SPECIAL FEATURE: ORIGINAL ARTICLE

Individuals within the Larger System to Support the Energy Transition

Empowering citizens for the energy transition: facilitating role change through real-world experiments

Helena Trenks[1] · **Paula Maria Bögel**[2]

Abstract

Empowering citizens to take on new, more active roles is a central element in a successful energy transition. Yet, models that allow direct involvement and prosumer practices on the part of individuals are still not widely implemented. Real-world labs offer a supportive environment for citizens to experiment with new roles, allowing them to test transition processes within a protected niche. This study investigates the development of an empowering role change in the context of the real-world experiment "Your Balcony Network—Energy Creates Community". The experiment serves as a case study to offer a better understanding of how real-world labs can support citizens toward an empowering role change that actively and positively affects the energy transition. In a mixed-method, longitudinal study, we first identify indicators of citizens' role change in the energy transition and analyze their development in the course of the experiment's first year. Second, we studied the role-changing process, identifying key mechanisms of change and contextual factors that accompanied and supported the role-changing process. Building on the "Embedded Agency Perspective" as our analytical framework, we applied a process perspective, empirically investigating how participants' roles changed through taking part in the experiment. Our findings support the conclusion that real-world experiments can foster empowering role change among citizens, especially emphasizing the importance of real-world labs as places for experimentation, learning by experience, and networking. The study thus also contributes to the discourse about the impact of real-world labs.

Keywords Energy transition · Citizens · Empowering role change · Real-world lab · Transition experiments · Agency in action

✉ Helena Trenks
Helena.Trenks@kit.edu

Paula Maria Bögel
paula-maria.boegel@uni-vechta.de

1 Institute for Technology Assessment and Systems Analysis, Karlsruher Institute for Technology, Karlstraße 11, 76131 Karlsruhe, Germany

2 Vechta Institute of Sustainability Transformation in Rural Areas (VISTRA), University of Vechta, Große Straße 49, 49377 Vechta, Germany

Introduction

Society is currently facing many challenges that require sustainability transitions at all levels and in all sectors. The need to move toward more sustainable and just ways of producing and consuming energy is one of the most important—and most difficult—challenges for society: The energy transition is not just a technical or political challenge; it requires change from society as a whole (Miller et al. 2013). Besides changes in production and technologies, changes in individual actors' daily routines and behaviors are needed (Huttunen et al. 2021). Citizens are particularly called upon to support this transition, e.g., by saving energy, consciously choosing a sustainable energy supplier, or investing in renewable energy (Schreuer et al. 2020).

Yet, if we call for an energy transition that is, as an overall societal task, equitable and just (Jenkins et al. 2016; van Veelen and van der Horst 2018), energy transitions need to

🖄 Springer

focus more on new, more active roles of citizens and how they can be supported to engage more in the energy transition. Drawing on studies about energy citizenship (Hamann et al. 2023; Bögel et al. 2021) we want to analyze individual role change in energy transitions in this study. This role change is defined as a process in which (1) citizens are encouraged to reflect on their role in energy transitions and are (2) empowered to adopt a conscious attitude toward their own energy consumption and production. This includes (3) producing (partly) their own energy, (4) acquiring new capabilities that are needed for engagement, and (5) taking further actions to support energy transitions locally and on a broader level. We will refer to this as *empowering role change*.

So far, some pioneering projects have already seen citizens taking up more active roles in energy transitions, e.g., as prosumers rather than consumers (Bögel et al. 2021) However, models that allow direct involvement and consumer ownership by individuals are still not widely implemented across Europe (Lowitzsch 2019), whereas notable exceptions of particular community energy concepts can be found (for an overview see Hewitt et al. 2019; van der Schoor and Scholtens 2019; Bauwens et al. 2022). There is debate among scholars about how to change the status quo and foster the engagement of citizens in energy transition (Colasante et al. 2022; Ryghaug et al. 2018). In addition to changes in policies (Burke and Stephens 2017), this will require an improved understanding of actors and their agency in energy transition processes (Fischer and Newig 2016; Bögel and Upham 2018) to better understand what leads people to change their roles and become engaged.

Concerning the question of how citizens can be encouraged to take up more active roles in the transition process, transformative research approaches play a role in actively implementing projects that facilitate role change, e.g., through transition management and transition labs (Loorbach 2010; Nevens et al. 2013). One promising new approach from the field of transformative research are real-world labs (Schneidewind 2014; Parodi et al. 2017; Wanner et al. 2018). Real-world labs provide an environment where civil society actors can try out new roles within a protected niche. The labs' supportive infrastructure enables individual actors to try out new (more sustainable) ideas, behavioral patterns, or ways of living in an experimental setting (Parodi et al. 2023b; Bergmann et al. 2021; Wanner et al. 2018). Typically, this is done in real-world experiments (Beecroft et al. 2018) defined as spatial and temporal interventions in real-life contexts (Wirth and Levin-Keitel 2020). In our study, we want to explore how the context of a real-world experiment supports empowering role change in the energy transition.

The majority of concepts in transition studies so far depict role change rather abstractly (DeHaan and Rotmans

2018). For instance, the multi-level perspective (MLP) distinguishes between niche, regime, and landscape actors (Geels 2002, 2011), allowing us to analyze long-term patterns but not to examine the actors' roles in detail. As a result, some scholars have started to investigate individual actors' roles more closely (DeHaan and Rotmans 2018; Wittmayer et al. 2017; Hauck et al. 2020). While this research highlights the importance of individual actors, especially citizens, in the transition process, it does not provide insights into how they became actively involved. In our study, we are interested in better understanding the process, meaning concrete actions and underlying factors, encouraging individuals to change their roles and contribute proactively and positively to the energy transition. For this purpose, we adopt a process perspective, namely we empirically investigate how "change is made in action" (Roeck and van Poeck 2023, 5).

To study the process of 'role change in action' in a real-world lab we apply the "Embedded Agency Perspective" (EAP) (Augenstein et al. 2022a; Bögel et al. 2022) to an energy-related real-world experiment. This framework integrates the understanding of socio-psychological and spatial structures and allows us to explore how role change takes place in a socio-spatial context. Through this framing, our study addresses two other research gaps. First, it offers the opportunity to study the socio-psychological processes of the transition process in more depth, which is still scarce in transition research (Bögel and Upham 2018). Second, the EAP also addresses another research field that remains understudied in transition research, namely the influence of the spatial context on actors and their roles (Fischer and Newig 2016; Coenen et al. 2012).

The real-world experiment "Your Balcony Network— Energy Creates Community" serves as a case study for our analysis. This experiment was intended to encourage citizens to participate more proactively in the energy transition by using photovoltaic balcony modules (Albiez et al. 2022). Balcony modules are small photovoltaic systems designed for private households that can be installed on balconies or in other outdoor locations around people's homes. The experiment focused on groups that are underrepresented in the current transition process (Radtke and Drewing 2020; Tjørring 2016), namely women, tenants, and co-owners of apartment buildings. An initial analysis of the study with a focus on studying inclusive engagement indicated that participants underwent an empowering shift in their role perception through taking part in the "Your Balcony Network" experiment (Bögel et al. 2023, p. 10). Building on these preliminary findings, this study analyzes whether an empowering role change has actually taken place and especially what mechanisms facilitated this change. The research questions addressed in our study are:

RQ1: Did the real-world experiment lead to an empowering role change among the involved citizens?

RQ2: Which processes and mechanisms are involved in supporting an empowering role-changing process?

This paper is structured as follows: the next section ("Real-world labs as an environment for competence development and empowering role change") takes a closer look at the real-world lab approach to further clarify the setting of our study. The section "Conceptual framework" introduces the conceptual framework that forms the basis for our analysis: after looking at the concept of role change, we outline our approach to investigate this change using an action-oriented research approach. We introduce the Embedded Agency Perspective (EAP) as our guiding analytical framework and its application within the case study. This is followed in Sect. "Material and methods" by a description of our case study and the data used for the analysis. In Sect. "Results", we then present the results, whether the real-world experiment facilitated empowering role change and which processes and mechanisms were involved. We conclude by discussing our findings in Sect. "Discussion" and "Conclusion".

Real-world labs as an environment for competence development and empowering role change

As a new research approach intended to support sustainability transitions, real-world labs have attracted a lot of attention recently. Particularly from the sustainability science community in Germany (Kampfmann et al. 2022; Huning et al. 2021; Bergmann et al. 2021) but they are also becoming more prominent in the international discourse (McCrory et al. 2020). This transformative research approach builds on the traditions of transdisciplinary research, sustainability research, and transformative research (Beecroft and Parodi 2016) and belongs to a family of experimental lab approaches that try to foster sustainable societal transformation processes at the interface of science and society (McCrory et al. 2020; Schäpke et al. 2018b). While the "real-world lab" is part of the German discourse about support for the "great transformation," (Schneidewind 2014; WBGU 2011) other forms of sustainability-related labs like (Urban) Living Labs (Liedtke et al. 2015) or Urban Transition Labs (Nevens et al. 2013) have a similar mission to manage sustainability transitions[1]. We understand real-world labs as one example of a sustainability-related lab and consider our questions and findings relevant to similar research approaches.

