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Citizens' participation in local energy communities: the role of technology as a stimulus

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ABSTRACT
Because of their focus on the acquisition of new technologies, local energy communities are increasingly being recognised as major players in the current energy transition and revealing the valuable role of technological solutions in sustainable development. Nevertheless, the success of these communities is not limited to the acquisition of technologies. Instead, it is strongly dependent on citizen participation. Prior literature has focused much more on the institutional and policy factors than on the roles of citizens and their participation in such communities, and indirectly on sustainability. To address the lack, this study aims to explain the determinants of citizen participation in local energy communities by developing a research model grounded on the stimulus-organism-response (S-O-R) framework, and then through a mixed-methods design, study the impact of technological factors as a stimulus on more social outcomes, namely the organism and response behaviours. Our results highlight the strong impact of sustainable technologies and gamification in citizens' attitudes. Moreover, the research model reveals a strong influence of empowerment and pro-environmental behaviour in the citizen intention to participate in local energy communities.

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KEYWORDS
Local energy communities; empowerment; pro-environmental behaviour; mixed-methods; sustainable technologies; S-O-R framework

1. Introduction

Directives from the European Union (EU) are increasingly searching for ways to tackle environmental issues and the decarbonisation of the energy system (European Parliament, 2019). Many strategies have relied on sustainable technologies, and the role of information technology (IT) on the control of pollutant emissions and energy consumption, among other efforts (Butler, 2011). Nevertheless, the success of all these strategies unequivocally depends on citizen engagement in these sustainable solutions, thereby contributing to the increased use of renewable energy in people's everyday lives and transforming energy citizens into active energy citizens (Azarova et al., 2019). The present global situation suggests the need to change the current conditions of the energy market (Bartolini et al., 2020), reinforcing the role citizens may have in it.

One of the main solutions proposed is the creation of local energy communities that can empower citizens and put them at the centre of the desired energy transition process (Krietemeyer et al., 2021). However, the implementation of these communities relies greatly on citizen engagement with the enabler technologies, such as smart metres, renewable energy installations, etc (Wunderlich et al., 2019). Despite the importance of creating the energy community and citizen engagement, literature has been sparse on this topic, focusing more on institutional and governance sides (Emelianoff & Wernert, 2019). Specifically, past research has examined the role of government agencies, regulations, and formal policies, neglecting the citizen perspective (Leonhardt et al., 2022).

This study contributes to the extension of the current body of knowledge on the topic by examining the key drivers of citizens' participation in local energy communities, and understanding the impacts of technology-related factors in more humanistic and social outcomes, following the current trend of linking instrumental factors related to the use of technologies, which are dominant in IS research, with humanistic outcomes (Sarker et al., 2019). Although a wide range of factors, such as environmental or financial determinants, can be examined to understand citizens' behaviour within these communities, we intend to extend the research on how technology can be used to support sustainable strategies as a main concern (Mikalef et al., 2022). This work focuses on the technological stimuli and the tremendous role technology can have in obtaining more sustainable solutions. In fact, Watson (2010) developed a work recognising the need to develop a field of IS that addresses environmental sustainability – energy informatics. However, until today, this need of investigating the role of technology for sustainability purposes has not been exhausted; on the contrary, the current scenario has reinforced this need. Therefore, the study proceeded in this direction.

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We address the question by drawing on the stimulus-organism-response (S-O-R) framework to understand the impact of technology-related drivers. Despite the rich body of literature on technological characteristics within the IS discipline, we have little idea of the specific characteristics that are likely to be relevant in the context of citizen engagement in energy issues. We therefore resort to a mixed-methods design to first uncover the specific characteristics and then test the developed model (Venkatesh et al., 2016).

The contributions of this paper are the following. First, it contributes to the research on local energy communities, focusing on the citizen perspective, and reinforcing the role of these communities in the energy transition process. Given the somewhat recent nature of the topic, most literature has focused on bureaucratic, organisational, and infrastructural features of these communities, such as power-gas infrastructures, institution arrangement, and regulations (e.g. Azarova et al., 2019; Berka et al., 2020; Rosenow et al., 2017). However, communities' success strongly relies on consumers' interactions with the enabling technologies and their commitment to behave sustainably. Second, following the suggestion of Venkatesh et al. (2013), our research enriches qualitative and quantitative insights that enhance the understanding of the phenomena. Most studies on the topic have adopted a qualitative approach. The qualitative study is drawn upon to identify and more deeply understand relevant dimensions, and then test them using a large quantitative study, resulting in findings that are more precise and quantifiable. Therefore, the mixed-methods design overcomes the weaknesses of one method using the strengths of the other, and vice-versa (Wunderlich et al., 2019), resulting in stronger inferences for the phenomenon being examined. Finally, our study's findings may help practitioners to understand the main citizen motivations and thereby better formulate strategies towards participation in local energy communities.

The paper is structured as follows. Section 2 presents the theoretical background. Section 3 presents the mixed-methods design and the qualitative study. Section 4 presents the research model and its hypotheses. Section 5 presents the methods, and Section 6 the results. In Section 7 the findings are discussed along with their implications and limitations. Finally, conclusions are presented in Section 8.

2. Theoretical background

2.1. Local energy communities

Several strategies have been developed for decentralised energy systems, namely microgrids and community energy systems. The first tends to be more independent and is usually employed in remote areas. On the other hand, community energy systems involve a strong engagement of citizens thereby enabling greater energy independence, and increased investment in renewable energies (Kühnbach et al., 2022). These communities emerge from the joint use of several technologies, including IoT devices, renewable energy installations, and others. Regarding this, technologies such as smart home devices have already been widely adopted (Sequeiros et al., 2021). However, employing more costly solutions such as renewable energy installations is still a challenge (Cohen et al., 2021).

In recent years the EU has introduced the concept of local energy communities as a strategy that not only empowers communities but also reduces energy poverty by providing lower tariffs. These communities enable the active participation of citizens in the energy market, producing, consuming, or selling renewable energy, contributing to an overall feeling of citizen empowerment (Malik et al., 2022). Local energy communities accelerate the implementation of renewable technologies, support pro-decarbonisation policies, and better distribute the costs and benefits of this energy transition (Berka et al., 2020). Overall, they promote a sustainable lifestyle and are facilitators of social innovation and local sustainable development. The benefits of local energy communities exceed the expected environmental contribution. In fact, these communities can greatly influence the community socially and economically (Azarova et al., 2019). Currently, small local energy communities are being created especially in countries like Germany and Netherlands (Bukovszki et al., 2020) – notably northern countries that have a high interest in these investments (Cohen et al., 2021).

2.2. Earlier research

Previous research has examined local energy communities through different lenses (see Appendix A, Table A1). The majority of these studies have focused on the importance of institutions and governments to this energy transition, analysing the impact of policies and rules for the implementation of these communities (Rosenow et al., 2017). In European countries, including Germany and the Netherlands, local energy communities are already a reality. Taking advantage of that experience, some studies suggest several barriers to the formation and existence of these communities, such as organisational and institutional issues, and resource management. Other studies have centred more on the methodological approach, studying business models, and urbanisation measures (Bukovszki et al., 2020; Lowitzsch, 2019). Thus, much of the previous research has studied the phenomenon from a more institutional perspective, instead of the citizen point of view. Nevertheless, the success of these communities relies greatly on the community spirit, norms, and responsibilities to the environment (Koirala et al., 2018). In fact, previous research on local energy communities indicates that these communities' impact is not equal across the board, as their effectiveness depends strongly on the motivation of citizens and community engagement (Berka et al., 2020).

The limited number of published studies focusing on the citizen perspective highlights the importance of personal and social norms regarding participation in local energy communities (Soeiro & Ferreira Dias, 2020). For example, Holstenkamp and Kahla (2016) suggest that environmental motivation is one of the most important factors. Besides norms, previous investigations have also examined the role of financial factors, suggesting that the possibility of having savings or financial returns is a driver to invest in local-level energy systems (Holstenkamp & Kahla, 2016). However, according to Bauwens (2019), financial drivers are better motivators of large communities. In small communities, non-financial factors are much more important. In fact, given the current situation of high energy costs, several articles have focused on policies responses, such as the attribution of vouchers, or fixed discounts to utility bills, and also considering that the rising cost of fossil fuels can also be seen as an opportunity to increase the use of renewables (Celasun et al., 2022).

In summary, empirical studies on the drivers of citizen participation in local energy communities have emphasised institutional and organisational issues, instead of examining the citizen perspective and the factors that may influence citizen decisions and attitudes. And although some recent studies have focused more on the citizen, the perspective is still narrow, and little is known about the factors influencing citizens' participation in local energy communities (Soeiro & Ferreira Dias, 2020). In fact, the studies on the role of the citizens to contribute to ecological and participatory projects is starting to increase, under the name of citizen science. This concept relates citizens and science, which when coupled with technologies creates new possibilities for environmental research, and overall public engagement projects (Newman et al., 2012). In many studies, citizen science refers to the collaboration of the citizen in collecting and processing data, improving inclusivity of data collection, and new perspectives to the research (Isley et al., 2022; Leonard et al., 2022). Therefore, we focused on this recent topic, studying the role that citizens have, empowered by technological solutions. Given our interest in the citizen perspective, we turned to a known theoretical lens often used for understanding citizen behaviours.

