly on distribution networks	[29]
	Negative thinking in the governance of energy projects	[26]
Ethics	Environmental effects of new technologies	[35]
	Conflicts with legislation	[35]

their line of study or profession. In addition to the AU community, some groups of high school students were contacted, given that they were interested in the application of citizen science in the energy transition. Their answers and opinions were also collected in the survey.

3 Results

This section presents the results of this study, which identify the design factors necessary to transform social communities into ad hoc energy communities with the primary objective of serving as universal citizen science and educational hubs, thereby promoting a change of behavior toward a sustainable lifestyle. Following this, the current section provides an overview of the underlying principles of the model created for a university campus community. Finally, it presents the public feedback gathered following the analysis of the surveys conducted, which identified possible barriers and drivers of the concept.

3.1 Design factors to consider in the definition of the energy community

3.1.1 Operational principles

Operational principles define how a system or organization functions. Such principles can help guide the decision-making process and ensure that operations run smoothly. When developing these principles, the review paper by Wuebben et al. was considered [13]; it provides insights into how to better align public participation in energy communities with citizen science initiatives. Such an approach guided the definitions of the following operating principles, which subsequently helped to create the rationale explained in Sect. 3.3.

3.1.1.1 Benefits and values Generally, participating in renewable energy communities offers diverse and numerous benefits, which encompass social advantages such as stronger community ties, financial benefits such as reduced monthly energy bills, and environmental benefits such as decreased air pollution. However, the approach presented in this paper does not focus on creating a standard energy community. Instead, it strives to transform social communities into energy communities that act as citizen science and education networks for energy-related topics. While the benefits of participating in these upgraded energy communities may be similar to those of other energy communities, their relative importance may vary. In this context, the upgraded energy communities will still provide equal climate benefits; simultaneously, for the individual and for the community, the main benefits will be as follows:

Educational: Education should be the main driver for people participating in these ad hoc energy communities and must be guided by citizen science principles, where members of the public are invited to participate in scientific investigations by collecting and analyzing data or contributing in other ways to the research process. Therefore, it is essential to enable activities that promote first-hand knowledge about the impacts of citizens' energy choices not only from the consumption point of view but also from the production perspective in an overall framework based on electricity, heating, cooling, and mobility. Other educational activities can also be operated within the energy community to obtain such educational benefits;

Financial: In this type of energy community, where most participants are unlikely to be the final energy consumers and thus do not see a direct financial benefit in their energy bills, the willingness to volunteer is higher than the willingness to invest money. However, it has been often suggested that investing money reinforces a citizen's commitment to any initiative [36]. Additionally, such investment is a way to fund a larger energy infrastructure, which will in turn serve as an educational tool for the participants. Therefore, the financial aspect must be addressed by providing an acceptable return on investment while ensuring a proper design, where shares are appropriately sized so that no participant dominates the process;

Community building and self-realization: Similar to small rural energy communities that have flourished through citizens' movements, an energy community created from any other preexisting social community structure can strengthen community cohesiveness and empowerment. The significant potential of these energy communities created from large social communities is that they offer people the chance to step outside their private lives and bring change to institutions, clubs, associations, etc., where community members work, play, or enjoy their time.

3.1.1.2 Energy citizenship and practices Another pathway found in the review performed by Wuebben [13] is related to initiatives that aim to assist citizens in their energy citizenship. Such assistance is made through the acquisition of knowledge about the interconnections of energy practices, thereby empowering citizens to advocate for cleaner energy options and utilizing their political power to influence new energy policies. As such, the energy community must act to cultivate energy citizenship through methodologies and practices linked to citizen science practices or other highly engaging public engagement methods. The practices promoted by our ad hoc energy communities can certainly lead to various behavioral changes in participants. However, they should be designed with the objective of fostering one or more of the following set of attitudes:

- *Energy conservation*: Individuals must be invited to become less energy intensive citizens by adopting more sustainable energy practices in their homes and workplaces;
- *Renewable energy production*: Individuals should have the chance to produce their own renewable energy to drive improved energy citizenship.
- *Advocacy and activism:* Energy citizenship can also be manifested through advocacy and activism. This involves working to influence decision-making.
- *Education and awareness:* Energy citizenship can also involve educating oneself and others about energy issues and solutions. It can, for example, include sharing information about the benefits of renewable energy and the negative impacts of fossil fuels.
- *Community engagement:* Energy citizenship can be manifested through community engagement. This includes the definition of different models for enabling people's active participation in the community.

3.1.1.3 Intermediaries The final operation principle draws attention to the identification of individuals who are of particular importance to the energy community but who may not necessarily hold leadership roles. These individuals play a critical role in creating a sense of confidence and trust among their members.

3.1.2 Functional factors

3.1.2.1 Location It has been reported that there are three critical factors related to creating an energy community, namely trust, community identity, and social norms [37]. Trust is the belief in the reliability and capability of a person or organization to achieve goals based on their demonstrated competencies, values, and aligning intentions with those of the public [38]. Community identity refers to the sense of belonging and shared characteristics that individuals within a particular community possess. It encompasses the shared values, beliefs, customs, and practices that define a community and distinguish it from others. Community identity can include shared physical and emotional experiences, history, and sense of purpose or goals. This sense of identity can be a powerful force in bringing people together and fostering a sense of belonging and connection among members of the community. Finally, social norms refer to the unwritten rules and expectations that govern behaviors within a society or group. These norms are shaped by social and cultural factors and often reflect what acceptable or appropriate behavior is in each context. Social norms can have a significant impact on behavior, as individuals often conform to the norms of their social group to fit in and avoid social disapproval.

Thus, it is crucial to take into account these three key factors when determining the implementation of our energy communities, which are defined as spaces that foster a sense of community and belonging, with clear values that align with the promotion of the energy transition, and whose members are environmentally conscious. In addition to these requirements, the need for space and minimum critical mass can determine a proper location for activating these citizen science hubs.

3.1.2.2 Universal participation By establishing energy communities that extend beyond people's neighborhoods, we can pave the way for universal access to the energy transition while opening the door to new alliances in the quadruple helix[2] framework consisting of companies, citizens, policy-makers and academics [39]. The working hypothesis also suggests that citizen science and educational hubs will operate more effectively within energy communities with a stronger citizen character rather than those whose members are merely passive users. Therefore, it is crucial to design ways in which to enable full citizen participation and ensure that there are no barriers beyond themselves that hinder their involvement in the community.

Moreover, the social and transformative nature of energy communities means that traditional models establish ways in which the energy communities fight energy poverty and enable vulnerable people to access cheaper energy. Consequently, the presented model must consider how the energy community is not only a way in which to obtain cheaper energy but also a center for systemic changes regarding citizens' energy behaviors. The community must facilitate and invite the participation of vulnerable groups in the experience.