As real-world labs are still a young and emerging approach there is an ongoing discussion about key components and an overall definition (Parodi et al. 2017, 2023b; Wanner et al. 2018; Schäpke et al. 2018b), but some common ground can be set. Very generally speaking they "comprise aspects of lab design, experiments, and interventions" (Kampfmann et al. 2022, p. 2). More precise, a real-world lab can be understood as a research infrastructure in which scientific and societal actors invent and conduct real-world experiments in real-life contexts (Parodi et al. 2023b; Groß 2015) to initiate and support transformation processes and gain knowledge (system knowledge, target knowledge, and transformation knowledge, WBGU 2016) to support a more sustainable development of society (Schneidewind et al. 2018). These real-world experiments are the characteristic form in which the transdisciplinary work in real-world labs takes place (Beecroft et al. 2018). They approach and test possible solutions for societal problems (Arnold and Piontek 2018) and serve as a bridging activity for bringing knowledge about needed change into action (Räuchle et al. 2021).

Concerning our focus topic of role change, real-world labs "aim to contribute to local action for sustainable development and the empowerment of change agents" (Wanner et al. 2018, p. 94). This empowerment of civil society actors is an essential element of these labs' activities (Meyer-Soylu et al. 2016). Following the premise that "to achieve transformation, various societal actors have to learn new perspectives, skills, competencies, practices and develop new concepts of their own role," (Singer-Brodowski et al. 2018, p. 28) these supportive spaces may offer stimulating environments for processes of role change, as they provide an 'infrastructure' (Singer-Brodowski et al. 2018), in which old roles can be reflected upon and processes of change are encouraged. Real-world labs and their experiments therefore aim to provide places for learning through experience, testing, and reflection (Parodi et al. 2017; Schäpke et al. 2018a).

Given real-world labs are starting to become an important part of the transdisciplinary research agenda, the debate in the field has recently turned to whether they can live up to expectations and support the more sustainable development of society (Schneidewind et al. 2018), and how their impact can be measured (Kok et al. 2023; Augenstein et al. 2022a; Kampfmann et al. 2022; Schäfer et al. 2021). The concept of empowering role change could introduce a new perspective to this discussion. While empowering citizens to take up more active roles in the transition process is implicitly part of the labs' aims (Wanner et al. 2018; Meyer-Soylu

---

[1] In their literature review, McCrory et al. (2020) explored 53 sustainability-related labs attributable to 7 different research communities. Within the field of sustainability transitions, they found (Urban) Living Labs, Real-World Labs, and Urban Transition Labs; in other research areas, they explored Evolutionary Learning Labs, Change Laboratories, and Transformation Labs (T-Labs).

et al. 2016) it has not yet been empirically investigated in depth[2,3]. Addressing this research gap, our study introduces the concept of empowering role change as an approach to empirically assess the impact of real-world experiments on the involved citizens.

Conceptual framework

Role change in transition

So far, the literature on sustainability transition lacks clear definitions of actor roles in the transition processes (Hauck et al. 2020; Avelino and Wittmayer 2016; Wittmayer et al. 2017). This does not mean that actors do not appear in different roles in transition literature, but that they have been defined mostly on a more abstract level, e.g., niche vs. regime actors, or described collectively, e.g., depending on their institutional status (state, private sector, and civil society actors) or the level of governance (local, regional, or national) at which they operate (Fischer and Newig 2016). Citizens' actions and motivations thus remain bound to their institutional or social roles, leaving transition literature with a static understanding of such roles (Pesch 2015) that provides little room to analyze individuals' contributions. To arrive at a better understanding of citizens' individual contributions to transition processes, DeHaan and Rotmans (2018) developed a typology of four roles individuals can adopt: (i) frontrunners (also mentioned in Loorbach 2007), (ii) connectors, (iii) topplers, and (iv) supporters. Other researchers like Wittmayer et al. (2017) use roles such as frontrunners, change agents, champions, and policy entrepreneurs to describe individuals who "push forward" in transition processes. While this helps to shed light on the importance of these actors in the transition process, the question of what drives citizens to move toward more active roles is only touched on in passing. To address this research gap, this paper focuses on empirically investigating the processes and actions that lead to an empowering role change among citizens in the energy transition, aiming to operationalize and analyze the process. We begin by exploring the concept of roles and role changes, to establish our understanding of empowering role change in the context of the energy transition.

In more general terms, roles can be understood as activities and behaviors that characterize a person in a certain (social) context (Biddle 1979; Carter and Cook 1995) and role change as a "change in the shared understanding and execution of typical role performance and role boundaries" (Turner 1990, p. 88). In this respect, analyzing role and role change offers a perspective to discuss and examine transition processes as it "may be fundamental in understanding adjustment to change" (Carter and Cook 1995, p. 2). For our understanding of role change we refer back to Wittmayer et al. who defined roles as "a set of recognizable activities and attitudes used by actors to address recurring situations'' (Wittmayer et al. 2017, p. 49). Similar to this, Hilger et al., propose that, "roles can be identified by observing actors' activities" (Hilger et al. 2021, p. 2051). Some approaches distinguish between the "role-taking" and the "role-making" process. While "role-taking" normally accrues in situations with clear expectations (e.g., taking over an already established role), "role-making" happens in new or uncertain situations that require the actors to be creative in establishing a new role for their own (Hilger et al. 2021; Schimank 2016). For our study, we draw inspiration from the interactionist perspective on roles, which focuses on the role-making process, analyzing "how roles are adopted, adapted, enacted, performed, and made by an individual" (Wittmayer et al. 2017, p. 49; reffering to Biddle 1986, Hilbert 1981). This emphasizes that roles are not static and societally given, but can be altered by performing them differently. This capacity for role change is influenced by the actor's internal and external context (Carter and Cook 1995).

Drawing on studies that have analyzed role change in the energy transition (Hamann et al. 2023; Bögel et al. 2021), we assume that empowering role change means that (1) citizens are encouraged to reflect on their role in the energy transition and (2) adopt a conscious attitude toward their own energy consumption and production. This includes (3) producing their own energy (at least partly), (4) acquiring new capabilities needed to engage in the transition process and (5) taking further actions to support the energy transitions locally and on a broader level. Unlike the role of the passive consumer, this changed role emphasizes individuals' capacities and willingness to actively participate in the energy transition.

This role understanding comes with two annotations. First, this understanding is based on sustainability transitions' normative character (Köhler et al. 2019) seeing citizens' participation as a central and supportable part of a democratic and just energy transition, based on increased local energy ownership (Wahlund and Palm 2022). Second, it emphasizes that citizens are interested in taking up a constructive role in the transition process.

---

[2] For notable initial approaches in this direction, please see Charli-Joseph et al. 2018, who attempted to foster changes in participants' perceptions of their roles within their socio-ecological system in a T-lab in Mexico.

[3] In contrast to the new roles of scientists in real-world labs, which have been thoroughly examined (see for example Huning et al. 2021; Hilger et al. 2018).

Understanding role change in action

As stated above, our understanding of the processes involved in citizens' role change is still limited and quite abstract (Pesch 2015). To better understand how an empowering role change takes shape, we will adopt a process perspective in our analysis, focusing on investigating what De Roeck & van Poeck call "agency in action" and how it is formed in interplay with the given context (Roeck and van Poeck 2023). Concerning the authors' work we claim that we need to develop a proper understanding of "how actors act in transitions" (Roeck and van Poeck 2023, p. 1) and "how change is made in action" to understand how processes of societal change happen (ibid., p. 5). In line with this, we will place the analytical focus of our study on empirically investigating which actions and factors accompany and influence the individual role-changing process in our case study.

Referring back to Wittmayer's framing of roles as activities and attitudes (Wittmayer et al. 2017), and Hilger's suggestion to observe actors' activities to understand their roles (Hilger et al. 2021), we assume that examining role change associated with change in individual actors' activities and behaviors offers a promising way to operationalize the process and open up the 'black box' of societal change (Pesch 2015).

As these actions are always embedded in a certain context (Roeck and van Poeck 2023), that influences how roles can be perceived (Carter and Cook 1995), we advocate for an approach that allows us to empirically uncover how roles emerge in interplay within the given context. Common analytical concepts have been criticized for inadequately representing this interplay between individuals and their environment, (Weik 2012; Roeck and van Poeck 2023) not depicting how the context either facilitates or constrains the transition processes, especially neglecting spatial factors (Coenen et al. 2012). In the next section, we will, therefore, introduce the Embedded Agency Perspective (EAP) as an analytical framework that allows us to consider the individuals' actions in the interplay with the social and spatial context when analyzing the role-changing process in our case study.