2.3. S-O-R framework

In recent years several theories have been employed to explain the drivers of consumer behaviour, namely, adoption and usage of technologies (e.g. Davis, 1989; Venkatesh et al., 2003). Additionally, numerous studies have investigated consumer behaviour by gathering factors more related to psychology and marketing fields, such as norms, values, risks, etc (Brown & Venkatesh, 2005). In the field of sustainable technologies, those variables have been extended to pro-environmental norms and ecological responsibilities, among others (e.g. Schwartz, 1977). It is thus valuable to investigate specific characteristics of the phenomena under study that might influence citizens' behaviour. Having this in mind, several frameworks have been developed to better comprehend the human behaviour. One of these is the stimulus-organism-response (S-O-R) framework, which originates in the field of environmental psychology, and suggests that citizen behaviour is a complex phenomenon. Based on this framework one can argue that many environmental features act as stimuli that influence individuals' internal states, which in turn affect their behaviour (Mehrabian et al., 1974). External (or psychological) stimuli are related to the external environment of the individual. Organism refers to the cognitive and affective internal states of the individual, influenced by a stimulus. Finally, response corresponds to the behavioural reaction to the stimulus and organism (Mehrabian et al., 1974).

The S-O-R framework has been widely used, especially in marketing and tourism studies involving tourism-destination (Su & Swanson, 2017), mobile social tourism shopping studies (Hew et al., 2018), and IS studies pertaining to mobile learning (Loh et al. 2022), social media (Peng Luo et al. 2021), and smart technologies (Cho et al., 2019). In fact, within IS, a similar framework has been recognised within the literature on environmental sustainability (belief-action-outcome framework), revealing three processes for sustainability phenomena: (1) how beliefs and opportunities emerge; (2) sustainable practices and processes; and (3) environmental outcomes (Melville, 2010). Translated to the S-O-R framework, stage (1) can be also seen as stimulus, since it comprises factors that can give rise to cognitive beliefs about sustainability. Stage (2) can also be formulated as organism, in the way that it includes sustainable processes, attitudes, and practices. Finally, stage (3) corresponds to the response behaviour, as it includes the outcome. Therefore, this type of process framework has in fact also been used in IS studies related to environmental sustainability. However, in this framework, the properties, functions, or features of a technology are not considered (Recker, 2016). For this reason S-O-R was chosen, as it uncovers the intrinsic process of consumers' responses, and is more open to the inclusion of any type of stimuli (P. Luo et al. 2021). In fact, stimuli can include both object stimuli or social psychological ones (Su & Swanson, 2017). Therefore, several studies have investigated more objective technological stimuli, such as app design (Hsiao & Tang, 2021) and smartwatch characteristics (Cho et al., 2019). Given this, S-O-R better fits technological variables as a stimulus.

The S-O-R framework will allow us to examine the drivers and processes of citizen participation in local energy communities. It will be used as a theoretical foundation, suggesting that external factors will act as stimuli, individuals' cognitive and internal states will be the organism, and finally the intention to participate in local energy communities will be the response behaviour (see Figure 1). We examine the impact of technologies as stimuli on the feeling of empowerment, as energy communities are effective at empowering their citizens and the pro-environmental behaviour of individuals' internal states by addressing actions or feelings that can trigger the response. These two factors of organism are developed in the following sub-sections.

2.3.1. Empowerment

A key factor of citizen engagement is the feeling of empowerment (Zimmerman, 1995), especially regarding organisational citizenship behaviours (Ma et al., 2021), and even some pro-environmental behaviours (Hartmann et al., 2018). More recently, in relation to technology, empowerment has been used to understand the acceptance of technologies in the workplace, connected with concepts such as work performance and work productivity (Junglas et al., 2022), and also used to study smart city apps, for example, demonstrating the importance of smart technologies in supporting citizen empowerment (Zhu & Alamsyah, 2022). Additionally, researchers have investigated if using technology for e-participation and e-government purposes provides a sense of empowerment (Naranjo-Zolotov et al., 2019). Empowerment has also been analysed in light of online solutions such as social media platforms, virtual communities, etc (Füller et al., 2009; Richard & David, 2018). and showed to be an effective tool for empowering citizens. Given this, two conclusions can be highlighted: (1) Although past literature has related technology and empowerment from different perspectives, there is always a common line of thought – technology can empower citizens and communities (Junglas et al., 2022); (2) This empowerment can be extended to other contexts like sustainable purposes, but also diminished if individuals lack the skills to use the technologies, or if the social structure in which they live is not open to innovations (El-Haddadeh et al., 2019).

Empowerment is therefore conceptualised as "the connection between a sense of personal competence, a desire for, and a willingness to take action in the public domain" (Zimmerman & Rappaport, 1988, p. 746). Empowerment is composed of four dimensions: competence, meaning, impact, and self-determination. Competence refers to the degree to which an individual has sufficient skills to perform a certain behaviour or action. In the local energy community's context competence refers to knowing how to use smart metering technologies, for example. The next element is meaning, defined as the individual judgement of the value of a certain activity. For example, if participating in a local energy community brings value for the citizens, such as greater energy independence, the individual will be more willing to participate. Impact suggests the degree to which a certain activity is perceived as having an intended effect – for example, investing in renewable energy installations that will later contribute to the flexibility of the energy system. Finally, self-determination refers to the perception of having responsibility for a particular outcome of a performed activity (Ryan & Deci, 1985). When participating in decision processes, the citizen may feel involved and responsible for creating a more sustainable energy community, thereby creating a sense of empowerment in that citizen, and empowerment can be a strong driver for citizen engagement.

2.3.2. Pro-environmental behaviour

Local energy communities are the basis of many strategies for sustainable development. An appropriate construct to explain participation in local energy communities is pro-environmental behaviour (PEB), adding a "green" perspective to the model. Many studies have sought to define PEB, suggesting that its multiple dimensions should be disaggregated (Larson et al., 2015). Based on this, PEB can be conceptualised in the following dimensions: social environmentalism, conservation lifestyle, and environmental citizenship. Social environmentalism refers to social engagement,

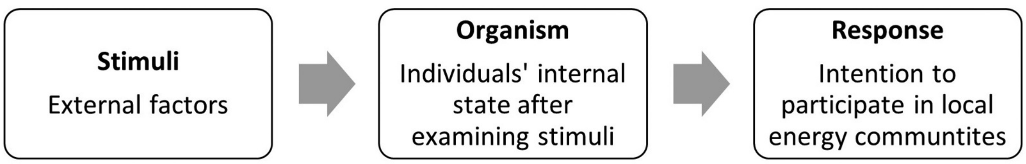

Figure 1. S-O-R framework.

i.e. informing others about the importance of conservation actions (Larson et al., 2015). Conservation lifestyle is seen as one of the most common citizen pro-environmental behaviours, as it includes actions such as recycling, saving water when possible, etc (Larson et al., 2015). Finally, environmental citizenship behaviour is defined as the civic or political engagement in supporting policies favouring environmental conservation.

The combination of empowerment and PEB, not yet tested in the literature, allows us to integrate the motivational perspective with a pro-environmental one, which results in a more comprehensive understanding of the drivers of participation in local energy communities. We view these constructs as the organisms. As previously studied, responses are significantly influenced by internal cognition, attitudes, and motivations (Chopdar & Balakrishnan, 2020). Indeed, empowerment and PEB have been previously examined as antecedents of individual behaviours, including citizen participation (Naranjo-Zolotov et al., 2019), and are described as motivational and attitudinal means that may trigger individuals to engage in a response (Hartmann et al., 2018). Therefore, citizens' perceptions about the feeling of empowerment and pro-environmental experiences can constitute internal motivations and attitudes that trigger a response among citizens.

However, the organism might be stimulated by several external factors, and although some studies have been conducted on the topic of sustainable technologies and local energy communities, very few have considered this perspective. This encourages us to adopt a mixed methods design as suitable for creating a more contextualised model, as well as for obtaining a better understanding of individuals' stimulus. Specifically, we hope to determine which technological signal can affect the organism. The next section presents the mixed methods design.

3. Mixed methods design

A mixed-methods design calls for the inclusion of both qualitative and quantitative methodologies. This approach should be implemented when researchers wish to holistically explain a phenomenon for which prior research is fragmented or when a single method or perspective is not enough to explain the complexity of the phenomenon (Venkatesh et al., 2016). Mixed-methods have the ability to address confirmatory and explanatory research questions, providing stronger inferences than a single method (Venkatesh et al., 2016). Therefore, given the wide range of factors that can influence the citizen engagement on local energy communities and our objective of uncovering technological impacts in more social and attitudinal outcomes on citizen participation, we believe that mixed methods is a suitable approach. The purpose of the design in our study was developmental, as the results from the qualitative phase were used to develop the research model, more specifically to help understand the individual's stimulus (e.g. technological factors that may influence a citizen's internal state). The mixed-methods design allowed us to overcome the weaknesses of one method using the strengths of the other, and vice-versa (Wunderlich et al., 2019). While the qualitative study presents a rather small sample, and subjective descriptions that are difficult to represent in numerical data, the quantitative research was designed to allow for a large sample. Moreover, when applying this, results are relatively independent from the researchers, since it relies on statistical methods, providing a more precise, and quantifiable result. It also provides greater confidence in the generalisability of results, since a probability sample is collected. The qualitative findings are difficult to be extended to wider populations with the same degree of certainty as the quantitative findings (Venkatesh et al., 2016). Therefore, the strategy applied to complement the two methods is to identify possible stimulus variables using the qualitative study, and then test them on a wider and purposive sample in the quantitative study, to examine their effect truly and quantifiably.

in light of the above, we start with the qualitative study, followed by the quantitative one. It is therefore a sequential design (Venkatesh et al., 2016). Finally, given the generally limited knowledge on the topic, a purposive sampling was used for the qualitative study and a probability sampling for the quantitative study. In qualitative study, interviewees were selected from European working groups, energy companies and universities. After exercising the two methods there is a need to triangulate the data of both phases of the study, responding to the mixed-methods research question, in the form of meta-inferences (Venkatesh et al., 2016). Table 1 contains further details on the mixed-methods design choices.