3.2 Rationale of operation in technical university communities

Following the examination of the design factors described in the preceding section, a blueprint for the implementation of citizen science and education hubs was established, which shows how they would appear in practice.

First, the design factor related to practical considerations was addressed. After careful consideration of the options presented in Sect. 3.1.2.1, it was determined that a university

[2] The quadruple helix refers to a collaborative model of innovation involving government, industry, academia, and civil society working together to address complex societal challenges. It emphasizes the importance of including the perspectives and expertise of all four sectors in the innovation process to promote sustainable and inclusive development.

campus would be the most suitable choice. Specifically, it was decided to create an energy community demonstration at the Campus Sur of the Technical University of Madrid (henceforth referred to as Campus). As previously noted, intermediaries play a vital role in such projects. Therefore, this energy community is based on an existing university community, where prominent energy experts are involved in the grassroots movement, thereby ensuring the identified trust component.

The target audience for this energy community comprises students, professors, and other staff who already have a powerful sense of belonging to the institution, with well-established social connections that ensure a community identity. This environment provides an excellent opportunity to engage with a considerable number of people, ultimately creating a citizen science hub while reinforcing the social norms factor.

Despite the significant administrative burdens that must be overcome, the university has enough free space on its rooftops to offer to the energy community for use. This, in turn, will provide the university with a lower-than-market electricity price and technology that aligns with the university's green policy. By facilitating the setup and constitution of an energy community, the university can avoid making a large investment and allocate such funds to other essential purposes, e.g., the replacement of old appliances, investments in energy efficiency, and the installation of electric vehicle chargers. On this campus, a photovoltaic (PV) installation of approximately 200 kWp would cover 30% of the energy demand, providing a renewable electricity source for the community.

Universal participation is a key factor to consider in the creation of an effective rationale for energy communities. It is essential to ensure that the energy communities created are accessible to all local community members. However, if the cost of a cooperative share exceeds approximately €500, it may not be affordable for many people. To achieve our objective of gathering and facilitating the participation of all community members, independently of their financial possibilities, we propose to offer shares as cheap as €20, which would significantly reduce financial barriers and enable broad participation. This economic model is feasible since the objective of the participants is not to reduce their own energy bill but rather to crowdfund a local PV facility that will provide self-consumption electricity for the university in many different buildings on the campus. Additionally, investment in the energy community should be viewed as an integral component of the educational process. Crowd funding for PV facilities can provide a small return to investors upon the sale of electricity, ensuring that participation in the energy community is part of the first-hand educational process. In our business model, we have set a return rate of 4% [40]. To ensure that financial interests do not interfere with community participation, we also set a maximum share limit of €3,000. Our approach emphasizes active engagement and welcomes nonfinancial contributions from participants who may not have financial means or are not willing to invest financially but possess the skills and knowledge necessary to support the energy community and citizen science activities. Last, to ensure that the experience is accessible to everyone, the plan additionally involves collaboration with an NGO working with young and marginalized individuals living in the vicinity of the university. This partnership entails the participation of these individuals in not only citizen science initiatives but also other educational activities.

From an operational perspective, the hub is driven by the concept of individuals becoming "near-zero emission citizens." This term is linked to a mathematical algorithm that we have developed, which provides personalized information through a visual label on how our daily energy decisions are contributing to achieving the European GHG emissions targets for 2030 [41]. To reach this goal, participants are invited to follow a "journey" in which their energy consumption and production are recorded in an app named AURORA, which focuses on different categories, such as electricity, heat, and mobility. The app is a tool designed to measure individuals' performance in achieving the objectives of the European Green Deal. By recording participants' data, the app generates information that is displayed in a labeling system. This information can be broken down into three areas of energy consumption: electricity, heating, and transportation. Additionally, it can be disaggregated by indicators, such as energy consumption and associated carbon emissions. By participating in the hub and acquiring new knowledge, community members can observe if their own "label" is modified thanks to these experiences. Individual data are shared with the rest of the community, including the scientific community, in an anonymized manner, with the expectation that they will contribute to the definition of user-centered energy planning instead of infrastructure-centered planning.

A visual representation of the operation rationale is illustrated in Fig. 1; it is defined as the “AURORA energy community rationale” because it is funded by the project of the same name. AURORA enables and promotes behavioral changes by periodic energy data collection together with individual and collective analysis and combines it with hands-on activities (specifically adapted to the social community we are addressing), such as fieldwork or laboratory experiments, i.e., termophotography[3] contests, energy meters, and other sensors do-it-yourself

[3] The term "thermophotography" was coined to describe the practice of scanning one's own home with thermography cameras to learn about energy efficiency. Practitioners share the photos taken with the hub, and the best picture, which showcases unexpected findings, is selected as the winner.