The embedded agency perspective: an analytical framework to study agency in action

To achieve a comprehensive understanding that encompasses the social and spatial contexts, the EAP (Bögel et al. 2022; Augenstein et al. 2022a) is applied as an analytical framework to monitor and guide the research that accompanied the real-world experiment "Your Balcony Network". The EAP builds on four analytical spatial dimensions that help to evaluate the local embeddedness of a real-world experiment: (i) the physical dimension, meaning all material and tangible elements in space; (ii) the cultural dimension,

meaning the spatial system of signs and representation; (iii) the dimension of actors and agency, which analyzes the social practices of production and use of space; (iv) the regulative dimension, meaning rules and norms (detailed explanations can be found in Bögel et al. 2022; Wirth and Levin-Keitel 2020). These dimensions are linked with the socio-psychological perspective on actors' perceptions and behavior at three levels (Elliott and Wattanasuwan 1998; adapted by Bögel et al. 2019) (i) the individual level, which describes the lived experience of the people involved; (ii) the social level, meaning discursive elaboration through interaction with others; and (iii) the societal level, meaning the mediated experience and representation of meaning at the public level (Bögel et al. 2022). Building on these levels, an in-depth analysis of the psychological mechanisms at play in the role-changing process becomes possible. Following colleagues like Taylor and Cook, who analyzed the role-changing progress in conjunction with the accompanying psychological resources (Carter and Cook 1995), we will connect to psychological concepts to identify indicators for empowering role change in the results section.

The combination of spatial and psychological concepts allowed us to study how participants and their roles are influenced by the embedded (social and spatial) system, but also how they influence that system. Each integrated dimension makes it possible to describe and analyze a dimension of change: (i) change of physical space and its perception, (ii) change in symbolic meaning and value, (iii) change in practices, pattern of use and agency, and (iv) change in rules and dealing with regulative norms (Augenstein et al. 2022a).

The following Table 1 shows how the EAP structured the accompanying research on the "Your Balcony Network"—experiment and framed its guiding research questions.

Relating to our action-orientated approach (see "Understanding role change in action") the (iii) dimension of changes in practices, patterns of use and agency allows us to understand how individual behaviors and practices change and whether new roles and role understandings emerge from these changes. Besides the EAP can help us to identify more important contextual factors underlying and influencing role change. The first dimension of change, (i) change in physical space and its perception, allows a closer examination of how different physical conditions affect opportunities for a role change. This is of special interest for real-world experiments, as they are always embedded in and influenced by a certain spatial context (Wirth and Levin-Keitel 2020). Dimension (ii), change in meaning and value, looks at changes in the symbolic meaning of balcony modules for the participants, and how this influenced new role understandings. Dimension (iv), changes in rules and negotiation of regulative norms, considers the requirements and regulatory framework conditions the participants may have to negotiate and helps to

Table 1 The EAP as a guiding framework in the experiment "Your Balcony Network"

Spatial dimension	Socio-psycho-logical dimension	Mechanisms of change (integrated dimensions)	Leading questions of the accompanying research (analysis of mechanisms of change)
Physical	Individual Social Societal	Changes of physical space and its perception	How did the outdoor space affect the interaction with the balcony modules? Did the physical space change for the participants because of the module use, and if so, how is this change perceived?
Cultural	Individual Social Societal	Changes in symbolic meanings and values	Which narratives and symbolic meanings did the participants relate to photovoltaic? Which narratives did they relate to the energy transition? Did the meaning change through the experiment?
Agentic	Individual Social Societal	Changes in practices, patterns of use and agency	Has the attitude of the participants towards the energy transition and PV technology, especially towards balcony modules, changed? Did new behavior or usage patterns result from participation in the experiment? If so, what do they look like? Did the participants gain new knowledge or skills by participating in the experiment? What possibilities do the participants perceive for their actions and did this affect their role understanding? How did the interaction and (direct) social environment influence the participants?
Regulative	Individual Social Societal	Changes in rules and dealing with regulative norms	Which requirements and regulatory framework conditions did the participants have to deal with? Were these inhibiting or helpful? Did the experiment initiate changes in administrative, planning, or similar requirements?

shed light on external conditions that hinder or enable role change.

Since not many transition research approaches have examined the role-changing process empirically, we take an exploratory approach alongside these four dimensions in our analysis of the case study. This will be further elaborated in Sect. "Data collection and analysis".

Material and methods

Case study: your balcony network

The energy transition experiment "Your Balcony Network—Energy Creates Community" is part of the real-world lab "District Future - Urban Lab" in Karlsruhe, Germany (Parodi et al. 2016). The overall aim of this real-world experiment was to explore how an energy transition that integrates environmental issues, as well as questions of inclusivity and social cohesion could be promoted. It sought to encourage citizens to participate more actively in the energy transition and explore how more sustainable energy production affects users' everyday lives (for more details on the experiment's

goal and setting see (Augenstein et al. 2022b). 22 households were given the chance to try out what are known as "photovoltaic balcony modules" for at least 12 months. These small solar systems are specially designed for private households and offer individuals comparatively inexpensive,

Fig. 1 Pictures of participants' PV modules (District Future—Urban Lab 2021)

Fig. 2 Pictures of participants' PV modules (District Future—Urban Lab 2021)
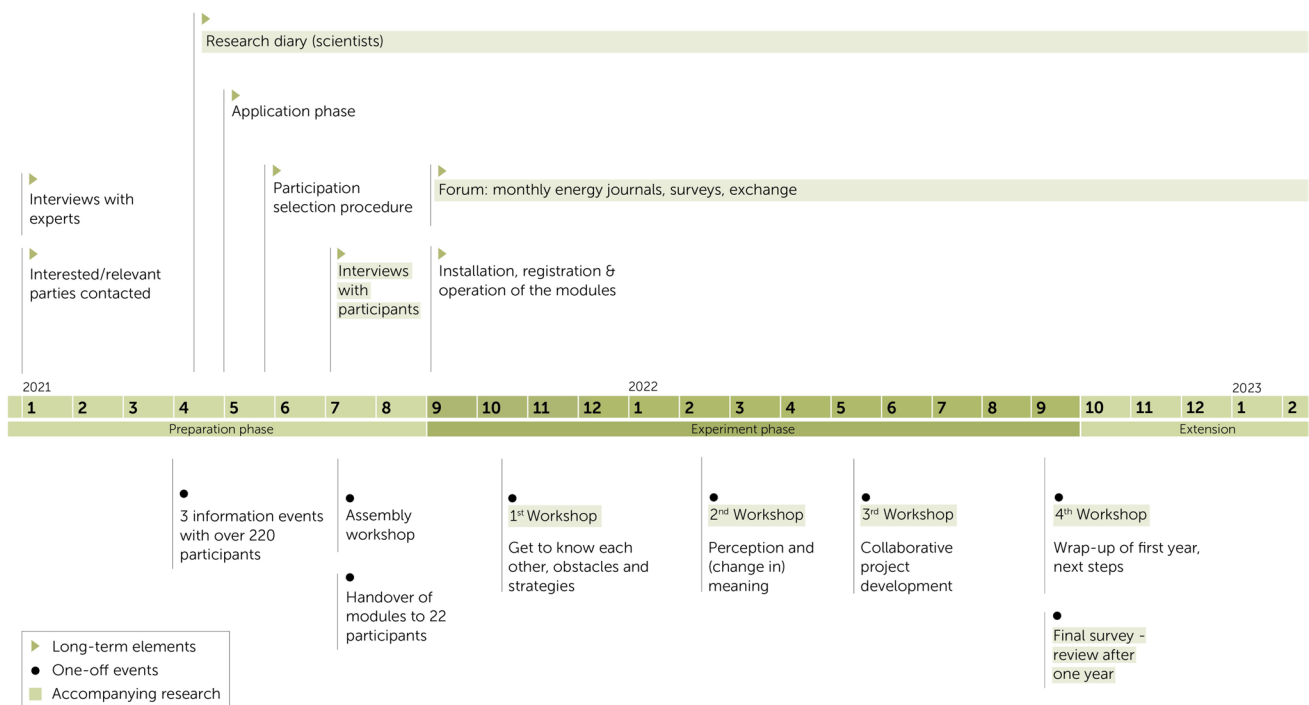
module came with an inverter and digital electricity meter to track its power output. The authorization process in Germany is also relatively straightforward: the mini solar plants must be registered with the local grid operator and the Federal Network Agency, but no formal approval is needed.

The aim of the experiment was to, firstly, investigate transition processes around the adaptation and application of this new niche technology from a sustainability perspective and, secondly, study how using such modules influenced participants' roles in the energy transition (Albiez et al. 2022). The participants were monitored by researchers from the real-world lab throughout the whole period and documented their experiences in journals and questionnaires. Figure 3 shows the project's timeline, with the 12 months of the experiment highlighted in dark green. It was extended in September 2022 due to its success and requests from participants.

After a preparatory phase, during which dialogue with energy experts (scientists and practitioners) and parties like the local energy agency helped shape the experiment design, information was disseminated through the local media, followed by three (online) information events for interested citizens. The subsequent application phase resulted in the selection of 22 households. To support the community-building process a strong focus was placed on group activities and exchange among the participants from

unbureaucratic opportunities to participate in the energy transition with a low technical threshold (Figs. 1 and 2).