3.1. Qualitative study (phase 1)

The purpose of the qualitative study was to identify specific technology-related variables that can act as the stimulus of the citizen behaviour. For that, 18 experts and consumers were interviewed in April of 2021 in order to gain different viewpoints of what drives individuals to feel empowered or to embrace pro-environmental behaviours. Interviewees were selected from European working groups, energy companies, and universities, according to the availability and convenience of meeting. The interviewees were mainly individuals responsible for the decision of adoption of technologies in their household and were personally and/or professionally interested in the energy sector. The number of interviews was based on data

Table 1. Mixed-methods design.

Topic	Decision	Design
Research questions	Mixed-methods research approach to address the research question	- Qualitative research question: "Which technology-related variables determine the citizen intention to participate in local energy communities?" - Quantitative research questions: "Does the S-O-R model developed explain the intention to participate in local energy communities?" Mixed-methods research question: "Are the technology related variables identified in the qualitative study supported by the results in the S-O-R model developed?
Purpose of mixed-methods research	The purpose is to help to develop the hypotheses using the qualitative study results	Developmental purpose – the results from the qualitative study are used to develop the research model and tests in the quantitative study
Epistemological perspective	Different epistemological assumptions	Multiple paradigm stance
Paradigmatic assumptions	We assume different methodological approaches	Interpretivism/constructivism for the qualitative study and a positivism paradigm for the quantitative study
Design investigation strategy	The strategy adopted was to develop the research model with the help of the results from the qualitative study and then test the theory on the quantitative one	Qualitative study corresponds to the first study (exploratory) and the quantitative corresponds the second study (confirmatory)
Research strands	Multiple phases	Multistrand design
Mixing strategy	The qualitative and quantitative elements were mixed in the inferential stage	Partially mixed methods
Time orientation	The first study was the qualitative and the second was the quantitative	Sequential design
Priority of methodological approach	The quantitative study is more dominant	Dominant-less dominant design (dominant – quantitative; less-dominant – qualitative)
Sampling design strategies	The sample for both studies was collected from the same population. However, different sampling strategies were adopted for each study	Purposive sampling for the qualitative study – it included experts in the areas of energy and consumers, given some limited knowledge on local energy communities. Probability sampling for the quantitative study
Data collection strategies	Two data collections: one for the exploratory study and the other for the confirmatory study	- Qualitative study: open-ended questions (a semi-structured interview guide was used) - Quantitative study: close-ended questions (online questionnaire)
Data analysis strategies	Qualitative data were analysed based on open-coding methodology, by reducing the content of the interviews to codes. Quantitative data were analysed using structural equation modelling. We first analysed the qualitative data and then the quantitative one	Sequential design - Qualitative study: transcription of all interviews, creation of codes based on the quotes of interviewees, selection of the most-mentioned codes - Quantitative study: sample size of 1602 individuals. Samples from each country were compared to the country population in terms of age and gender patterns
Types of reasoning	We first developed the hypotheses and then confirmed them	Inductive (qualitative study) and deducting (quantitative study)
Inference quality	Qualitative and quantitative study, and meta-inferences met the quality standards. Also, all possible threats were analysed	Conventional qualitative and quantitative standards were used. Internal validity was addressed by developing a theoretically robust model, testing the reliability of the instrument by applying the appropriate statistical tests. Construct validity, appropriate level of significance for tests, and multicollinearity were tested appropriately.

saturation (Fusch & Ness, 2015), suggesting that saturation is achieved when there is enough information, there is no more capacity to obtain new information, and additional coding is no longer possible. To achieve data saturation, a saturation grid was used, listing the main topics mentioned per interviewee (Brod et al., 2009). Therefore, we believe that the qualitative sample is representative (Wunderlich et al., 2019). Note that the 18 interviewees did not include a consumer from the UK or an expert from Germany. Therefore, two additional interviews were added in March 2023, in order to have representativeness of all countries' consumers and experts. These additional interviews not only brought greater representativeness to the sample, but also confirmed data saturation. Table 2 contains interviewees' details. Each interview had a duration of approximately 45 minutes. All interviewees agreed with recording for transcription purposes. Appendix B presents the interview guide.

We followed an open coding methodology to analyse the qualitative data, segmenting data into quotes and associating them with a category. Thus, a list of categories was created based on the transcriptions and notes from the interviews (Table 3). The main codes were recorded and for each code a set of quotes from respondents was saved (see Table C1) (Miles & Huberman, 1994). Note that the use of inductive coding such as this has been demonstrated to be acceptable in prior research (Wunderlich et al., 2019). This analysis was conducted over a period of approximately two months. Figure 2 illustrates the process of data analysis.

One of the most-mentioned factors in the interviews was the use of what we labelled sustainable technologies, i.e. technologies that resort to

Table 2. Interviewees details.

ID	Country	Role	Occupation	Household role
I1	Italy	Expert	University professor	Responsible for the decision to adopt technologies
I2	Italy	Expert	Researcher	Responsible for the decision to adopt technologies
I3	Italy	Expert	Researcher	Responsible for the decision to adopt technologies
I4	Greece	Expert	Head of applied research and innovation	Responsible for the decision to adopt technologies
I5	Germany	Expert	Electrical Engineer	Responsible for the decision to adopt technologies
I6	Portugal	Expert	Environmental engineer	Responsible for the decision to adopt technologies
I7	Portugal	Expert	Researcher	Responsible for the decision to adopt technologies
I8	Portugal	Expert	Project manager	Responsible for the decision to adopt technologies
I9	United Kingdom	Expert	Sustainability manager	Responsible for the decision to adopt technologies
I10	Italy	Consumer	Unemployed	Not responsible for the decision to adopt technologies
I11	Italy	Consumer	Communication department employee	Responsible for the decision to adopt technologies
I12	Italy	Consumer	Mechanical engineer	Not responsible for the decision to adopt technologies
I13	Greece	Consumer	Marketing assistant	Responsible for the decision to adopt technologies
I14	Greece	Consumer	Marketing and communication officer	Responsible for the decision to adopt technologies
I15	Germany	Consumer	Project leader	Responsible for the decision to adopt technologies
I16	Germany	Consumer	Self-employed baker	Responsible for the decision to adopt technologies
I17	Germany	Consumer	Mechanical engineer	Responsible for the decision to adopt technologies
I18	Portugal	Consumer	University professor	Responsible for the decision to adopt technologies
I19	Portugal	Consumer	IT consultant	Responsible for the decision to adopt technologies
I20	United Kingdom	Consumer	Medical doctor	Responsible for the decision to adopt technologies

Table 3. Codes by interviewees.

	Use of sustainable technologies		
Interviewees/ Construct	For pro-environmental purposes	For empowerment-related purposes	Gamification
I1	X		X
I2			
I3	X		
I4	X	X	
I5	X		X
I6	X		X
I7		X	
I8	X	X	
I9	X		
I10			
I11			
I12	X	X	X
I13	X	X	
I14	X		
I15			
I16			X
I17			X
I18			X
I19	X	X	
I20	X	X	

sustainable resources, that by itself are more sustainable and efficient (Dadzie et al., 2018), or that can help consumers to behave more sustainably (Barreto et al., 2014). Specifically, the technologies mentioned were internet of things (IoT) wearable devices, IoT smart home devices, renewable energy sources installations, electrical vehicles, batteries for energy storage, and energy dashboards like the ones provided by smart metres. These technologies comprise the basis of interaction, and therefore engagement, of the citizen with the local energy community. Once these technologies are set up in citizens' households, the success of the community will depend in large part on how citizens use the enabler technologies, and how their use makes citizens feel. Interviewees referred to the *use of sustainable technologies* as a great motivator for their participation in local-level actions, but also in overall pro-environmental behaviours. For example, interviewee 8 mentioned: "*That these kinds of technologies allow me to track and to get some feedback regarding my energy consumption, and therefore improve my energy behaviours. I think that's the most important thing (...). I believe that I'm helping the environment*". Also, interviewee 4 mentioned: "(...) *I would like to have a solution that I can check it from time to time just to see that I am doing something good for the environment.*". Interviewee 6 also mentioned: "*The fact that using them [sustainable technologies], I would have*

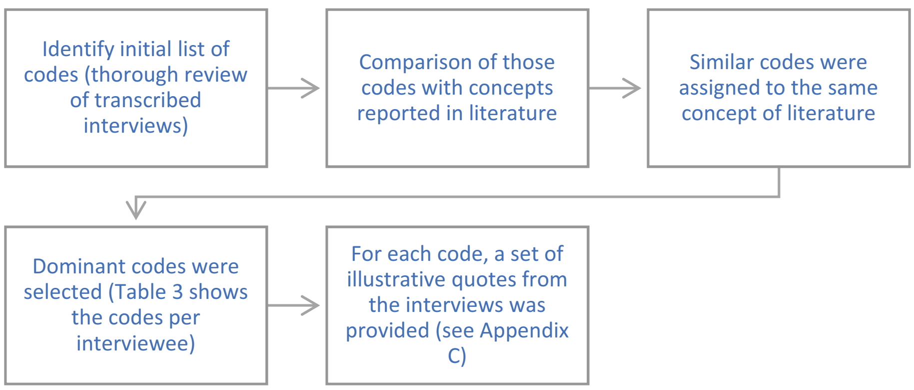

Figure 2. Qualitative data analysis process.