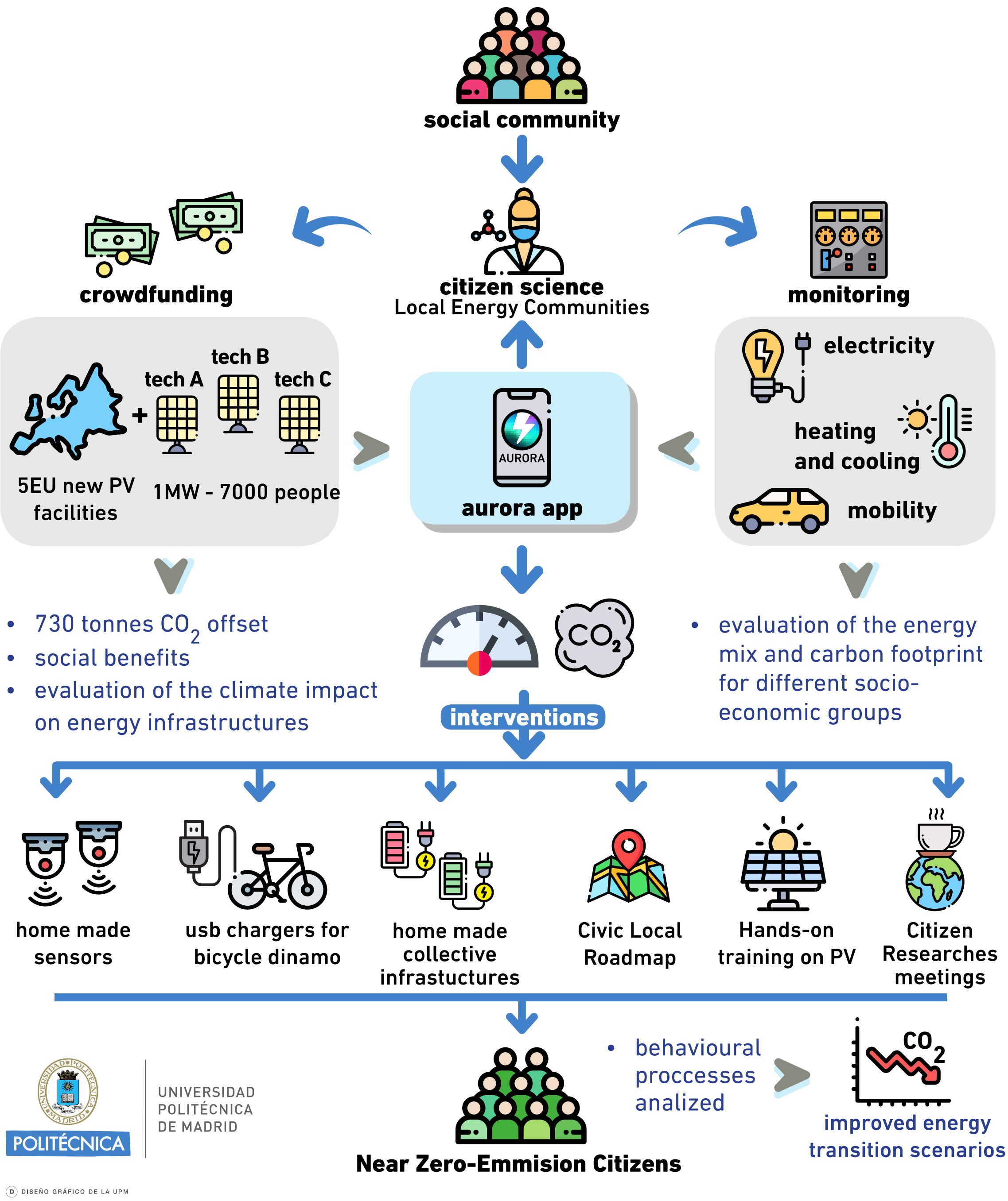


Fig. 1 Operation rationale of a citizen science hub established through an energy community, which is defined as a social community belonging to a technical university campus. AURORA rationale

workshops, the fabrication of homemade PV modules, the fabrication of USB-C bicycle chargers, etc. It also provides other educational activities, such as cafes or more general talks given by experts invited by the community.

3.3 Citizen science hub: community feedback

The energy community rationale described herein was explained in communication campaigns to different members of the community.

At the Technical University of Madrid, the discussions and surveys were conducted after the presentation of the rationale described in this paper; they were conducted in two phases. In the spring of 2022, we obtained our first set of results, which comprised 85 responses from a group of university students aged between 18 and 25 years old. The second set of results was obtained in the autumn of 2022, where 108 responses from different university community members were obtained; 37% of them belonged to the 51–60 age group, 19% belonged to the 41–50 group, and 12% belonged to the 18–25 group. In this way, we ensured that the study provided equal opportunities for representation to individuals from various age groups within the campus university, which has a population of 5000 people. Female respondents accounted for 40% of the respondents, and males accounted for 60%. Sixty-one percent of the respondents had a postgraduate degree, and 20% of them were currently studying. The sample size allowed us to work with a margin of error of 7% and a confidence level of 95%. Given the qualitative approach of the survey, the sample size was considered adequate for the intended purposes.

The results indicate that 80% of the respondents felt co-responsible for the energy situation and its impact on climate; they also considered themselves part of the solution to the climate emergency in the local environment. Additionally, 7% of the respondents viewed themselves as part of the solution but did not feel responsible. These findings reveal a strong sense of community responsibility and motivation to be part of the solution, which can serve as a driver to implement the citizen science hub.

In Question 2, participants were asked about their perception of how to operationalize an energy community such as that described in this paper. The results show that 61% of the public prioritized their motivation to act in providing environmental benefits to the local area, closely followed by the social benefits of the chosen action, which were prioritized by 52% of the respondents. The third most-voted response was linked to the idea of acting within their own social community (35%). However, respondents showed a real awareness of the implications of constituting an energy community since in Question 3, they indicated the importance of knowing what their legal implications are when participating in an energy community project. Second, they considered the energy savings and environmental impact of the shares offered by the energy community important, followed by access to information and contact details for asking questions.

Exploring the factors that could prevent people from taking part in the initiative, we found that 45% of respondents agreed on supporting the initiative with a minimum of €20, and an additional 47% expressed a willingness to support the community with a higher investment. This outcome was corroborated in a second form they could fill out, which served as an expression of interest in investing in the community; the respondents were asked to include their contact details and the tentative amount of money they were willing to invest. This was only accomplished in Madrid, where we received 160 expressions of interest raising a total of €140,000. In Question 4, participants ratified a point already considered in the modeling, namely, the importance of technical and legal staff to support participants.

Finally, in regard to how respondents would support the initiative (this was a multiple choice question; thus, respondents could choose more than one answer), 26% were mainly interested in investing in the energy community, 22% reported that they would act by providing their data (through citizen science actions), another 22% reported wanting to be trained on energy aspects (first-hand actions), and 14% offered to volunteer for the initiative (see Fig. 2).

The rationale is currently being tested in multiple locations, including Évora (Portugal), Ljubljana (Slovenia), Aarhus (Denmark) universities, and the English council known as Forest of Dean, which is interested in adapting the university model proposed in this paper. The rationale was presented by local intermediaries who are recognized experts on energy topics in their communities. We have received 72 responses from Portuguese participants, 49 from the Aarhus University community, 13 from Slovenia, and 10 responses in English that cannot be truly assigned to a particular demo. Although it is challenging to establish differences between communities due to the lack of representativeness in some locations, we can still use the responses as aggregated data with which to identify drivers and barriers in the conclusions as part of the whole study. Next, we briefly describe the profile of the respondents. People from the Évora demo site belonged mostly (31%) to the 18–25 group or (24%) to the 51–60 group, and the respondents were mostly males (59%). Fifty-five percent had a postgraduate degree, and 21% reported currently studying. The gender distribution was 42% females and 58% males. In Denmark, most of the respondents (53%) were 18–25 years old and 26–30 (22%), and 14% of the respondents were < 18 years old. The respondents were mostly males (76%), and most of them (25%) had a college degree, while 20% had a postgraduate degree and 29% reported currently studying.