The PV modules are relatively small and lightweight (measuring 1.6 m × 1 m × 0.035 m and weighing 7.5 kg) and have a plug for easy connection to the building's electricity network via a normal outlet. They are typically installed on balcony railings or in other outdoor locations and can be set at different angles. Their rated capacity is around 300 watt peak (Wp). Furthermore, each solar

Fig. 3 The entire project process, including the most important milestones. One-off and long-term events are marked with different symbols. The occasions when data were collected for the accompanying research are highlighted in green (authors' graphic).

the beginning. The participants first met at the "assembly workshop" at which the participants got to know each other and learned how to assemble the modules. They had time to install their modules and get used to operating them in the summer before the official start in September. During the experimental phase, the participants had the chance to exchange in four group workshops organized by the research team. Additionally, they were encouraged to exchange via an online forum that accompanied the whole experiment. The group workshops had three main functions. First, they worked as an update and "check-in" between the participants and the scientists to see how the process evolved and what topics accrued. Second, they functioned as a networking event to strengthen the group spirit by exchanging experiences, creating an open and supportive environment, and working jointly together on occurring problems. Third, during the workshops different participatory methods like group work and discussion, living statistics, or wish walls were used to collect additional data. An overview of the workshops, their topics, and how they stimulated the exchange in the group can be found in Bögel et al. 2023).

Data collection and analysis

Sample and data collection methods

As shown above in Fig. 3, the experiment was monitored during the 12 months in different ways and settings (interviews, online-forum, participatory methods during workshops, surveys). From this data, the initial interviews and the final surveys were selected for the analysis of the role-changing process. In summer 2021, after the handover of the modules, interviews were conducted with all 22 participating households ($n = 22$). A list of the participants' characteristics can be found in Table 2 in the appendix. Each interview was carried out by two members of the research team. Due to coronavirus restrictions, all interviews were conducted online using video conferencing software. The first part was designed as a narrative interview (Bohnsack 2014) the goal of which was to find out more about the interviewees' previous involvement with energy topics, e.g. (i) the participants' "energy history". This was followed by the semi-structured part of the interview, in which the participants were asked about (ii) their plans for the modules, (iii) their motivations for participating in and expectations of the experiment, and (iv) their general attitude toward photovoltaics. The interview closed with a question about (v) their expectations and the responsibilities they see among different stakeholders in the energy transition. At the end of the 12 months period, a survey was conducted ($n = 20$) featuring mainly open questions (with several closed "Yes/No" introductory questions)

that aimed to supplement the knowledge gained from the interviews and capture processes of change initiated by the experiment. The survey was divided into five sections: (i) changes at the personal level, (ii) changes in the social environment, (iii) reflection on participants' expectations of the project, (iv) the influence of the group and of networking, (v) recommendations. The questions of the survey can be found in the appendix. The interviews were conducted and surveys were completed in German; all quotations have been translated by the authors.

Data analysis

To better understand how the experiment empowered individuals to change their roles, we applied a qualitative content analysis following Kuckartz and Rädiker (2022). The data was processed using MAXQDA software. For the analysis, we followed a deductive-inductive strategy to develop our coding scheme (Kuckartz and Rädiker 2022). First, we derived indicators for a role-changing process from the integrated dimensions and leading questions of the EAP (see Subsect. "The embedded agency perspective: an analytical framework to study agency in action"). For this process aspects of the dimension "change in practices, patterns of use and agency" were used as initial codes and starting points for the first coding cycle, as this overlaps best with our notion of roles as "recognizable activities" and our action-oriented approach. Second, the codes identified this way were realigned and supplemented with more aspects from the EAP to further encompass any missing contextual factors that influence role change with a particular focus on spatial aspects. This process led to an initial coding system, that was tested on one-third of the data by two members of the research team in a "collegial validation process" (Kuckartz and Rädiker 2022, p. 136), leading to some adjustments and inductive additions. Third, the final coding system was applied to all the data by one of the researchers. Figure 4 illustrates the development process of the coding scheme. The final coding scheme (Fig. 5), is given in the appendix.

Results

In our study, our objective was to analyze whether an empowering role change occurred in the real-world experiment "Your Balcony Network" (RQ1), as well as to examine the processes and mechanisms that supported the role-changing process (RQ2). Building on the assumption that role change can be identified by observing changes in actors' activities and behaviors we applied a process perspective, empirically investigating how participants' roles
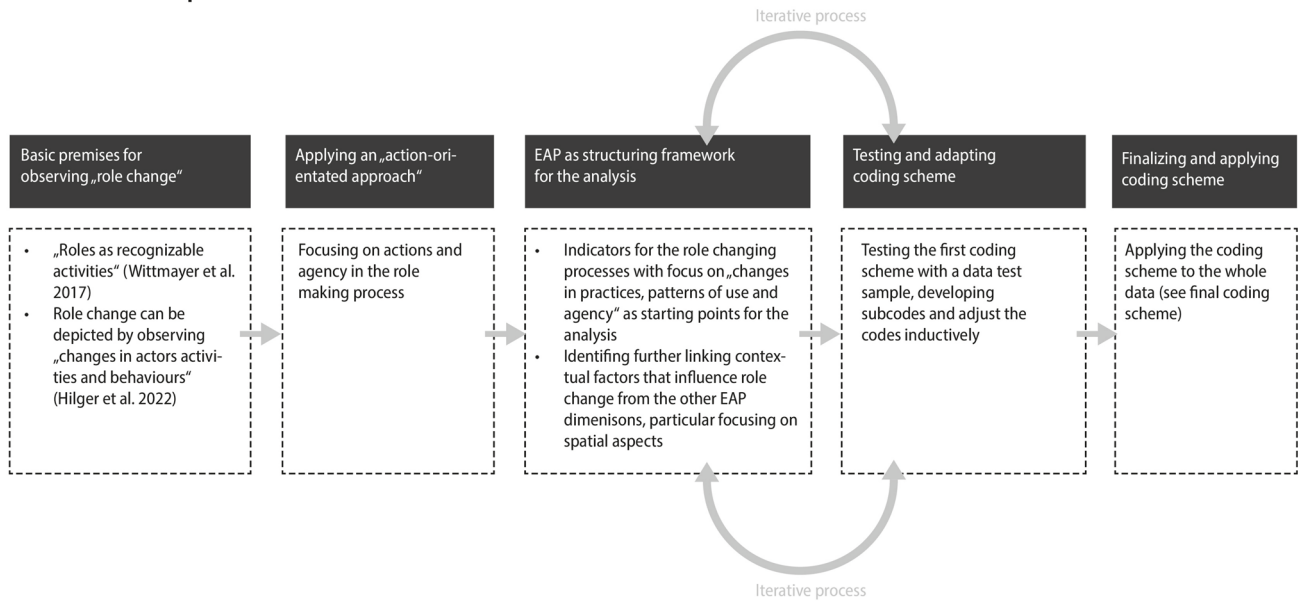
Process of code exploration

Fig. 4 The process of code exploration in the data analysis of "Your Balcony Network" represented in a flowchart

changed through taking part in the experiment. Following the agency in action approach, we will examine what activities changed in the first research question, followed by analyzing the process of how this role change unfolds in the second research question. We will report the results of our empirical analysis in Subsects. "Role change during the experiment" and "Understanding the process of role change—mechanisms and interplay with the socio-spatial context", devoted to our two main research questions.

Role change during the experiment

In this first section, we aim to depict changes in the actions and behaviors of the participants within the real-world experiment setting to uncover if an empowering role change took place. Following an action-orientated approach, we first want to understand how the participants acted in the setting

of the real-world experiment, to identify possible indications for an empowering role-change.

Through our analysis, we could inductively identify five psychological indicators, that positively altered the actors' agency within the experiment, encouraging changes in actions and behaviors. We will refer to these aspects as "indicators for empowering role change". Alongside these five indicators, we will describe the situation at the beginning of the experiment, followed by presenting how these aspects have changed after the first year ("Indicators for empowering role change"). Finally, we compare our findings with our understanding of empowering role change in the energy transition ("Summing up—empowering role change in the energy transition within the experiment"), showing that an empowering role change occurred among the participants answering our first research question (Did the real-world experiment lead to an empowering role change among the involved citizens?).

Fig. 5 Factors indicative of role change at the beginning (T1) and after 12 months of the experiment (T2)

Indicators for empowering role change

Changed energy behavior Some participants stated at the beginning that they were already trying to adopt more environmentally and climate-friendly lifestyles. Sustainable consumption, nutrition/food, and mobility were mentioned most frequently as areas for personal action. Energy was also mentioned as important but was described as elusive, often highly technical, and less interesting. The exceptions to this were those participants who were already heavily involved with energy-related topics due to their work or hobbies and the two house owners already running PV-systems. Otherwise, sustainable energy behavior is mostly related to the consumption of energy, e.g., choosing a "green power provider" or turning off lights, with participants seeing themselves mainly in the consumer role.

In the course of the experiment, the majority of participants began to adapt parts of their daily routines in line with the levels of electricity the modules generated. Seventeen of the twenty reported adjusting their behavior in response to the weather, using electrical devices primarily when the sun was shining to consume as much of the energy they produced as possible. The two main changes involved adjusting the use of appliances and energy-saving measures. Additionally, the majority of the respondents claimed they had developed a more energy-sensitive lifestyle generally and were using electricity more consciously, particularly thanks to their intensified engagement with energy production. This consciousness was stronger when the modules produced high levels of energy output, but sensitization effects could also be identified among participants with less efficient installations. Besides, many participants reported wanting to implement long-term changes, thinking about buying a balcony module once the experiment ended (14/20), or wanting to install a PV system (2/20).