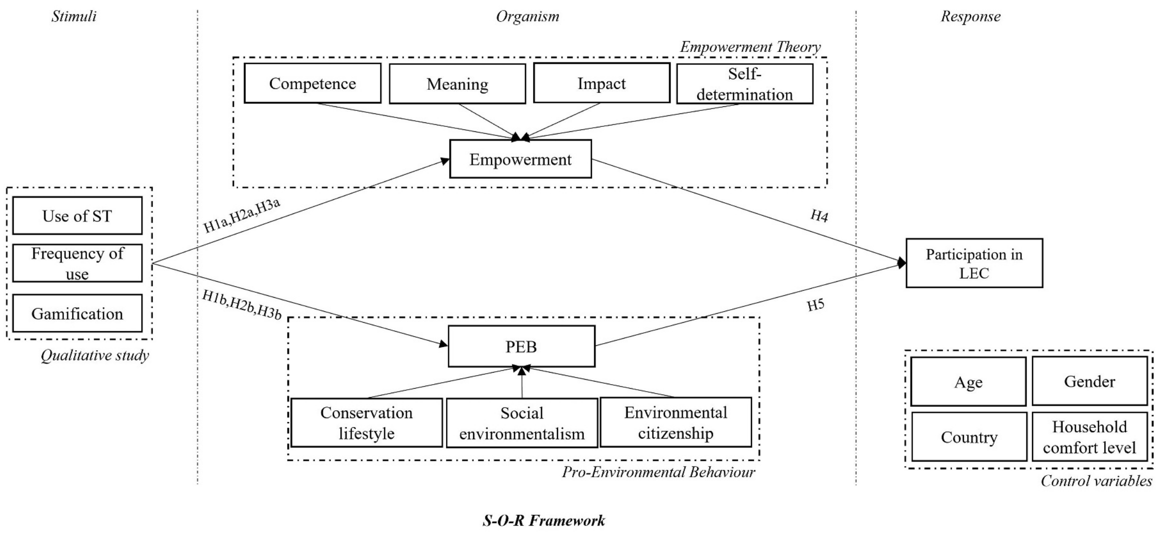

Figure 3. Citizen participation in local energy communities' model. *Note: The model represents three stages of the citizen intention to participate in local energy communities, starting with technology related variables as stimulus of citizen attitudes, namely, empowerment and pro-environmental behaviour, leading to its intention to participate in local energy communities.*

a lower impact in the environment that's a key point". In fact, tracking devices and their application have turned out to be very popular and successful in changing user behaviour (Constantiou et al., 2022). But more than enabling more pro-environmental behaviours, interviewees also stated that the use of sustainable technologies made them feel more in control and have greater competence in managing their consumption. For example, interviewee 13 stated that: *"(...) generally these technologies make my life easier*". Also, interviewee 4 stated that: "*For example, I changed my energy provider some months ago, and now my [consumption is] tracked, and so I can check [it] in my bill*". Even interviewee 19 referred to the use of these solutions as a great way to have a positive individual and shared impact on the community: "*If I have enough for me and to supply to the network, I'm not only reducing my current footprint, but I'm also helping to reduce others' because I'm producing for them*". Also, interviewee 20 mentioned: *"I believe that this [sustainable technologies use] will only truly be successful when my community is aware of the impact we can have".*

Along with the use variable, gamification was also referred to as a relevant technology-related variable. In this specific case, the gamification forms that were mentioned were the inclusion of a rewards from points collection systems and/or badges, as well as the creation of a competition between neighbours and/or neighbourhoods, attributed accordingly to their energy performance measured by technologies, like smart metres. Gamification is therefore studied as a feature added to the technologies. In fact, previous studies report that gamification features such as visibility of achievement and competition encourage citizens to perform pro-environmental behaviours, and also influences their perception of effectiveness in achieving their goals of environmental conservation with the help of technologies (Ke et al., 2019). This was also confirmed in the interviews. For example, interviewee 1 said that: "*I think this [gamification] may help a specific type of end-users to be more interested in it. Also, it potentially may support continuous sustainable behaviours.*". Interviewee 5 also observed: *"[using gamification] many of them (citizens), they need to know it and they got the information in another and simpler way"*.. Interviewee 12 also stated: *"... when you do that, like a game, then I think it gets on the routine pretty soon and [it helps] to keep the interest*". Therefore, gamification can be an influential strategy to support pro-environmental behaviours and to make the citizens feel more competent.

4. Research model

As mentioned above, our holistic research model is grounded on the S-O-R. This framework allows us to better understand the impact of several technological factors on organismic states and the resulting response (Chopdar & Balakrishnan, 2020). Due to the complexity of the phenomenon, we also relied on qualitative data to better understand the technological factors that may act as a stimulus. Then, we examined how these factors are associated with the feeling of empowerment and pro-environmental behaviour, i.e. the individual's motivations and attitudinal reactions to the stimulus. Finally, we analysed how the organism affects participation in local energy communities (response). Figure 3 presents the research model. The following sub-sections present the research hypotheses.

4.1. Technological factors as stimuli (S)

Stimulus is defined as the external environment that may influence individuals' attitudes and motivations. Previous studies using the S-O-R model have defined stimulus as technology-related factors, especially resorting to the DeLone and McLean's IS model constructs (Lian, 2021). In our study, instrumental factors are examined as the stimulus in the environment that can affect an individual's organism and consequently a response behaviour. Hence, the qualitative study raised two variables – use of sustainable technologies and gamification of sustainable technologies – as having a potential impact on the organism. Overall, sustainable technologies have been defined in several ways (Neves & Oliveira, 2023). Given this, we have defined sustainable technologies (ST) in two ways: (1) as technologies that resort to sustainable resources, such as solar panels (Crosno & Cui, 2014), or that by themselves are more sustainable and efficient, such as efficient and smart home appliances (Dadzie et al., 2018); (2) as technologies that can help consumers to behave more sustainably through more active actions based on metering technologies such as smart metres (Wunderlich et al., 2019), which provide feedback to their users. In the first perspective the sustainable feature is embedded in the technology, while in the second the technology is a support for the user to behave more sustainably. We believe that these two perspectives capture the main characteristics of these technologies. These technologies are essential for the implementation of a local energy community. Most interviewees reported that their use would undoubtedly influence their behaviour and how they feel about behaving pro-environmentally. For example, interviewee 1 mentioned: "*To be friend of the environment, this is the most important to me*". Interviewees also stated that the use of sustainable technologies makes them feel empowered and have an impact. For example, interview 3 mentioned: "*The benefits to me is to feel well with myself because I know I am using energy solutions that are environmental friendly*".

In this study the use variable will be tested in two ways: the general use behaviour of sustainable technologies and the frequency of use of different sustainable technologies, including renewable energy installations, smart appliances, etc. These two constructs will provide interrelated, but still different, perspectives of the use behaviour. Frequency of use is a more precise measure of the use behaviour and is usually related to external factors and depends on the citizens' environment and defined interaction with the technologies, as some of the tasks associated with the technologies might be scheduled and vary upon users' goals and interest (Venkatesh et al., 2008). Frequency of use is therefore a more precise conceptualisation of system use (Burton-Jones & Straub, 2006). Therefore, we hypothesise that:

H1a: Use of ST positively impacts empowerment.

H1b: Use of ST positively impacts pro-environmental behaviour.

H2a: Frequency of use of ST positively impacts empowerment.

H2b: Frequency of use of ST positively impacts pro-environmental behaviour.

Besides the use of sustainable technologies, interviewees also suggested that the inclusion of some gamified features in the technologies would make them feel more engaged in pro-environmental actions. In fact, gamification has been studied as a driver for pro-environmental behaviour (Morganti et al., 2017). Schweiger et al. (2020) focused on the role of gamification as a way to continuously engage citizens in local energy communities. Strategies that include receiving badges, recognising achievements, and/or the existence of competitions have been demonstrated to effectively stimulate individuals and increase their willingness to engage in a certain behaviour. For example, the introduction of gamification, such as the attribution of awards and community badges (e.g. eco-stars) have boosted ecologically conscious behaviours (Lounis et al., 2013). Interviewees similarly suggested that gamification may not only help them to engage in sustainable behaviours but would also help them to feel more competent and empowered when using any solution. For example, interviewee 1 reported that: "*I think this [gamification] may help a specific type of end-users to be more interested in it. Also, it potentially may support continuous sustainable behaviours.*". Therefore, we hypothesise the following:

H3a: Gamification positively impacts empowerment.