In Évora, Portugal, 75% of the respondents considered themselves partially responsible for the energy transition in their university, a value that matches the 76% reported in Aarhus, Denmark. The primary motivation for participating in the initiative was the opportunity to provide environmental benefits to the local community, as indicated by 65% of the respondents in Portugal and 51% of those in Denmark. When asked about the information requested for joining the hub, respondents in Denmark highlighted financial incentives first, followed by energy savings and environmental impact, and then legal implications. In contrast, legal implications ranked first in Portugal, tied with Spain, with energy savings and environmental impact as the second most important factor, followed by full access to information

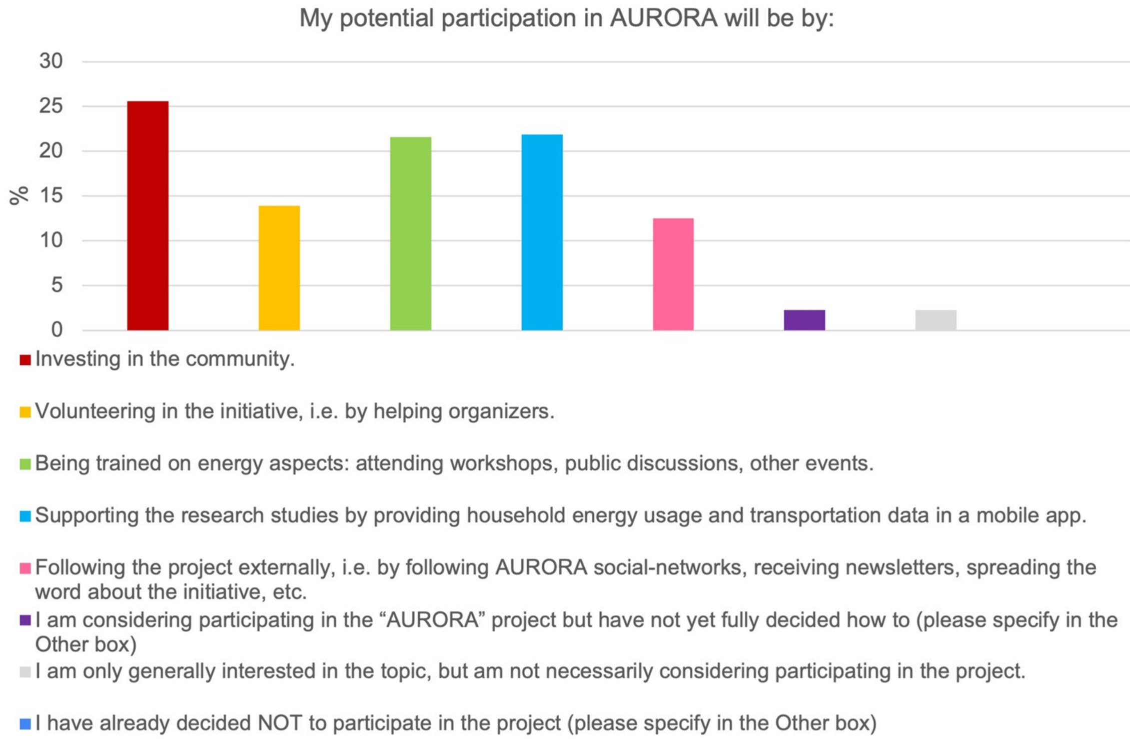


Fig. 2 The perspective of citizens' participation in Madrid

and contact details for asking questions. Across all surveyed locations, including Madrid, Évora, and Aarhus, respondents agreed on the three main reasons for joining the initiative; they also reported that their decision would not be influenced by the type of educational, training, or social activities offered by the community.

In Denmark, 57% of the participants reported finding the minimum investment reasonable and acceptable, with an additional 33% willing to invest even more. Meanwhile, in Portugal, 58% of the respondents considered the minimum share reasonable, and only 13% were willing to invest more. However, in Madrid, nearly 50% of respondents were willing to make larger investments. In general, approximately half of the individuals across all locations indicated their willingness to participate in the initiative with the minimum investment amount. It is possible that analyzing the data by age and socioeconomic status could provide insight into this discrepancy. For Question 5, both locations emphasized the significance of having technical and legal staff to provide support for the participants.

When people were asked about how they would participate in the project, we found a diverse range of motivations. In Denmark, the results shown in Fig. 3 reveal that 27% of respondents wanted to invest in the community, 11% were interested in volunteering, 11% wanted to receive training, and 23% were interested in supporting and participating in citizen science actions. Another 11% of respondents wanted to be informed through different channels, while the remaining 12% did not intend to participate in the hub.

In Portugal, (Fig. 4), we again verified the diversity of citizens' potential participation in the hub. Eighteen percent would invest money, 14% would volunteer, 16% would take courses, and 21% would take part in citizen science action. A lower engagement level is shown by another 19% of the community, who stated that they were only interested in supporting the project externally.

4 Analysis

The rationale behind this work was carefully thought out and designed to fully exploit the growing popularity of energy communities as a means of providing universal access to education on energy-related topics through first-hand experiences and citizen science actions, while also exploiting the traditional benefits of energy communities. The rationale identified those aspects that have become critical in the design of such energy communities according to their main objective. As a result, we can upgrade current established social communities, which are exemplified in university communities, to new pro-environmental civic consortia acting as citizen science hubs. These hubs will work to empower citizens on the path toward climate neutrality by increasing awareness, providing new energy choices, and

Fig. 3 The perspective of citizens' participation in Aarhus

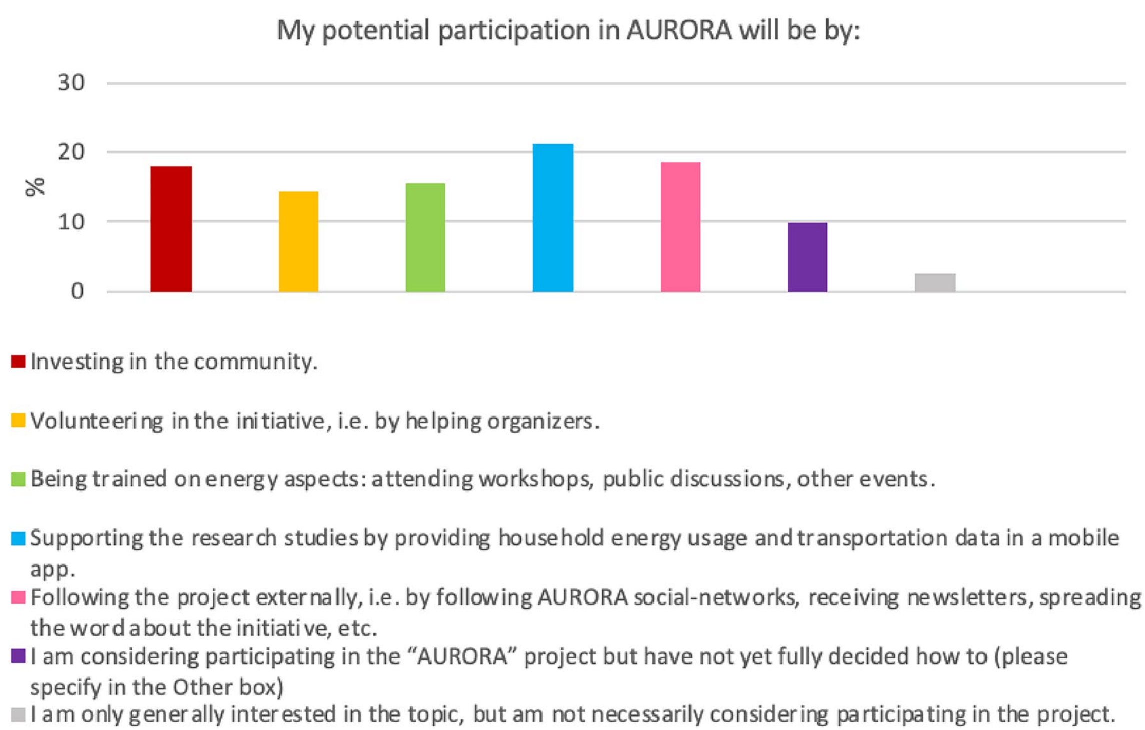


Fig. 4 The perspective of citizens' participation in Évora

ultimately fostering systemic changes toward more sustainable lifestyles. The rationale opens up the possibility for energy communities to become citizen science hubs with the main objective of creating "near-zero emission citizens," i.e.,