Acquiring new knowledge The participants knew very little about the possibilities of electricity production by balcony modules at the beginning of the experiment. Among those who already knew about them in theory, the barriers to purchasing the modules seemed too great (e.g., their cost, their effectiveness, inopportune timing, or uncertainty about which module to select). In both cases, the experiment was regarded as an opportunity to try something new, gain practical knowledge, and learn about energy production generally.

Using the balcony modules during the experiment fostered a better understanding of energy issues and helped participants overcome technical barriers. In the final survey, they reported that they had now gained new expertise, for example, that they "know from almost all devices how much electricity they consume and [how to] use them consciously" (final survey) or had gained a better technical understanding from "PV to touch, try out, experience for yourself" (final survey), and therefore engaged in discussions more frequently and confidently.

Enhanced environmental awareness The participants already showed a general awareness of climate and environmental issues at the beginning of the experiment, which was one of the motivations for them to participate. Climate change and the necessity of environmentally friendly lifestyles were frequently brought up in the initial interviews, with photovoltaics mentioned as one possibility for the energy transition, but their own actions were focused more on their immediate living environments.

After the first year, PV had become more important as a technology for sustainable energy production in the eyes of most participants. They had gained a new understanding of the processes required for the energy transition and how they could contribute. In general, the modules seemed to stimulate engagement with the topic of energy and each individual's options in the transition process.

Experience of self-efficacy The majority of the participants in the experiment lived in rented accommodations. At the beginning of the experiment, this group felt their options for action were limited, except for switching energy providers. As tenants, they felt "left behind," not being able to take major decisions while the responsibility mainly lay with others (policymakers especially). The participants who were house owners saw a little more room for maneuver but reported significant financial hurdles or restrictions imposed by heritage planning restrictions as the main obstacles to the use or expansion of PV in their homes.

After the first year of the experiment, many reported they had become aware of new opportunities to participate in the energy transition. Some participants stated they were now able to "contribute some of my power supply myself" (final survey), which made them feel more involved in the transition process. They also described PV modules as facilitators and low-threshold opportunities to make themselves and others more aware of possible ways of engaging in the energy transition.

Shift in role perception In line with their low levels of perceived self-efficacy at the beginning of the experiment, participants saw the main responsibility for advancing the energy transition and the expansion of PV mainly at the political level ('creating suitable framework conditions'). This was accompanied by the expectation that industry and business would follow suit and develop the technology further. The development of these technologies was also mentioned as a matter of science, the aim being to make them more efficient and affordable. Besides, it was seen as part of

scientists' role to inform society about new developments, as well as conducting research on the acceptability of technologies and users' motivation to adopt them. Individuals were described mainly as consumers, although the importance of the 'conscious consumer' to the energy transition was emphasized.

During the experiment, the participants discovered new options to contribute to their own energy production as prosumers which led to an empowered self-perception of their own role and opened up new opportunities for action. As a result, some participants took on new roles as pioneers or role models. Some also claimed they wanted to share their expertise with others, proactively approaching neighbors or friends and trying to motivate them to install balcony-PV, thus helping to change mindsets. The participants were still aware of the need for systemic change and called particularly for policymakers to create incentives and remove barriers.

A table of exemplary quotes (Table 3 in the Appendix) gives additional insights into the participants' views.

Summing up—empowering role change in the energy transition within the experiment

In summary, we have identified five factors indicative of role change (see Fig. 6). By referencing our definition in Sect. "Role change in transition" it becomes evident that an empowering role change among the participants took place.

Throughout the experiment, the participants took up an active and conscious attitude toward their energy production and implemented actions that support a sustainable energy supply, e.g., altering their everyday practices, cultivating energy-sensitive lifestyles, or adapting more sustainable routines (2)[4]. Within the experiment, they were
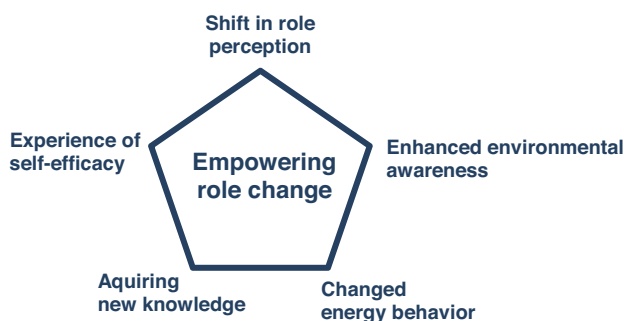
Fig. 6 The process of empowering role change. Role change is indicated by changes in knowledge, behavior, awareness, self-efficacy, and role perception (authors' graphic).

---

[4] The numbering refers back to the numbering in our definition in Sect. "Role change in transition" to highlight the different aspects of empowering role change.

enabled to produce their own energy directly (3) and acquire new capabilities within this process, e.g., new (technical) expertise (4). This also influenced their self-understanding and environmental consciousness, as they recognized the necessity and new opportunities for themselves to participate in the energy transition. This helped shape a new perception of their own role in the transition process, including acknowledging their contribution to the collective effort of the energy transition and experiencing a sense of relatedness and self-efficacy (1). As a result, the participants assumed new proactive roles in their immediate living environment, such as pioneers or role models, departing from the passive consumer role (5).

Understanding the process of role change— mechanisms and interplay with the socio-spatial context

While the findings discussed above are clearly indicative of an empowering role change among the participants, we are also interested in a deeper understanding of the processes involved (RQ2: Which processes and mechanisms are involved in supporting an empowering role-changing process?). Having looked at what changed in the first subsection, we therefore analyze in this subsection "how this change is made in action" (van der Rock and van der Pock, p. 5), meaning how these factors come together in the role-changing process. Our analysis revealed three main mechanisms of change associated with changes in participants' roles, outlined in Sect. "Key mechanisms of change" (Fig. 7).

As these mechanisms show, the new roles come to life in interplay with the participants' environment, emphasizing that the process of role change is always embedded and influenced by the socio-spatial context. In this section, we therefore also aim to gain a deeper understanding of the contextual factors involved in the role-changing process. Our analysis enabled us to illustrate four contextual factors, which had a great influence on the process within the experiment, which we will present in Sect. "Incorporating the interplay with the socio-spatial context".

Key mechanisms of change

Change in energy behavior due to practical knowledge and new expertise By engaging with their own power production, the participants acquired new knowledge, e.g., about appliances' energy consumption. Most importantly, this knowledge was not theoretical, but acquired by means of intrinsically motivated 'learning by doing'. The participants tried out different options and routines, thereby creating a small experimental setting of their own. In the final survey, it became clear learning from practical examples and personal
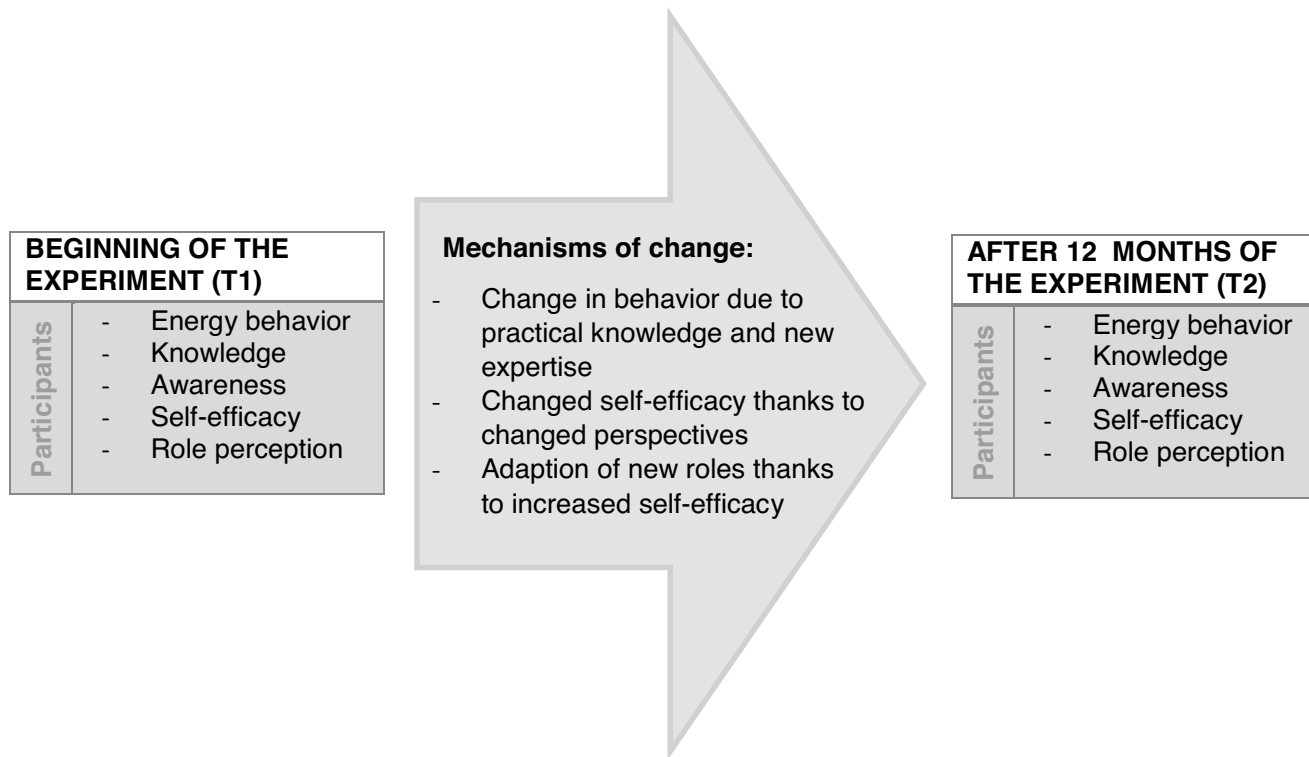
Fig. 7 Mechanisms of change underlying the role-changing process in the experiment "Your Balcony Network".

experience was essential for the actors. E.g., one participant stated he/she now had "more knowledge from direct experience" (final survey) and another said, "before, most of the talk about it was very theoretical. Thanks to the experiment, we were able to talk about our actual experience" (final survey). They also reported now being more aware of their electricity consumption and what appliances they use.