H3b: Gamification positively impacts pro-environmental behaviour.

4.2. Empowerment and pro-environmental behaviour as organism (O)

The first emotional state of organism to be studied is empowerment. The feeling of empowerment is described as the motivational means that will trigger individuals to engage in behaviours, especially proactive ones, or that leads to the achievement of a feeling of control (Hartmann et al., 2018). Empowerment has been widely employed, especially for citizen activities such as e-government participation (Naranjo-Zolotov et al., 2019) and IoT public services participation (El-Haddadeh et al., 2019), and has proved to have a substantial impact on explaining citizen participation. When citizens perceive that participation in a certain activity may create feelings of competence, meaning, impact, or self-determination, they feel empowered, resulting in a genuine interest in participating in the activity. Therefore, we hypothesise that:

H4: Empowerment positively impacts participation in local energy communities.

Pro-environmental behaviour is another relevant organism in our model. Recently, few studies have used ecological concern to study local energy communities, but have confirmed their impact on the attitude towards joining a renewable energy community (Conradie et al., 2021). Individuals who behave pro-environmentally may be more willing to engage in other pro-environmental behaviours, such as participating in a local energy community. More than just wanting to protect the environment, individuals who perform concrete pro-environmental behaviours are expected to be much more eager to participate in local energy communities. Therefore, we hypothesise that:

H5: Pro-environmental behaviour positively impacts participation in local energy communities.

5. Quantitative study research methodology (phase 2)

The second phase of the mixed-methods approach was to conduct the quantitative study, and to test the research hypothesis created based on both the qualitative study results and literature review. This phase sought to answer the research question: "*Does the S-O-R model developed explain the intention to participate in local energy communities?*". The emphasis was on the use of statistical methods on a large dataset to test the research model. Nevertheless, both quantitative and qualitative data were brought together in the last step – meta-inferences stage, in which results of both methods were compared.

Starting the quantitative study, an online survey of European citizens was built to collect data in order to test the expected relationships. Given that local energy communities are a recent concept, an introductory video was shown at the beginning of each questionnaire episode to guarantee that the respondents were aware of and shared the same interpretation of the concept of local energy communities and sustainable technologies.

5.1. Data

For the quantitative phase an online questionnaire was administered for one month (July 2021). We collected data from Germany, Greece, Italy, and Portugal in order to capture a large sample from southern and western Europe. These countries present a similar profile regarding the adoption of sustainable technologies. For example, in terms of renewable energy, all counties present a similar profile in terms of renewable energy share in total final energy consumption (World Bank, 2022). These countries present interesting characteristics to analyse the phenomenon of local energy communities given their similar geographical situation, as well as the increased efforts towards these sustainable initiatives (Lafortune et al., 2022). Nevertheless, results were controlled for the countries, preserving the impacts of the explanatory variables regardless of the countries' characteristics.

The sample can be considered to be probabilistic, consisting of randomly selected residents from each country, participants involved in the decision to adopt technologies in their households (Wunderlich et al., 2019). Citizens of each country were invited to participate in the survey via email. In this selection quotas were set in terms of age classes and gender distribution, as well as filtered according to their role in deciding to adopt technologies in their household. In this way we were able to capture a large sample from central west Europe. A total of 1602 responses remained following data cleansing and removal of incomplete responses. The risk of common-method bias was also examined using two methods. First, the Harman's one factor test (Podsakoff et al., 2003) showed that no indicator individually explained more than 50% of the variance. Also, a theoretically irrelevant marker variable was added to the questionnaire, and had a maximum shared variance of 0.048 (4.8%), a value considered low according to Johnson et al. (2011). Therefore, no significant common-method bias was indicated.

Regarding sample characteristics (see Appendix D, Table D1), respondents have an average age of 50 years old, and are split evenly by gender. A chi-squared test was conducted, confirming no statistically significant difference of age and gender between each country's sample and the general population (see Appendix D, Table D2). Also, most of the respondents live in an urban area, mostly in buildings of individual flats. The average number of individuals living in a household is 3, and with an average of 1 child. These statistics conform with the EU statistics on household composition (Eurostat, 2019). Finally, most respondents were homeowners, as expected (Warkentin et al., 2017).

5.2. Measurement

The questionnaire was composed of items of each construct identified and then adapted to the context (see Appendix E, Table E1). Most questions were measured on a seven-point numerical scale (1-completely disagree; 7-completely agree). The questionnaire was first developed in English and reviewed by academic researchers. Based on the English version, the questionnaire was then translated into the four appropriate languages and back-translated to English, ensuring that all questions had equivalent meanings (Cha et al., 2007). A pilot test was performed using a total of 200 responses, which indicated that the items were adequately measuring the constructs.

Studies involving citizen behaviour typically include some control variables, especially socio-demographic and/or household characteristics (Erell et al., 2018). Consequently, age, gender, country, and household comfort level were selected as control variables in our study, preserving the impacts of the explanatory variables, regardless of the above factors.

6. Analysis

The partial least squares (PLS) technique was used to estimate the research model. This method seems to be adequate since it is used to test research models not yet tested. Also, PLS allows the use of formative-type constructs and does not demand strong distribution assumptions (Fornell & Bookstein, 1982). Therefore, PLS is a suitable method. Smart PLS 3.0 was used to test the model (Ringle et al., 2018). First, the measurement model will be analysed, followed by the structural model.

6.1. Measurement model

Several measures were examined to assess the measurement model. The means and standard deviations of the reflective constructs, together with the composite reliability (CR) and average variance extracted (AVE) were calculated (Table 4). All constructs show a CR higher than 0.7 and an AVE higher than 0.5, ensuring reliability of scales and convergent validity (Fornell & Larcker, 1981; Hair et al., 2011). Three criteria were used to test discriminant validity. First, we followed the Fornell-Larcker criterion, indicating that the square root of the AVE is higher than the correlation between constructs (Fornell & Larcker, 1981). Secondly, the Heterotrait-Monotrait Ratio (HTMT) was assessed (see Appendix F, Table F1), verifying that all diagonal values are lower than 0.9, with the exception of environmental citizenship with the social environmentalism construct. Nevertheless, the 95% confidence interval did not exceed the value of 1 (0.897–0.938). Finally, the loadings were always greater than the cross-loadings (Chin, 1998) (see Appendix F, Table F2). Thus, discriminant validity was established.

For the formative constructs, multicollinearity, significance, and relevance of the indicator weights were assessed (Hair et al., 2011) (see Appendix G, Table G1). VIF values are lower than 5, indicating no multicollinearity issues (Lee & Xia, 2010). Also, all indicators that do not have a significant weight present a significant loading. Therefore, the formative constructs can be used to test the structural model. For the two reflective-formative constructs, we also assessed the multicollinearity, statistical significance, and relevance of the weights (Becker et al., 2012). We checked VIF to examine multicollinearity, which resulted in a value lower than 5 in both cases, suggesting no collinearity issues (Hair et al., 2011). Moreover, all weights are statistically significant (Appendix G, Table G2).

6.2. Structural model

Before examining the structural model, the multicollinearity between constructs was assessed using VIF. All values were lower than 5, indicating no multicollinearity issues (Hair et al., 2016). Figure 4 presents the path coefficients, the significance of which was assessed through the means of bootstrapping with 5000 iterations of resampling. The model explains 55.1% of the variation of the participation in local energy communities, and 53.45% and 51.8% of the variation of empowerment and pro-environmental behaviour, respectively. From stimuli to organism, use of ST, frequency of use, and gamification show a statistically significant impact in empowerment and pro-environmental behaviour,

Table 4. Means, standard deviations, CR, and fornell-lacker table. The diagonal elements are the square-root of AVE.

	CR	Mean	STD	CP	SE	EN	IP	SD	MN	CL	EC	UB	GA
Competence (CP)	0.958	4.165	1.564	0.940									
Social environmentalism (SE)	0.915	3.777	1.594	0.575	0.884								
Environmental citizenship (EN)	0.905	3.319	1.666	0.494	0.789	0.839							
Impact (IP)	0.962	4.038	1.573	0.709	0.604	0.527	0.945						
Self-determination (SD)	0.928	4.574	1.441	0.534	0.409	0.349	0.597	0.901					
Meaning (MN)	0.960	4.386	1.559	0.698	0.597	0.507	0.820	0.540	0.943				
Conservation lifestyle (CL)	0.820	5.502	1.120	0.324	0.488	0.351	0.338	0.339	0.405	0.780			
Participation in LEC (EC)	0.980	3.655	1.797	0.597	0.602	0.555	0.656	0.451	0.702	0.311	0.971		
Use behaviour (UB)	0.969	3.853	1.700	0.580	0.585	0.520	0.543	0.443	0.538	0.441	0.570	0.956	
Gamification (GA)	0.864	4.053	1.382	0.529	0.461	0.382	0.549	0.343	0.581	0.240	0.494	0.429	0.784