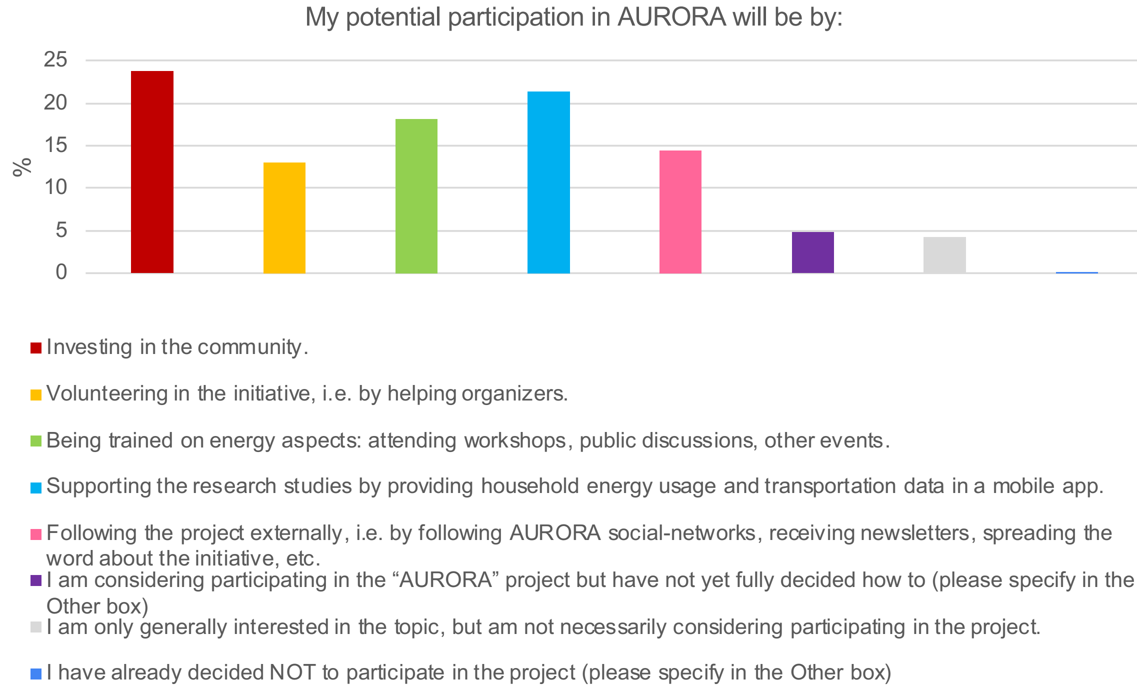


Fig. 5 The perspective of citizens' participation (aggregated data)

promoting and measuring individual and collective behavioral changes through hands-on activities. Thus, through the collection and analysis of their own energy data, new behavioral changes in citizens' energy practices are expected. These usually involve individual actions, which can range from small daily habits to more significant lifestyle adjustments, such as buying electric vehicles or installing solar panels. Moreover, the existence of an energy community is an additional advantage for citizen science and educational hubs since its energy facilities are educational resources; thus, the participants can have real, first-hand experience with renewable energy and learn about the operational rationale behind it. Additionally, these facilities can help universities and municipalities acquire clean and less expensive electricity.

Three social communities affiliated with universities publicly scrutinized the rationale before implementing the first pilot study. The results were used to verify and validate the rationale and to gauge the university community's interest in transitioning to an energy community guided by citizen science actions. The obtained feedback highlighted the great interest demonstrated by the communities with regard to the initiative; 95% of the respondents in Madrid and 87% of those in Évora and Aarhus said they would participate in the hub.

However, this type of energy community or hub is an opportunity for universal access to a holistic energy experience. The true measure of its success lies not in the number of potential members but in the diverse ways in which people find to be integrated into the hub and participate fully. Aggregated responses are shown in Fig. 5. While a classical energy community may only be accessible to those willing to invest as shareholders, the AURORA approach allows for a greater level of inclusivity by enabling people to participate in various manners that truly align with their interests; i.e., in a social community of approximately 5000 individuals, investors would represent just 24% of those individuals. To raise funds for a 200 kWp PV facility, the average investment would be approximately €200 per person considering that 1000 people were willing to invest, which is feasible given the successful expression of interest at the Madrid demo. In Madrid, 160 participants expressed a commitment to investment, raising a total of €140,000, which equates to an average investment of €875 per community member. For those remaining, approximately 13% of people reported being willing to volunteer in the hub, 19% would be willing to take part in training activities, 21% would be willing to take part in the citizen science initiative, and 15% would be willing to follow the initiative with a lower level of engagement.

Using the obtained results, drivers and barriers to the creation of these energy communities were identified and are reported in Tables 3 and 4, respectively. Drivers should be carefully considered when designing energy community demonstrator activities and associated communication

Table 3 Drivers found in the analysis

Drivers
Conscious about the energy transition and feel part of the solution
Provide environmental benefits to the community
Provide social benefits to the community
Participation in the dissemination and communication activities of citizens who previously invested in renewable facilities
The label highlighting if their daily habits are friendly to the environment
The label is recognizable, similar to the energy-efficiency label
Interest of participants in investing in the energy community
Interest in supporting research studies to contribute to science
To understand and be trained in the topic of energy transition
To follow the project on social media, newsletters, etc.
To volunteer helping the organizers

Table 4 Barriers found in the analysis

Barriers
Lack of clear information regarding financial and legal implications
Lack of information regarding energy savings and environmental impact
Lack of appropriate support from technical and legal experts
Lack of support from community leaders
No knowledge about the energy and carbon footprint data
Discrimination by using the label

campaigns. Through the reinforcement of the drivers perceived by the potential members of the energy communities, it is possible to maximize the number of people who will embark on the journey toward citizen science platforms on energy issues using the energy communities as motivation.