Changed self-efficacy thanks to changed perspectives In the final survey, 19 out of 20 participants stated the experiment had given them new perspectives on the energy transition. They described feeling "being able to contribute something ourselves" (final survey) and having a better understanding because of their personal experiences. This new expertise empowered them to act with greater confidence. Many participants said they now talked differently and more proactively about PV and energy production with family, friends, and acquaintances, taking on new expert roles due to the practical experience they gained. As one participant reported, "I get involved in conversations more often, encourage and support any initiative" (final survey). Participating in decentralized energy production further encouraged the feeling of self-efficacy, since it was associated with a sense of freedom and empowerment, as expressed by this participant: "one feels at least to a small extent more independent and self-determined thanks to the module" (final survey). The par-

ticipants associated the balcony modules with feelings like self-determination or independence; generating electricity at home was described as "exciting," "interesting" and "joyful/fun" or as giving a "good feeling." This shows energy had left the 'tech zone' and become an 'emotional topic' for some actors. Besides, many respondents also mentioned taking pleasure in generating energy themselves.

New roles adopted thanks to increased self-efficacy Many participants described occasions when they were asked for their opinions and were able to tell others about their experiences. Their new expertise also led some to become more actively involved in the topic, taking up new leadership roles and acting with greater confidence. Whereas the majority reported talking more often about PV, some went further and stated they had now become strong advocates for the technology. Some even claimed they had become role models and hoped to function as multipliers. Many also reported they would like to help remove obstacles so it would be easier for others to use balcony-PV. Sharing their knowledge was mentioned as an important thing they could do to support the spread of this technology. Although they had gained new opportunities to participate in the energy transition as tenants, they were also aware of the importance of politics in creating supportive conditions for the transition process.

Incorporating the interplay with the socio-spatial context

Spatial conditions affect opportunities for role change The majority of the tenants attached their module to the railing of a balcony while house owners also installed them freestanding in their gardens or on terraces. The fact that installation did not require elaborate changes or adjustments of the space can be seen as a supportive factor in the adoption of active roles and was also positively named by the participants. Nevertheless, people who rent apartments are disadvantaged because the space they can use is ordinarily limited and they have fewer options to move their modules and test out different locations. In addition, this group was more often affected by disputes with landlords and tenants' associations.

Supportive interactions and exchange within the group encourage role change The fact that the participants did not have to deal with the modules alone was perceived as positive and helpful, especially at the beginning when they faced questions about installation and assembly and problems registering the modules. Being part of a network was also identified as an important motivation to participate in the experiment in the first place. During the experiment, particularly the initial phase, there was a lot of mutual assistance and a lively exchange of knowledge. The dialogue within the group was described as very useful by the vast majority of stakeholders in the final survey ($n = 17/20$). Some reported they would probably have given up if they had not been involved in the experiment. Here, the support and exchange within the group and the support from the real-world lab team proved to be essential helping factors. Meeting like-minded people, exchanging ideas, learning about new viewpoints, and seeing how others negotiated situations were mentioned as positive aspects of the exchange that took place. They even prevented one participant from leaving the experiment. As the participants had different backgrounds and different prior knowledge, they contributed a wide range of views to the group, which was perceived as an enriching factor.

The experiment as a facilitator and catalyst of the process The real-world experiment itself served as a supportive factor, functioning as a 'window of opportunity' and stimulus for some to engage with the topic and become involved straight away, rather than continuing to wait. It was also claimed that being embedded in a context that provided support and guidance lowered the barriers to participation. Besides, nearly a quarter of the actors reported that being part of a research project was one of the reasons why they chose to participate. It also seemed to increase network operators' and landlords' acceptance and made the participants more determined to persist.

Legal regulations and bureaucracy as main obstacles to role change Especially at the beginning of the experiment, the regulatory and bureaucratic requirements proved to be very big obstacles to the modules' installation and therefore the uptake of new more active roles. Many stakeholders reported problems with unclear, contradictory, or confusing information and requests or troublesome communication with their network operators. Surprisingly, the obstacles turned out to be motivating for some, who stated their wish to pass their gained knowledge to others, to make future processes easier. Some even expressed a desire to join and campaign for de-bureaucratising the process.

Discussion

This study aimed to investigate the development of an empowering role change in the context of the energy transition and how a real-world lab could support citizens in this process. Since no clear understanding of the processes involved in individual role change within the transition literature exists, we first derived our understanding of empowering role change in the energy transition. To comprehensively represent the dynamic interplay between the actors and their environment during the role-changing process, we adopted the Embedded Agency Perspective (EAP) as our analytical framework and starting point for our empirical analysis of changes on a psychological-spatial level. Our analysis was guided by the 'agency in action' approach, placing the focus on understanding the actors' activities and behaviors as the starting point for our empirical examination of the process.

Our analysis shows participants' actions and perceptions changed in several ways as the real-world experiment continued, e.g., they started to use energy more consciously and acquired new practical knowledge that enabled them to engage more actively and frequently with energy-related issues. The empowering experiences they had led them to take up new roles as pioneers or role models and demand structural changes from policymakers. Through our empirical analysis, we identified five indicative psychological factors of role change. By analyzing the changes within these factors and aligning it with our understanding of empowering role change, it became clear that the real-world experiment provided a stimulating environment that facilitates empowering role change among the involved participants, answering the first research question (RQ1: Did the real-world experiment lead to an empowering role change among the involved citizens?). By operationalizing role change using psychological concepts, we have provided a practical way to make the process of citizens' role change more tangible and transition processes empirically analyzable, as demanded by Wittmayer et al. (2017). The indicators identified in this study can be applied to further support citizens' involvement in

the energy transition, as they provide valuable insights into the aspects that need encouragement to promote these processes. Studies in the field of energy citizenship and energy democracy can benefit from these insights. It can also be adopted and serve as a starting point to facilitate empowering role change in other areas.

To better understand the processes involved (RQ2: Which processes and mechanisms are involved in supporting an empowering role-changing process?) we identified three interlinked mechanisms of change that promote role change by imparting new expertise and boosting self-efficacy. Concerning the claim of real-world labs to be "a learning environment" (Singer-Brodowski et al. 2018), one important finding is, that learning from practical examples and personal experience seemed to have a more profound effect on the participants' role development than merely theoretical knowledge. These findings are also consistent with the conclusions drawn by previous studies from the field of environmental psychology on sustainable energy behaviors and knowledge (Steg et al. 2015; Frick et al. 2004). The experimental setting created by a real-world experiment helped participants gain practical knowledge on a low-threshold, "learning-by-doing" basis, confirming the distinctive advantage of a real-world lab as a learning environment (Singer-Brodowski et al. 2018; Schäpke et al. 2018b) and 'experimental space' (Parodi et al. 2023b). This practical knowledge and their new expertise empowered the participants to act in a more self-determined manner. Besides, the possibility of producing their own energy in the experiment encouraged them to "change perspectives" on the energy transition generally. This increased experience of self-efficacy supported the participants' adoption of new, more active roles.

Given, that the role-changing process unfolds within the participants' environment, we also aimed to properly depict the contextual influence involved in the transition process (Roeck and van Poeck 2023; Weik 2012). Using the dimensions of the EAP as a starting point in our empirical analysis enabled us to focus more closely on the socio-spatial context and to identify contextual factors influencing the role-changing progress. For example, the disposition over spaces emerged as a crucial prerequisite for empowering role changes. This supports the claim that it is crucial for the understanding of transitions to gain a deeper insight into the spatial contexts' influence on actors in transition processes (Coenen et al. 2012). We could also show that the encouraging social context of the real-world experiment facilitated the role-changing process: Firstly, the possibility of exchange within the group proved to be supportive at all stages of the experiment. This supports the great emphasis placed on experiments and networking activities in real-world labs (Meyer-Soylu et al. 2016). It also underlines the importance of networks if individual actors are to have an impact on the transition process (Fischer and Newig 2016). Secondly, the experiment and the real-world lab setting itself functioned

as a facilitator. It became evident the real-world experiment was perceived as an important, supportive infrastructure by the participants throughout. This suggests real-world labs are living up to their aim of being places for learning through testing and experience (Parodi et al. 2017). It also became apparent that, even though the experimental setting provides some kind of freedom, it is heavily influenced and often hindered by the regulatory and bureaucratic context of policies. This hurdle is also reflected in the current discussion on a political level in Germany about a "real-world lab law" that should ease testing (Parodi et al. 2023a; BMWI 2021).