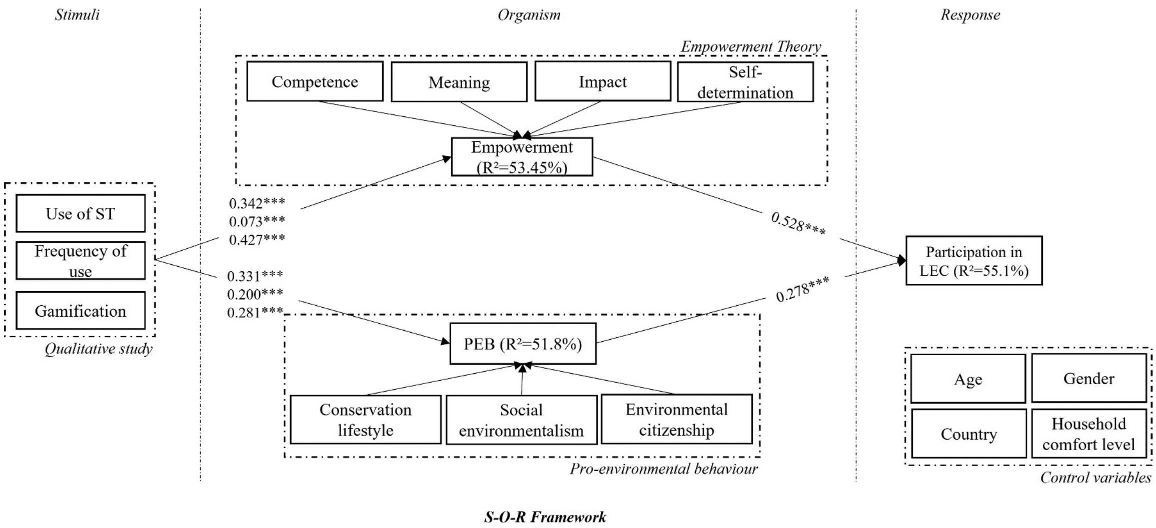

Figure 4. Structural model (*p<0.1;**p<0.05;***p<0.01).

supporting H1a $(\hat{\beta} = 0.342, p < 0.01)$, H1b $(\hat{\beta} = 0.331, p < 0.01)$, H2a $(\hat{\beta} = 0.073, p < 0.01)$, H2b $(\hat{\beta} = 0.200, p < 0.01)$, H3a $(\hat{\beta} = 0.427, p < 0.01)$, and H3b $(\hat{\beta} = 0.281, p < 0.01)$. From the organism to the response behaviour, the model also suggests a statistically significant effect of empowerment $(\hat{\beta} = 0.528, p < 0.01)$ and pro-environmental behaviour $(\hat{\beta} = 0.278, p < 0.01)$to participation in local energy communities, supporting H4 and H5. Therefore, all hypotheses are supported.

7. Discussion

Resorting to the S-O-R framework and a mixed-methods approach, this work examines the impact of technology variables on the empowerment and pro-environmental behaviour, which in turn impact the response behaviour, i.e. participation in local energy communities. To the best of our knowledge, this is one of the first studies to have focused on both instrumental and social factors that affect citizen behaviour in the context of sustainability.

Regarding the stimulus dimension, all technology-related variables were found to be significant. This finding is not surprising since the use of sustainable technologies is a key factor for a strong active participation in local energy communities. In fact, the frequency of use of several sustainable technologies, as well as the use behaviour of overall sustainable technologies are the ones with greatest impact on the pro-environmental behaviour. This is extremely important since this type of feeling may drive people to pursue other pro-environmental behaviours, namely the participation in local energy communities. Regarding the empowerment feeling, the use behaviour of sustainable technologies and gamification present the greatest impact. In fact, although gamifying sustainable technologies is an emerging phenomenon, previous studies report a significant impact of gamification in motivating individuals to adopt more green behaviours (Ke et al., ; Sheffler et al., 2020). A meta-inference from this is that citizens might feel more empowered when using gamified solutions. Therefore, the presence of gamification may play a key role in local energy communities, as citizens may feel more competent and/or entertained. Meta-inferences are summarised in Table 5, and represent an integrative view of the findings of both qualitative and quantitative methods, establishing relationships between explanatory and target variables, in this case, the response dimension (Venkatesh et al., 2016).

Moreover, when it comes to the organism phase, although pro-environmental behaviour presents a significant positive effect and therefore people who already perform some sort of sustainable behaviour(s) are more willing to participate in local energy communities, empowerment was found to be the greatest predictor of citizen participation. This finding suggests that if citizens feel empowered by local energy communities, it will strongly and positively influence their intention to participate in such communities. A meta-inference from this result is that greater motivation comes from personal feelings about the community than actual pro-environmental behaviours that citizens might have already adopted. This finding is in line with previous studies (e.g. Naranjo-Zolotov et al., 2019).

Finally, regarding the response dimension of the S-O-R framework, the model was able to explain 55.1.% of its variation, which is considered a satisfactory number. Nevertheless, it is important to recognise that local communities are complex to implement and to participate in, and other factors might certainly influence citizens' behaviour. Nonetheless, attitudes such as pro-environmental behaviour and empowerment feeling, fostered by

Table 5. Qualitative, quantitative, and meta-inferences.

S-O-R model	Construct	Qualitative inference	Quantitative inference	Meta-inference	Explanation
Stimulus	Use behaviour of ST	Citizens with greater use of ST will be more likely to feel empowered and to behave in a more pro-environmental way.	Consistent finding.	When it comes to stimulus related variables, the use behaviour and frequency of use positively affect the feeling of empowerment and the adoption of pro-environmental behaviours, revealing the strong role technology might have in organism states that might lead to sustainable response behaviours. Although all variables have positive effects, citizens might feel more empowered when using gamified solutions, as gamification revealed stronger effects.	Although gamifying sustainable technologies is an emerging research area, previous studies also report a significant impact of gamification in motivating individuals to adopt more green behaviours (Ke et al., ; Sheffler et al., 2020).
	Frequency of use of ST	Citizens who use ST with more frequency will be more likely to feel empowered and to behave in a more pro-environmental way.	Consistent finding.		
	Gamification	Gamification of enabler-technologies of a local energy community will make citizens more likely to feel empowered and to behave in a more pro-environmental way.	Consistent finding.		
Organism	Empowerment	-	Citizens who feel more empowered will have a greater intention to participate in local energy communities.	When it comes to organism related variables, although both empowerment and pro-environmental behaviour positively influence the participation in local energy communities, empowerment shows a greater impact. Citizens who feel more competent, with a meaning, and impact on the community will be more likely to engage in these communities. So, greater motivation comes from personal feelings about the community than from actual pro-environmental behaviours citizens might already have adopted.	This finding is in line with previous studies on drivers for pro-environmental behaviours (Hartmann et al., 2018) and also studies of other types of participations, such as e-participation (Naranjo-Zolotov et al., 2019).
	Pro-environmental behaviour	-	Citizens who perform more pro-environmental behaviours will have a greater intention to participate in local energy communities.		

technological stimuli factors, are showed to have an important role in the citizen interaction with the community, contributing to its success.

8. Implications and future research

8.1. Theoretical implications

Regarding theoretical implications, this is one of the first studies that explores the drivers for citizen participation in local energy communities focusing on the citizen perspective, as most prior research has focused more on institutional or operational drivers. Our model highlights variables that have not been previously investigated. The literature on local energy communities is more focused on policy regulations that should be taken by governments or operational aspects (Leonhardt et al., 2022), not providing a deep understanding of the intrinsic process related to citizen behaviour in engaging these communities.

Based on mixed-methods, we have developed a model grounded on literature and qualitative data, including an important set of technological related variables, as well as two important citizen attitudes – empowerment and pro-environmental behaviour, rarely studied in the context of any form of local energy community. Second, by investigating three technological variables as stimuli of the citizen behaviour, we contribute to the research that examines the importance of technologies in sustainable behaviours, reinforcing the understanding of the strong role technologies can have in a greener future. Third, we resort to the S-O-R model, which proved to be advantageous in explaining environmental-related phenomenon. S-O-R has been used successfully to explain behaviours in the marketing and IS fields. Here, we extend the applicability of the S-O-R framework to a new and current subject: participation in local energy communities. This study thus expands the use of the S-O-R framework by confirming its robustness when applied to local energy communities. Additionally, prior research has used more utilitarian/hedonic concepts as organism, while social and psychological factors were less investigated (Hsiao & Tang, 2021). Given this, we are able to provide a better understanding of how empowerment and pro-environmental behaviour can act as organism, enriching the field of investigations on S-O-R, and extending it to other contexts, namely participation in local energy communities. This reinforces the applicability of the S-O-R framework for several contexts, especially in complex behaviours, where it is possible to better understand the formation process of a certain behaviour, allowing the inclusion of several types of stimuli (e.g. internal, external, tangible, intangible) (Sultan et al., 2021). In prior research on citizens sustainable behaviours, theories such as TAM and TPB have been extensively and repeatedly used (Conradie et al., 2021), disregarding the complexity of these types of behaviours. Based on this, we were able to uncover key citizen characteristics for its participation, namely empowerment and pro-environmental behaviour, as well as the importance of the citizen interaction with technology on those attitudes. Finally, we have demonstrated the relevance of using a mixed methods design, reinforcing the importance of employing both qualitative and quantitative methods in the investigation of citizen behaviour. In fact, apart from some works (Wunderlich et al., 2019), the joint field of energy and technology have tended to rely on either quantitative or qualitative methods. We therefore show the importance of applying both methods to more complex behaviours – the participation in local energy communities.