In relation to the barriers, appropriate mitigation measures were analyzed and discussed. This is an important part of the co-design of the rationale with the members of the community.

a. Lack of clear information on financial and legal implications.

At the early stages of communication for the energy community project, it is crucial to provide potential participants with comprehensive information regarding the legal and financial implications of their involvement. To avoid any confusion or misunderstandings, all doubts and questions should be addressed with appropriate answers. Having a list of frequently asked questions (FAQs) on the website would be highly beneficial to potential participants.

b. Lack of information about the energy savings and the environmental impact.

Potential participants in the energy community should be involved in activities such as but not limited to designing PV systems and calculating their expected annual production, as well as the corresponding impact on reducing their CO_2 emissions. They should also participate in translating these results in terms of carbon footprint reduction and their impact on the proposed label categorization. Such involvement from the initial stages of design does not negate the need for the widespread dissemination of the expected results among all potential stakeholders, such as making them available on the community website.

c. Lack of appropriate support from technical and legal experts and lack of support from the leaders of the community.

The lack of legal and technical support is a barrier for potential participants in the energy community who are not specialists in either PV technology or the associated legal-economic apparatus. It is crucial to involve external experts in engineering PV systems and in the legal and fiscal aspects of energy communities and renewable energy investments during dissemination and communication campaigns. This will help potential participants to feel confident and supported in these unknown areas.

In addition, support from community leaders such as university rectors and campus directors is necessary. This could be achieved by inviting them to participate in open communication events and encouraging them to not only participate in the energy community but also share their vision through communication channels, i.e., institutional website, social networks and periodic newsletter. By taking these actions, the barrier of a lack of support from community leaders can be overcome.

d. No knowledge about the energy and carbon footprint data.

A barrier to joining the EC is the lack of knowledge about energy and carbon footprint data, which leads to doubts and questions from potential participants. To overcome this barrier, technical terms should be explained in a way that is understandable to the public. Training sessions on energy issues, including practical examples and everyday language, can help potential participants understand the production of a PV system and the reduction in CO_2 emissions. Relating these concepts to the proposed labeling system and providing practical examples of how to progress through the different levels, such as micro-investing in solar panels, can be beneficial.

e. Discrimination by using the label linked to citizen science activity.

To overcome this barrier, it is important to demonstrate that the label is a tool for personal understanding and the improvement of energy consumption habits. Practical training sessions with clear examples should be provided to help people understand the benefits of the label. It should also be emphasized that personal information about a specific person's label position will not be publicly shared unless the person chooses to do so. The app will only display aggregated data to reduce the risk of discrimination.

5 Conclusions and future work

Energy communities position themselves as a transformative element for citizen participation in energy issues. After analyzing several energy community models, it can be seen that the participation of citizens in energy communities is mostly driven by the desire for economic benefit, while at the same time, such participation cannot be separated from the environmental benefit. In contrast, the social and educational benefits of energy communities remain practically unknown or poorly developed and perceived. In this work, an energy community model that precisely enhances this figure as a generator of systemic and transformative change in local environments through its conversion into hubs of citizen science was studied, presented, and created. Access is available to anyone who is interested regardless of their financial capability, their possession of available surfaces for the installation of renewable energy systems, or the distance from their home to the generation point (limitations of shared self-consumption). The proposed model has been adapted to suit university communities, including activities that could better fulfill the interests of these communities; the model has been presented at various events held in four European cities. The results show a high degree of awareness of these communities about their capacity to generate local changes regarding the use and production of energy, as well as a great interest in the role that the communities play in these initiatives. With the results obtained, the barriers and drivers regarding the model have been identified and analyzed to facilitate the implementation of the first pilot studies of these experiences more accurately.

This study has some limitations that suggest the possibility of further studies. One significant limitation is that the responses were collected only from university communities, which may introduce bias due to the specific social norms of these settings. People within these communities are expected to be more open to innovation, and their high level of education may contribute to a greater awareness of global climate issues, which could justify the observed level of proactivity. Examining the rationale in other social communities may reveal different drivers and barriers, which could in turn suggest alternative pathways for action.

A second limitation is that the rationale was tested with communities from technical faculties such as mechanical engineering, electrical engineering, computer science, and telecommunications engineering. Although our sample aimed to represent both genders, the reality of these campuses is that they are predominantly male (approximately 80% on average). Therefore, testing the rationale in other university communities may verify whether the findings from this research can be extrapolated.

Appendix 1

Questionnaire:

1. Considering the option of contributing to the energy transition in my University /in my neighborhood and contributing to reach the 2030 climate targets sooner, I consider:

Responses: Please select one:

A. I am co-responsible and I am part of the solution.

B. I am co-responsible but I am not part of the solution.

C. I am not co-responsible but I am part of the solution.

D. I am not co-responsible and I am not part of the solution.

2. Energy communities are a new instrument to incentivize citizens' participation in the energy system. According to my own criteria, I would prioritize:

Responses: Please classify them from the most important (1) to the less important (7).

[] Provide profitability to the investment done by their members.

[] Provide in-kind benefits to the investment done by their members: first-hand education on energy aspects, return on investment through local coupons or discounts, etc.

[] Provide social benefits to the community, i.e., contributing to fight against energy poverty, use the installations to feed cheaper electric chargers points for citizens, reduce the cost of electricity for public institutions and use such savings for encouraging other social actions, etc.

[] Provide environmental benefits to the community, i.e., reducing the carbon emissions of the local area.

[] Provide a way for me to act into my community according to my values.

[] Provide a way for me to challenge the rules of the traditional electric system and take part of new demonstrators.

[] Foster social identity of the community where their members are coming from while increasing networking.

3. Considering a tentative participation on the local energy community, I would need to know beforehand:

Responses: Please classify them from the most important (1) to the less important (7).

[] Financial implications of my participation, e.g., return on investment.

[] Legal implications of my participation.

[] The procedures to formalize my participation.

[] How and where to access all information and documentation as well as contact details for asking questions.

[] Educational /Training /Social Activities that the energy community would implement.

[] Energy savings and Environmental Impact of the shares offered by the energy community.

[] Ways of taking part more actively into the energy community beyond the economic investment.

4. Considering that an energy community should run at least one renewable energy facility, as for the large collective social energy community model, I consider:

(please select one).

[] The minimum investment proposed by the organizers is reasonable and acceptable for me to take part on the energy community.

[] I could even consider major investments.

[] I prefer to donate an undefined amount I consider but not to engage legally with the community.

[] I don't participate in actions implying money even considering the action according to my values.

[] I would invest but.

(blank space)

[] I The action is not interesting for me entailing no investment at all.

5. For me it is important that,

Responses: Please classify them from the most important (1) to the less important (5).

[] The leaders of my community show a strong and continuous support to the initiative as a key action.

[] The initiative is led by technical and legal experts to clarify all my doubts now and when the energy community is running.