Limitations and further research

While small-scale experiments are good starting points for the facilitation of learning in transition processes (van den Bosch and Rotmans 2008) the results should be viewed with caution because this real-world experiment only involved a small sample ($n = 22$), making its results difficult to generalize from or scale up. Moreover, the study was conducted in a German city and spatial circumstances or regulations may differ in other countries. Further testing in other contexts could help establish the results' general validity.

As the concept of empowering role change in the energy transition is still developing, future experiments could provide more empirical evidence that refines the concept of role change as an "indicator for transition" (Wittmayer et al. 2017). In this regard, further research would benefit from using the same measurements at different points in time to improve comparability. However, these methodological goals need to be balanced against the goals of a transdisciplinary designed research such as our real-world experiment; direct comparisons were not possible in our study because the experiment was co-designed with the participants and had to be continuously adjusted throughout the experimental phase.

In this study, we have limited our focus to role change on the individual level. While we made an effort to consider the context in our analysis, we acknowledge that concentrating on the micro-level can be both a strength and a weakness. We argue that placing a deliberate emphasis on role change on this level allows for great empirical and analytical depth, as well as a better understanding of what drives people to change and how bottom-up transition processes unfold. However, we recognize that social change requires the emergence and integration at a societal level, e.g., "mainstreaming" of new roles. In our study, we did not delve into the analysis of long-term transitions of citizens' roles at the societal scale. This would be an intriguing avenue for future studies in the field of energy transitions.

Further research could also aim to study the role changes examined here in relation to other mechanisms of change in

transitions and other actors (e.g., how local energy suppliers respond to stakeholders' changed roles), but also the structural or political context. Our study only touches fleetingly on the possible policy implications of our findings. Further research could focus on governance processes around the implementation of small-scale PV modules as part of an overall strategy for decarbonized cities.

Conclusion

Our study provides deep insights into the role-changing process in the energy transition, thus enriching the discussion about individuals' roles in transition processes (DeHaan and Rotmans 2018; Wittmayer et al. 2017) as well as introducing new perspectives on role changes in transdisciplinary projects (Huning et al. 2021). We have shown that taking part in a real-world experiment encourages changes in behavior and self-perception, leading people to support the energy transition more proactively, and

adding to the discussion about the effects of real-world labs (Schäfer et al. 2021). We have, furthermore, studied mechanisms of change to illuminate the role-making process itself and analyzed supportive contextual factors. Our findings support the conclusion that real-world labs can serve as a place for empowering role change among individual actors, especially emphasizing the importance of these labs as places for experimentation, learning by experience, and networking (Singer-Brodowski et al. 2018; Schäpke et al. 2018b; Parodi et al. 2023b). As evaluating the impacts of transdisciplinary processes, such as real-world experiments, is a challenging task (Lang et al. 2012), and there is no standard procedure (Bergmann et al. 2005), incorporating approaches from various disciplines appears to offer a promising avenue for elucidating the effects of transdisciplinary experiments. Integrative frameworks like the EAP hold great potential for overcoming disciplinary boundaries (Bögel et al. 2022). With our study, we have made the first attempts to put such an interdisciplinary framework into transdisciplinary practical

Table 2 Data sources and demographic data of the participants

Interview	Gender	Birth year	Educational level	Size household	Housing	Final survey
Interview 1	M	1959	University Entrance Qualification	2	Ownership	X
Interview 2* (double interview)	F	1990	Master degree	5	Rent	X
	M	1991	Bachelor degree			
Interview 3	F	1970	Diploma	2	Ownership	
Interview 4	M	1957	Vocational training	4	Rent	X
Interview 5	M	1964	Vocational training with Master qualification	1	Rent	X
Interview 6	F	1975	Diploma	4	Rent	X
Interview 7	F	1971	University Entrance Quali.	4	Ownership	X
Interview 8	F	1959	State exam teaching (element.& second.-school)	1	Rent	X
Interview 9* (double interview)	F	1969	Vocational training	4	Rent	X
	M	1966	Diploma			
Interview 10	M	1985	University Entrance Qual.	2	Rent	X
Interview 11* (double interview)	F	1987	Diploma	2	Rent	X
	M	1987	Master degree			
Interview 12*	F	1986	Bachelor degree	3	Rent	
Interview 13* (double interview)	F	1977	Vocational training	3	Ownership	X
	M	1976	2. state exam teaching			
Interview 14* (double interview)	F	1992	Bachelor degree	2	Rent	X
	M	1982	Vocational training			
Interview 15	F	1969	Diploma	3	Rent	X
Interview 16	F	1984	Master degree	3	Rent	X
Interview 17	F	1968	Vocational training	4	Ownership	X
Interview 18	M	1977	Diploma	2	Rent	X
Interview 19	F	1965	University Entrance Qual.	2	Ownership	X
Interview 20	F	1975	Bachelor degree	4	Rent	X
Interview 21	M	1957	Vocational training	2	Ownership	X
Interview 22	F	1991	Master degree	1	Rent	X

Coding scheme "Your Balcony Network"

Derivation Embedded Agency Perspective (EAP)	Main codes	Sub-codes
Changes in participants' attitudes (Dimension: Change in practices, patterns of use and agency) Changes narratives about energy (Dimension: Change in symbolic meaning and value)	Attitudes of the participants towards the energy transition	• Individual climate and environmental awareness • General attitude & wishes torwards the energy transition • Attitude regarding PV • Identified need for action & responsibility/ important players • Personal interests/affinity for technology • Contribution balcony modules: wishes & hopes • Others
New knowledge and skills (Dimension: Change in practices, patterns of use and agency)	Knowledge building of the participants	• Sensitization through new knowledge / experience • Already existing know-how, • (New) knowledge through direct experience • Getting to know a new technology • Interest & opportunity
New behavior or usage patterns (Dimension: Change in practices, patterns of use and agency)	Behavior change, changed actions & routines	• Energy sensitive lifestyle • Plans for the future • No belief in change/no change • Other changes
Influence of social context (Dimenson: Change in practices, patterns of use and agency)	Exchange and interaction with others in the course of the experiment	• Reactions of environment • Interest/importance of sharing & community • Getting help/to help others • Influence on others
Perceived options for action, one's own role understanding (Dimension: Change in physical space and it's perception)	Self-efficacy, empowerment and new role models	• Experiencing self-efficacy • Multiplier effect/being a role model, • Making a contribution/feeling like making a difference • Self-image/ role understanding • Independence • Having fun/enjoying the technology
Requirements and regulatory parameters (Dimension: Changes in rules and negotiation of regulative norms)	Challenges and hurdles for balcony PV	• Economic in-efficiency • Regulatory framework, bureaucracy & administration • Technology, assembly, installation • House community, neighbors, landlords • Knowledge hurdles/complexity • Historic preservation • Other hurdles
Change of physical space (Dimension: Change in physical space and it's perception)	Spatial adaptation through the module	• Structural attachment & adjustments (if necessary) • Exterior alteration or adaptation • Little alteration or adaptation needed
Inductive additions	Other interesting aspects/other	• Low-threshold, simplicity • Cost savings as motivation • Interest in research

Fig. 8 The final coding scheme used for the data analysis

Table 3 Table of exemplary quotes

Factor	Time	Object of matter	Quote
Environmental awareness	T1	Awareness as motivation	"So for me climate change and the environmental aspect are more important than the money. Of course, I think it's great if something comes out of it financially, that is also a useful thing. But to me it would actually be somehow more important, how can you really get away from coal and nuclear power and change to producing energy in a climate-neutral way?" (Interview 13, own translation) "For me, it's not about saving five cents or not, but simply using the opportunity to use the energy that comes from the sun. There's no need to burn coal, so it's the environmental idea" (Interview 7, own translation)
	T2	New understanding of the energy transition	[A new way of looking the energy transition is…] "that the energy transition can succeed not only "centrally from above" but also through each individual "from below" (final survey, own translation) "Generating electricity directly at the point of consumption seems to me to be a very sensible concept to me" (final survey, own translation)
		Increased importance of PV	„We thought it was important before and this opinion has been strengthened in the last year" (final survey, own translation)
		PV as a means of communication	"I think, or I hope, that the module is simply a means of communication. That it helps to exchange ideas. So in general it is simply an impulse for something new and can simply open doors for all kinds of things" (interview 17, own translation)
Energy behavior	T1	Experience of energy topics	"The energy issue is part of environmental issues, but it doesn't come intrinsically from my interest. But, it's part of the process that you deal with it because it has an effect. Exactly, but it's not that the energy topic catches me, because that is simply too little tangible and you can't touch it …" (Interview 2, own translation) "My basic values are very ecologically oriented. I started with nutrition and consumption and all kinds of other things, simply because I'm not interested in technology" (Interview 3, own translation)
	T2	Adoption of energy behavior	"I have optimized my power consumption and switched consumers (dishwasher/washing machine) on at sunshine when the module generates a lot of power. I also looked around the house to see what else could be switched off temporarily" (final survey, own translation) "Attempt to save energy through the module. Not turning on electrical devices until power comes on. Being more aware of how to use them" (final survey, own translation)
		Energy saving measures	"I looked at all of the 40 light bulbs in my large family apartment to see what bulbs are in them and what they consume. I replaced some with LED-lamps, and changed others so that the very old energy-saving bulbs are where they are very rarely used" (final survey, own translation)
		Sensitization effects	"Initially, nothing has changed, because the power output of the module was too small … after a few months I have nevertheless begun to use electrical energy purposefully when the sun is out, since there are also several (larger) PV plants in our environment, which produce then energy" (final survey, own translation) Although the output of the module was mostly too low to be able to cook or wash completely self-sufficient, my awareness of the fluctuation of renewables has nevertheless increased. I consciously used electrical appliances such as dishwasher or washing machine during the day. (final survey, own translation)