8.2. Practical implications

Concerning practical implications, first, it is extremely important to recognise the role of sustainable technologies in encouraging citizens to conduct more pro-environmental behaviours and feel more empowered. Thus, it is strongly recommended that local governments and nations develop strategies that promote their use, focusing on demystifying their complexity (Crosno & Cui, 2014) so that people may feel competent and empowered while using them. From the industry point of view, it is also important to point out that gamified solutions might promote positive feelings amongst citizens, creating a positive experience with the technologies. The dynamic of a game, with the achievement of points, competitions, visualisation of progress and pathways, not only creates a more enjoyable experience, but also empowers the citizens to autonomously understand their achievement, progress, and mistakes. In fact, it can improve citizens' energy literacy. Regarding metering technologies especially, the provision of feedback is the key for citizens to change their behaviour. Therefore, the inclusion of a simple gamified interface can help the citizens to easily understand their progress. All of this will create a sense of empowerment, while the healthy competition can in fact improve individuals' sustainable performances (Suh et al., 2018). This is in line with the qualitative remark by interviewee 12: "Being something that does not required expertise to be used. Any common person can understand how it works and its performance".

Also, the model showed a positive effect of both pro-environmental behaviour and empowerment. Thus, communities that already have a sustainable spirit might be the ones where it will be easier to implement a local energy community. This finding is aligned with previous research on other local sustainable initiatives (Koirala et al., 2018). Nevertheless, this also suggests that it is important to promote a spirit of sustainable habits and lifestyle, not necessarily the implementation of a local energy community, but government and municipalities should at least start to promote this type of life, which can later lead to a stronger solution including a local energy community. Regarding empowerment, results suggest the need of strategies that promote local energy commentators to focus on the four components of the empowerment feeling: competence, meaning, impact, and self-determination. For example, informational support that clearly explains the positive benefits and impact that citizens might have by participating in local energy communities may contribute to an overall feeling of empowerment and as a consequence create a greater intention to engage in a local energy community. Also, it is important to support the autonomous community management, promoting autonomy, but also transparency and trust amongst its citizens (Otamendi-Irizar et al., 2022). Nevertheless, there is still some reluctance regarding what a local energy community is, what the efforts are that people need to make, and what the possible benefits might be (Koirala et al., 2018). Thus, the creation of more informative strategies, including demonstrations, workshops, and forums is essential to create more informed citizens and an overall positive, trustful, and cohesive environment (Kim et al., 2022) for the community to engage in this type of solution.

8.3. Limitations and future research

The first limitation of this study resides in the fact that the qualitative study was restricted to individuals from the countries under study, which may not fully represent the general opinion and might have overlooked other technology-related variables. It is important to notice that this study's perspective of analysing technological-related factors on citizens attitudes towards participation in local energy communities might not include a set of other engagement factors that can affect citizen behaviour. Although the set of variables used in the S-O-R model were well justified, other variables could have been chosen to investigate the citizen perspective. For this reason, we recommend the use of the S-O-R framework in future research with other variables that may complement the perspective investigated herein. Nevertheless, we believe the inclusion of findings from both qualitative and quantitative methods has strengthened the chosen factors (Venkatesh et al., 2013). Finally, further studies could also undertake a country comparison, for which the authors encourage the inclusion of cultural factors. In fact, cultural norms might have a role in citizens' sustainable behaviours (Neves et al., 2022).

9. Conclusion

This study found valuable findings about the citizen drivers for engaging in local energy communities, focusing on the role of technology as the stimulus of their behaviour by drawing on the S-O-R framework and using a mixed-methods design. As main findings, the model suggests that the use of sustainable technologies and the inclusion of gamification features have a positive impact on citizens to conduct more pro-environmental behaviours, driving them to feel more empowered. As a consequence, both pro-environmental behaviour and empowerment positively affect the citizen intention to participate in local energy communities. Therefore, the use of sustainable technologies should be promoted, as well as the inclusion of more gamified features in them, as previously demonstrated (Ke et al.,), since it may drive consumers to feel more competent and empowered while using the technology. These findings can help policy makers to design strategies that reinforce the perception of empowerment in citizens, showing them that they can have a meaning and impact on the society by participation in local energy communities, as found in similar studies on renewable communities (van der Waal, 2020). Finally, this model provides a good basis for future research on citizens' inner motivations to participate in local energy communities.

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Appendix A – Literature on local energy communities

Table A1. Literature on local energy communities.

Authors	Factors used to explain the willingness/intention and/or acceptance of local energy communities/local energy systems/local renewable communities	Type of factors examined
(Koirala et al., 2018)	Environmental concern, renewables acceptance, energy independence, community trust, community resistance, education, energy awareness	Consumer related factors
(Azarova et al., 2019)	Solar farms and power-to-gas infrastructures, gas power plants, power lines, political opinion	Infrastructure related factors and political opinion
(Soeiro & Ferreira Dias, 2020)	Environmental concerns, climate impacts, trust, social norms, promotion of energy transition, energy guidance, social and green action activities	Consumer related factors
(Bukovszki et al., 2020)	Urban building energy modelling (UBEM)	Infrastructure related factors
(Berka et al., 2020)	Context-specific context factors, institutional arrangements, policy processes, regulations	Institutional related factors
(Schweiger et al., 2020)	Data and computational methods, psychological aspects of consumers	Institutional and operational factors; consumer related factors
(Bartolini et al., 2020)	Storage systems, poly-generation in renewables self-consumption	Operational related factors
(Conradie et al., 2021)	Theory of planned behaviour, new ecological paradigm, ecological behaviour, financial gain, willingness to change behaviour, technological innovativeness, home ownership, community identity	Consumer related factors
(Krietemeyer et al., 2021)	Environmental, societal, and financial benefits, individual and social norms, energy feedback, and energy culture	Consumer and operational related factors
(Leonhardt et al., 2022)	Government instruments, payment-based, grid access, environmental protection, and community planning and capacity	Institutional and operational related factors
(Malik et al., 2022)	Trading algorithm based on geographic location, maximum energy demand, maximum energy generated, pricing mechanism	Operational related factors

Appendix B – Interview guide

Table D2. Age and gender distribution.

Country	Age/Gender	Population[1]	Sample	Chi-Squared (p-value)
Germany	18–24	9%	9%	0.0396 (0.9804)
	25–49	37%	37%	
	>50	53%	53%	
	Female	51%	51%	0.0026 (0.9594)
	Male	49%	49%	
Greece	18–24	9%	9%	0.0377 (0.9813)
	25–49	40%	40%	
	>50	52%	52%	
	Female	51%	51%	(>0.9999)
	Male	49%	49%	
Italy	18–24	8%	8%	0.00335 (0.9834)
	25–49	38%	38%	
	>50	55%	55%	
	Female	52%	52%	(>0.9999)
	Male	48%	48%	
Portugal	18–24	9%	9%	0.0203 (0.9899)
	25–49	39%	39%	
	>50	53%	53%	
	Female	52%	52%	0.0023 (0.9617)
	Male	48%	48%	

Note[1]: http://appssoeurostateceuropaeu/nui/showdo?dataset=demo_pjan (EUROSTAT: Population on 1 January by age and gender (The last update was 27.04.21 and extracted on 20.05.21).

(1) Introduction on local energy communities.
(2) Introduction on sustainable technologies.
(3) Do you use any sustainable technology?
  a. If yes, which? Why? How was/is your experience with it?
(4) Which characteristics of sustainable technologies do you like? Which do you not like?
(5) Which motives would be relevant to you in adopting a sustainable behaviour, like participating in local energy communities?
(6) What you think organisations should do to engage more people in these sustainable behaviours?
(7) If you could, would you participate in a local energy community?

Appendix C – Selected illustrative quotes supporting the dominant codes

Table C1. Illustrative quotes per code.

Existing concepts	Codes	Illustrative quotes
Sustainable technologies use	Related to environmental purposes	*"The benefits to me is to feel well with myself because I know I am using energy solutions that are environmental friendly". (I3)*
		"That these kinds of technologies allow me to track and to get some feedback regarding my energy consumption, and therefore improve my energy behaviours. I think that's the most important thing (. . .) I believe that I'm helping the environment" (I8)
		"*(. . .) I would like to have a solution that I can check it from time to time just to see that I am doing something good for the environment.*". (I4)
		"*The fact that using them [sustainable technologies], I would have a lower impact in the environment that's a key point*" (I6)
	Related to empowerment purposes	*"(. . .) generally these technologies make my life easier*". (I13)
		"For example, I changed my energy provider some months ago, and now my [consumption is] tracked, and so I can check [it] in my bill". (I4)
		"I believe that this (sustainable technologies use) will only truly be successful when my community is aware of the impact we can have". (I20)
		"If I have enough for me and to supply to the network, I'm not only reducing my current footprint, but I'm also helping to reduce others' because I'm producing for them". (I19)
Gamification	Gamification	*"I think this [gamification] may help a specific type of end-users to be more interested in it. Also, it potentially may support continuous sustainable behaviours".. (I1)*
		"[using gamification] many of them (citizens), they need to know it and they got the information in another and simpler way". (I5)
	Making like a game	*". . . when you do that, like a game, then I think it gets on the routine pretty soon and [it helps] to keep the interest". (I12)*

Appendix D – Sample

Table D1. Sample characteristics.