[] People I trust, such as family or friends, also support the initiative.

[] I can receive feedback and information sharing from citizens who have previously invested in renewable energy facilities.

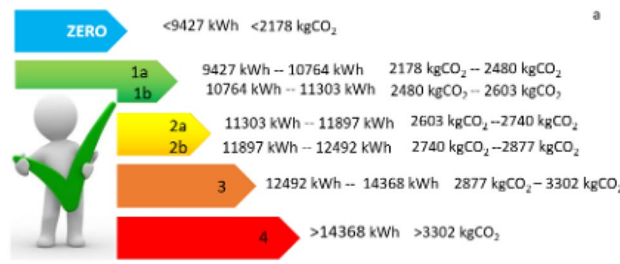
[] Knowing that the rest of the community members are also joining the initiative.

Questions 6 and 7.

"AURORA team is developing a label for citizens' carbon emissions based on energy and commuting behavior, as illustrated in the image here. By providing data regarding electricity and heating consumption, and commuting patterns, citizens can get a result of which label their carbon emissions entail.

Then, by acting through the project (becoming a member of an energy community that produces clean energy, changing his/her mobility patterns) the user can get an updated label."

Example of the label:



6. What do you think of the labels?

Responses: Please select one:

[] I am keen to provide some data and know what label I will get.

[] I would consider providing my data and use the label.

[] It is an interesting idea but I do not think I will use it.

[] I do not like this idea and I will not use it.

[] This is a terrible idea. I will not use it and will not recommend anyone in the community use it.

[] Prefer not to say.

7. Other comments to this label

[] (blank space).

And finally, please tell us a little bit about yourself:

8. How would you describe your interest in this initiative?

My potential participation will be by: (Please note that you do not commit to a membership of any kind).

Select all the options you consider appropriate.

[] Investing in the community.

[] Volunteering on the initiative, i.e., by helping organizers.

[] Being trained on energy aspects: attending workshops, public discussions, other events.

[] Supporting the research studies by providing household energy usage and transportation data in the AURORA App.

[] Following the project externally, i.e., by following AURORA social-networks, receiving newsletters, passing the word on the initiative, etc.

[] I am considering participating in the "AURORA" project but am not yet fully decided how. (Please specify why).

[] I am only generally interested in the topic, but am not necessarily considering to participate in the project.

[] I have already decided _not_ to participate in the project. (Please specify why).

9. Age

[] Please enter your age.

[] Prefer not to say.

10. Your gender?

Please select one of the options below:

[] Female.
[] Male.
[] Non-binary.
[] My gender is not listed here.
[] Prefer not to say.
9. Your highest educational qualification
Please select one of the options below:
[] No formal qualification.
[] Currently studying (school/college/university).
[] High school.
[] Some college/university (attended university/college but did not finish).
[] College/university degree.
[] Graduate/postgraduate degree.
[] Prefer not to say.

Author contribution Individual contributions included the following: A.B.C. was involved in conceptualization, writing—original draft preparation, funding acquisition and methodology; A.B.C., Z.Z., M.V., C.S-C. contributed to surveys definition and preparation; C.S-C., Z.Z., M.B., L.F. were involved in surveys translation; L.N., Z.Z., M.V., M.B. and L.F. contributed to engagement and rationale communication for surveys completion; C.S-C. and A.B.C. were involved in data curation and interpretation; C.S-C. contributed to writing—tables and graphs preparation; A.B.C., C.S-C., Z.Z., M.B. and A.C. were involved in writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no financial or proprietary interests in any material discussed in this article.

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References

1. Lieberman, B., Gordon, E.: Climate Change in Human History: Prehistory to the Present. Bloomsbury Academic, London (2018)
2. Guan, Y., Yan, J., Shan, Y., et al.: Burden of the global energy price crisis on households. Nat. Energy **8**, 304–316 (2023). https://doi.org/10.1038/s41560-023-01209-8
3. Carayannis, E., Campbell, D.: "Mode 3" and "Quadruple Helix": toward a 21st century fractal innovation ecosystem. Int. J. Technol. Manag. **46**, 23374 (2009). https://doi.org/10.1504/IJTM.2009.023374
4. Uitdenbogerd D, Egmond C, Jonkers R, Kok G (2007) Energy-related intervention success factors: A literature review. European Council for an Energy Efficient Economy: 2007 Summer Study 1:1853–1857. https://short.upm.es/clhqs Accessed 7 July 2023
5. Wahlund, M., Palm, J.: The role of energy democracy and energy citizenship for participatory energy transitions: a comprehensive review. Energy Res. Soc. Sci. **87**, 102482 (2022). https://doi.org/10.1016/j.erss.2021.102482
6. European Commission, Directorate-General for Research and Innovation (2016) Open Innovation, Open Science, Open to the World: a Vision for Europe. Publications Office. https://doi.org/10.2777/061652 Accessed 7 July 2023
7. European Commission, Directorate-General for Research and Innovation, Schuurbiers, D., Szavics, P., Ritschkoff, A., et al. (2018) Outreach to Newcomers and Societal Engagement in Industrial Technologies: Reports of the Horizon 2020 Advisory Group (NMBP). Publications Office. https://doi.org/10.2777/810639
8. Sovacool, B.K.: What are we doing here? analyzing fifteen years of energy scholarship and proposing a social science research agenda. Energy Res. Soc. Sci. **1**, 1–29 (2014). https://doi.org/10.1016/j.erss.2014.02.003
9. Atutxa, E., Zubero, I., Calvo-Sotomayor, I.: Scalability of low carbon energy communities in Spain: an empiric approach from the renewed commons paradigm. Energies **13**(19), 5045 (2020). https://doi.org/10.3390/en13195045
10. Directive (EU) 2018/2001 of the EU Parliament and of the Council of 11th December 2018 on the promotion of the use of energy from renewable sources
11. Directive (EU) 2019/944 of the European Parliament and of the Council of 5th June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast)
12. Directorate-General for Energy (2022) In Focus: Energy Communities to Transform the EU's Energy System. News from the European Commission. https://energy.ec.europa.eu/news/focus-energy-communities-transform-eus-energy-system-2022-12-13_en Accessed 23 February 2023
13. Wuebben, D., Romero-Luis, J., Gertrudix, M.: Citizen science and citizen energy communities: a systematic review and potential alliances for SDGs. Sustainability **12**(23), 10096 (2020). https://doi.org/10.3390/su122310096
14. Vélot, C.: Scientists and civil society must move together toward a new science. Front. Public Health **4**, 96 (2016). https://doi.org/10.3389/fpubh.2016.00096
15. Why researchers should resolve to engage in: Nature **541**, 5 (2017). https://doi.org/10.1038/541005aAccessed23February2023
16. Pain, E.: To be a responsible researcher, reach out and listen. Science (2017). https://doi.org/10.1126/science.caredit.a1700006AccesssedFebruary2023
17. See, L., Kraxner, F., Fuss, S., Perger, C., Schill, C., Aoki, K., Leduc, S., McCallum, I., Forsell, N., Fritz, S.: The potential of crowdsourcing for the renewable energy sector. Handb. Clean Energy Syst. (2015). https://doi.org/10.1002/9781118991978

18. Caramizaru, A., Uihlein, A. (2020) Energy communities: an overview of energy and social innovation. Publications Office of the European Union DOI: https://doi.org/10.2760/180576
19. Hannoset, A., Peeters, L., Tuerk, A. (2020) Energy communities in the EU—Task force energy communities. Dissertation CEER meets BRIDGE. DOI: https://doi.org/10.13140/RG.2.2.12023.65449
20. EIT Community New European Bauhaus initiative selected citizen engagement projects(2022). Prometheus. https://hei-prometheus.eu/eit-community-new-european-bauhaus-initiative-selected-citizen-engagement-projects/ Accessed April 2023
21. Dóci, G., Vasileiadou, E.: “Let’s do it ourselves” Individual motivations for investing in renewables at community level. Renew. Sustain. Energy Rev. **49**, 41–50 (2015). https://doi.org/10.1016/j.rser.2015.04.051
22. Bauwens, T.: Explaining the diversity of motivations behind community renewable energy. Energy Pol. **1**(93), 278–290 (2016). https://doi.org/10.1016/j.enpol.2016.03.017
23. Soeiro, S., Ferreira Dias, M.: Renewable energy community and the European energy market: main motivations. Heliyon **6**(7), 4511 (2020). https://doi.org/10.1016/j.heliyon.2020.e04511
24. Bomberg, E., McEwen, N.: Mobilizing community energy. Energy Pol **51**, 435–444 (2012). https://doi.org/10.1016/j.enpol.2012.08.045
25. Lennon, B., Dunphy, N.P., Sanvicente, E.: Community acceptability and the energy transition: a citizens’ perspective. Energy Sustain. Soc. **9**(1), 218 (2019). https://doi.org/10.1186/s13705-019-0218-z
26. Sebi, C., Vernay, A.L.: Community renewable energy in France: The state of development and the way forward. Energy Pol. **147**, 111874 (2020). https://doi.org/10.1016/j.enpol.2020.111874
27. Süsser, D., Kannen, A.: ‘Renewables? Yes, please!’: perceptions and assessment of community transition induced by renewable-energy projects in North Frisia. Sustain. Sci. **12**, 563–578 (2017). https://doi.org/10.1007/s11625-017-0433-5
28. Brummer, V.: Community energy—benefits and barriers: a comparative literature review of community energy in the UK, Germany and the USA, the benefits it provides for society and the barriers it faces. Renew. Sustain. Energy Rev. **94**, 187–196 (2018). https://doi.org/10.1016/j.rser.2018.06.013
29. Ivancic, A., Arranz, P., Gavldà, O., González, A., Pérez, A., Pérez, J.A., Sotil, A. (2019) Guía para el Desarrollo de Instrumentos de Fomento de Comunidades Energéticas Locales. Instituto para la Diversidad y Ahorro de la Energía (IDAE) https://www.idae.es/sites/default/files/documentos/publicaciones_idae/guia_para-desarrollo-instrumentos-fomento_comunidades_energeticas_locales_20032019.pdf Accessed 18 January 2023
30. Hoffman, S.M., High-Pippert, A.: From private lives to collective action: Recruitment and participation incentives for a community energy program. Energy Policy **38**(12), 7567–7574 (2010). https://doi.org/10.1016/j.enpol.2009.06.054
31. Amigos de la, T. (2020) Comunidades Energéticas Renovables. Análisis del Impacto Energético y Socioeconómico en el Estado Español. Amigos de la Tierra website https://www.tierra.org/wp-content/uploads/2020/11/Informe_ComunidadesEnergeticas.pdf Accessed 18 January 2023
32. Friends of the Earth Europe, REScoop.eu, Energy Cities (2020) Community Energy. A Practical Guide to Reclaiming Power. RescoopEu Web https://www.rescoop.eu/toolbox/community-energy-a-practical-guide-to-reclaiming-power Accessed 18 January 2023
33. Van Veelen, B.: Negotiating energy democracy in practice: governance processes in community energy projects. Environ. Pol. **27**(4), 644–665 (2018). https://doi.org/10.1080/09644016.2018.1427824
34. Honvári, P., Kukorelli, I.S.: Examining the renewable energy investments in Hungarian rural settlements: The gained local benefits and the aspects of local community involvement. Eur. Countrys. **10**(1), 74–88 (2018). https://doi.org/10.2478/euco-2018-0005
35. Herbes, C., Brummer, V., Rognli, J., Blazejewski, S., Gericke, N.: Responding to policy change: New business models for renewable energy cooperatives—barriers perceived by cooperatives’ members. Energy Policy **109**, 82–95 (2017). https://doi.org/10.1016/j.enpol.2017.06.051
36. Kalkbrenner, B.J., Roosen, J.: Citizens’ willingness to participate in local renewable energy projects: the role of community and trust in Germany. Energy Res. Social Sci. **13**, 60–70 (2016). https://doi.org/10.1016/j.erss.2015.12.006
37. Wüstenhagen, R., Wolsink, M., Bürer, M.J.: Social acceptance of renewable energy innovation: an introduction to the concept. Energy Policy **35**, 2683–2691 (2007). https://doi.org/10.1016/j.enpol.2006.12.001
38. Walker, G., Devine-Wright, P., Hunter, S., High, H., Evans, B.: Trust and community: exploring the meanings, contexts and dynamics of community renewable energy. Energy Policy **38**, 2655–2663 (2010). https://doi.org/10.1016/j.enpol.2009.05.055
39. Carayannis, E.G., Campbell, D.F.J. (2012) Triple Helix, Quadruple Helix and Quintuple Helix and how do knowledge, innovation and the environment relate to each other? A proposed framework for a trans-disciplinary analysis of sustainable development and social ecology. In: I. Management Association (ed) Regional Development: Concepts, Methodologies, Tools, and Applications. IGI Global, Hershey, PA, pp. 535–565 https://doi.org/10.4018/978-1-4666-0882-5.ch308
40. López Prol, J., Steininger, K.W.: Photovoltaic self-consumption is now profitable in Spain: effects of the new regulation on prosumers’ internal rate of return. Energy Policy **146**, 111793 (2020). https://doi.org/10.1016/j.enpol.2020.111793
41. Cristóbal, A.B., Sanz-Cuadrado, C., Zhang, Z., Rahdan, P., Victoria, M. (2022). AURORA D1.1 Near-zero emissions citizens label DOI: 10.5281/zenodo.7594878

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