Sample characteristics		Descriptive statistics
Gender	Female	52%
	Male	48%
Age (average)		50
Urban area		75%
Building Type	Terrace	10%
	Detached	21%
	Semi-detached	10%
	Flat	57%
	Other	1%
Employment	Student	6%
	Employed worker	45%
	Self-employed	12%
	Unemployed/Retired	37%
Education	No school degree	1%
	Primary school	7%
	High school degree	27%
	Apprenticeship	5%
	Bachelor's degree	31%
	Master's degree	17%
	Doctoral degree	13%
Number of individuals living in the household (average)		3
Number of children (average)		1
Homeowner		61%

Appendix E – Survey items

Table E1. Survey items.

Variable		Item	Source
Conservation lifestyle	CL1	Recycled paper, plastic, and metal	(Larson et al., 2015)
	CL2	Conserved water or energy in my home	
	CL3	Bought environmentally friendly and/or energy-efficient products	
Social environmentalism	SE1	Talked to others in my community about environmental issues	
	SE2	Worked with others to address an environmental problem or issue	
	SE3	Participated as an active member in a local environmental group	
Environmental citizenship	EN1	Voted to support a policy/regulation that affects the local environment	
	EN2	Signed a petition about an environmental issue	
	EN3	Donated money to support local environmental protection	
	EN4	Wrote a letter in response to an environmental issue	
Gamification		How important are the following features to you?	
	GA1	Rewards from a points collection system	(Hamari et al., 2018)
	GA2	Competition between neighbours	
	GA3	Competition between neighbourhoods	
	GA4	Achievements from more sustainable behaviour	
Competence	CP1	I have mastered the skills necessary for participating in a local energy community	(Naranjo-Zolotov et al., 2019)
	CP2	I am self-assured about my capabilities to participate in a local energy community	
	CP3	I am confident about my ability to participate in a local energy community	
Meaning	MN1	Participation in a local energy community is very important to me	
	MN2	Participation in a local energy community is meaningful to me	
	MN3	My local energy community participation activities are personally meaningful to me	
Impact	IP1	Based on the participation in a local energy community, my impact on what happens in the community is large	
	IP2	Based on my participation in a local energy community, I have significant influence over what happens in the community	
	IP3	Based on my participation in a local energy community, I have a great deal of control over what happens in the community	
Self Determination	SD1	I have significant autonomy in determining how I participate in a local energy community	
	SD2	I have considerable opportunity for independence and freedom in how I participate in a local energy community	
	SD3	I can decide on my own how to go about participating in a local energy community	
Use Behaviour	UB1	I often use sustainable energy solutions in my household.	(Venkatesh et al., 2012)
	UB2	I often use sustainable energy solutions to manage my energy consumption.	
	UB3	I often use sustainable energy solutions to monitor my energy consumption	
Frequency of use		Please choose your usage frequency for each of the following:	(Venkatesh et al., 2012)
	Use1	IoT wearable devices	
	Use2	IoT smart home devices	
	Use3	Renewable energy sources	
	Use4	Electrical vehicle	
	Use5	Batteries for energy storage	
	Use6	Energy dashboards	
	Use7	Energy digital transactions	
Participation in a local energy community	EC1	I intend to become part of the local energy community in the following months	(Venkatesh et al., 2012)
	EC2	I predict I will become part of the local energy community in the following months	
	EC3	I plan to become part of the local energy community in the following months	

Appendix F – HTMT and Loadings and cross-loadings – Reflective constructs

Table F1. Heterotrait-Monotrait Ratio.

	CP	SE	EN	IP	SD	MN	CL	EC	UB	GA
Competence (CP)										
Social environmentalism (SE)	0.641									
Environmental citizenship (EN)	0.551	0.918								
Impact (IP)	0.756	0.672	0.586							
Self-determination (SD)	0.583	0.465	0.395	0.648						
Meaning (MN)	0.743	0.665	0.564	0.872	0.589					
Conservation lifestyle (CL)	0.341	0.552	0.389	0.351	0.402	0.446				
Participation in LEC (EC)	0.626	0.659	0.608	0.687	0.483	0.735	0.314			
Use behaviour (UB)	0.615	0.646	0.574	0.573	0.481	0.568	0.477	0.592		
Gamification (GA)	0.609	0.551	0.454	0.631	0.409	0.665	0.348	0.558	0.488	

Table F2. Loadings and cross-loadings.

	Competence	Social environmentalism	Environmental citizenship	Impact	Self-determination	Meaning	Conservation lifestyle	Participation in LEC	Use behaviour	Gamification
CL1	0.067	0.131	0.066	0.073	0.143	0.152	0.600	0.057	0.131	−0.001
CL2	0.234	0.341	0.195	0.224	0.293	0.266	0.801	0.204	0.336	0.152
CL3	0.353	0.528	0.421	0.379	0.313	0.436	0.908	0.353	0.455	0.291
CP1	0.921	0.532	0.456	0.633	0.497	0.612	0.286	0.522	0.548	0.478
CP2	0.958	0.543	0.462	0.675	0.498	0.653	0.305	0.566	0.545	0.508
CP3	0.940	0.546	0.475	0.689	0.511	0.700	0.323	0.592	0.543	0.506
EC1	0.579	0.568	0.525	0.633	0.435	0.685	0.293	0.972	0.544	0.487
EC2	0.576	0.594	0.545	0.646	0.445	0.692	0.314	0.969	0.560	0.477
EC3	0.583	0.591	0.548	0.632	0.435	0.667	0.298	0.973	0.556	0.476
EN1	0.374	0.651	0.817	0.419	0.279	0.419	0.357	0.429	0.420	0.213
EN2	0.374	0.638	0.841	0.418	0.292	0.415	0.341	0.421	0.372	0.277
EN3	0.456	0.694	0.865	0.468	0.314	0.451	0.283	0.516	0.489	0.381
EN4	0.452	0.662	0.830	0.461	0.285	0.415	0.195	0.496	0.464	0.409
GA1	0.324	0.270	0.195	0.350	0.253	0.374	0.215	0.293	0.265	0.707
GA2	0.439	0.377	0.302	0.445	0.270	0.435	0.094	0.407	0.348	0.858
GA3	0.448	0.381	0.318	0.449	0.276	0.448	0.083	0.417	0.338	0.865
GA4	0.424	0.390	0.351	0.454	0.272	0.533	0.346	0.406	0.370	0.691
IP1	0.667	0.589	0.521	0.938	0.533	0.822	0.328	0.645	0.502	0.507
IP2	0.674	0.568	0.492	0.962	0.576	0.775	0.320	0.612	0.514	0.518
IP3	0.669	0.555	0.481	0.936	0.586	0.728	0.309	0.604	0.523	0.533
MN1	0.688	0.582	0.501	0.771	0.481	0.955	0.374	0.689	0.524	0.592
MN2	0.588	0.516	0.427	0.732	0.531	0.923	0.418	0.600	0.451	0.470
MN3	0.693	0.589	0.503	0.814	0.517	0.950	0.358	0.693	0.544	0.577
SD1	0.501	0.387	0.335	0.596	0.899	0.511	0.295	0.441	0.406	0.291
SD2	0.521	0.408	0.357	0.575	0.930	0.531	0.325	0.431	0.428	0.349
SD3	0.411	0.298	0.238	0.426	0.872	0.406	0.294	0.337	0.358	0.284
SE1	0.460	0.865	0.635	0.510	0.379	0.527	0.531	0.494	0.493	0.338
SE2	0.538	0.933	0.700	0.556	0.373	0.548	0.473	0.530	0.546	0.411
SE3	0.524	0.852	0.755	0.535	0.333	0.509	0.290	0.571	0.511	0.472
UB1	0.532	0.552	0.484	0.498	0.423	0.503	0.446	0.520	0.941	0.387
UB2	0.554	0.545	0.482	0.513	0.424	0.515	0.423	0.539	0.967	0.417
UB3	0.576	0.580	0.524	0.544	0.423	0.525	0.396	0.573	0.959	0.424

Appendix G – Formative constructs

Table G1. Mean, standard-deviation, weights, loadings, and VIF of formative construct indicators (* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01).

	Mean	STD	VIF	Weights	Loadings
Use1	2.956	2.070	2.003	0.089*	0.634***
Use2	3.034	2.020	2.458	0.053	0.720***
Use3	3.378	2.012	1.638	0.468***	0.856***
Use4	2.179	1.773	2.172	0.063	0.716***
Use5	2.805	1.958	2.159	0.005	0.700***
Use6	2.413	1.787	3.936	0.343***	0.876***
Use7	2.591	1.858	3.412	0.183***	0.849***

Table G2. Weights, loadings, and VIF of formative construct indicators (* p-value < 0.10; ** p-value < 0.05; *** p-value < 0.01).

		VIF	Weights
Empowerment	Competence	2.606	0.292***
	Impact	3.804	0.319***
	Self-determination	1.794	0.220***
	Meaning	3.581	0.321***
PEB	Social environmentalism	3.457	0.440***
	Environmental citizenship	3.196	0.514***
	Conservation lifestyle	1.591	0.188***