Table 3 (continued)

Factor	Time	Object of matter	Quote
Knowledge	T1	Lack of knowledge/barriers	"To be honest, I have never heard of this balcony module before. I knew PV only on the roof … but that there are such small modules for the household, I was not aware of it and so I just found it exciting" (interview 10, own translation) "And there came the solar panel as called. Because I had already thought about it and thought about buying one myself, but then I had too many doubts...starting with which panel to buy and continuing with the installation. If I had bought one of those things myself, I think I would have really despaired" (Interview 8, own translation)
		Expectation of new knowledge through experience	Kilowatt hours, that is a term, but how much it is exactly? I think many can not grasp it. If you haven't taken the advanced physics-class or studied astrophysics yes… . I'm honest, I don't need it in everyday life very often... if after a year I know better, that is also already an added value for me (interview 10, own translation) "When I have facts in my hand, then it becomes tangible for me and then I can tell something about it. Otherwise, it's, jus theoretical expertise, yes? I think, I just have to know how it works, what happens in use, then I can tell something about it" (Interview 09, own translation)
	T2	New expertise and engagement	"We now talk about the topic more often because we can also have a say through the module, exchange ideas, etc. In the past, PV was not really a topic that was talked about" (final survey, own translation) "The topic interested me before, but I had the feeling I couldn't have a say—now we have our own experiences to share, e.g. with neighbors" (final survey, own translation)
		Better understanding	"I know from almost all devices how much electricity they consume and use them consciously" (final survey, own translation) "PV to touch, try out, experience for yourself" (final survey, own translation)
Self-efficacy	T1	Perceived (limited) possibilities	"I have always kind of flirted with such things, how could we save energy? For example heat pump, hot water generation, solar power, but it was always like, well, you're just a tenant here first, you can't determine it yourself…" (Interview 9, own translation) "I honestly didn't know that you can also take individual modules with you. Because especially if you don't yet have a permanent residence and only live in rented accommodation, you don't really think about it" (Interview 2, own translation).
	T2	Experience of new possibilities to contribute	"that I generate my own electricity and can thus make a small contribution to the energy transition" (final survey, own translation) I felt more involved because I can contribute something myself" (final survey, own translation)
		PV as a facilitator for ones' own self-efficacy	"Photovoltaics have become a much more important part of the energy transition for me, because you can also make a difference yourself" (final survey, own translation) "The subject of photovoltaics can be made easily accessible to everyone with such a module" (final survey, own translation)

Table 3 (continued)

Factor	Time	Object of matter	Quote
Role perception	T1	Assigned tasks to official stakeholders	"There has to be interaction between industry and politics, otherwise the bottom line is nothing. Politicians have to set guidelines and create the framework conditions and industry has to go along with it and also make their contribution" (interview 04, own translation) "Basically, I don't think that the market regulates everything and that for some things, such as the energy transition here, there simply have to be government guidelines. And that it is the task of politics to create that framework" (interview 9, own translation) "And that's where I think research would be needed, behavioral research. What does that do to people? Which path is actually the one that gets us to our goal faster? … I think there needs to be more research than on the technical side" (Interview14, own translation)
	T2	Discovered new possibilities	" With this balcony solar system one also serves as a role model and that it is more than "just" having renewable energies for oneself, but that it can also motivate others to think about it and possibly provide an impetus for other people to rethink" (final survey, own translation). "You can simply start on a small scale and if everyone does a little, then I think we can achieve quite a lot. And then everyone gets a direct connection to the topic and can produce themselves, i.e. take action themselves. Then maybe this hurdle is not so big anymore, to think about it in a positive way" (interview 14, own translation).
		Taking up new roles	"With this balcony solar system one also serves as a role model and that it is more than "just" having renewable energies for oneself, but that it can also motivate others to think about it and possibly provide an impetus for other people to rethink" (final survey, own translation). "I was taken to the owners' meeting by my mother (living in a big housing complex with 144 apartments). There I clearly demanded that PV systems or even balcony modules should be purchased" (final survey, own translation).

use. We hope that future studies can build upon and refine our approaches further.

When reflecting on whether the concept of role change is suitable for measuring the impact of real-world labs, it proves helpful to contribute to the research gap of depicting transition processes at an individual level (Bögel and Upham 2018; Kaufman et al. 2021). We therefore regard it as a useful approach that will enrich the ongoing discussion and "one piece of the puzzle" on the way to a deeper understanding of complex societal transformation processes.

Appendix

See Table 2 and 3, Fig. 8, Final survey (Questions)

Final survey after 12 months of "Your Balcony Network"

Dear participants,

For 12 months now, you have had your balcony modules at home and mostly in operation. We are happy that we have been experimenting together for so long! We hope it was an exciting time full of new experiences for you and perhaps it was an inspiration to make some changes. In this final survey, we would like to look back on the last year together with you and find out what influence the experiment had on you and your environment, to what extent your expectations of the project were fulfilled, and how you evaluate the exchange with the group. The survey is, so to speak, the conclusion of a year and is something like the counterpart of the interviews we conducted with you at the beginning. Therefore, this survey is a bit longer; please allocate 30–45 min to answer everything at your own pace. The answers are an important part of our accompanying

research and final evaluation, so we hope for your active participation.

Thank you for your participation!

- Please enter your participant number.

Changes at the personal level

- What has changed in your everyday life as a result of the balcony module? For example, have certain routines changed, or have new patterns of use emerged? If so, please describe this change. YES/NO
  - If yes, did this change affect only one person at a time or multiple, family WG members?
- Did the experiment open up new perspectives on the energy transition for you, such as accessibility/proximity to everyday life, self-efficacy? YES/NO
  - If yes, which ones?
- Did the experiment open up new perspectives for you on climate change in particular or sustainability in general? YES/NO
  - If yes, which ones?
- Did your participation in the experiment change your attitude towards the use of photovoltaics? YES/NO
  - If yes, how?
- Do you remember any specific thoughts, conversations or situations that changed your perspective about using PV? If so, can you describe them?
- Have you purchased more solar panels, an electric car, new more fuel-efficient electric appliances or the like in the last year? YES/NO
  - If yes, how did the participation in the experiment influence this?

Changes in the social environment

- How has installing the module changed your balcony or outdoor space (e.g., structural changes, change in outdoor space use, etc.)?
- Did the way you talk about photovoltaics or the energy transition with family, friends. or acquaintances change in the course of the experiment? If yes, to what extent?
- How did your environment (family, friends, acquaintances …) react to the balcony module? If you can remember individual comments or situations, please note them down.
- Have changes in your personal environment (family, friends …) occurred at the time of the experiment? Have e.g. family or friends changed their views on the topics of energy transition, solar energy use, saving energy …? Were solar systems, electric cars, new economical electrical appliances purchased in your environment, and if so, were you able to support these changes through your experiences?

Reflecting expectations of the project

- Looking back after 12 months with the balcony module, which expectations have been fulfilled for you and which have not?
- In your opinion, what are the biggest advantages and disadvantages of a balcony module?
- Did you observe any effects in connection with the experiment that you would not have expected beforehand (positive, negative, or neutral effects)?

Influence of group and networking

- Did the exchange within the "Your Balcony network"-group (analog/workshops or digital/forum) help you to implement your experiment? If yes, for which topics was an exchange particularly helpful, and what helped them most?
- What do you appreciate about the exchange in the group?
- What bothers you about exchange within the group?
- In "Your Balcony Network" one of our goals was to address and involve women in particular. In your opinion, to what extent has this been successful? What has worked well and what needs to be improved?

Recommendations

- Would you buy another balcony module at the end of the project? Please give reasons for your decision.
- What else would you like to share with us?

Done—Thank you for your participation in the survey!

Declarations

Conflict of interest The authors declare no competing interests.

Informed consent The participants of the real-world experiment "Your Balcony network" have given their written consent that the data conducted in the experiment can be used for scientific purposes.

References

Albiez M, Stelzer V, Parodi O, Bögel PM, Trenks H (2022) Energiewende nah an Mensch und Alltag. Energiewirtschaftliche Tagesfragen 6:31–33

Arnold A, Piontek FM (2018) Zentrale Begriffe im Kontext der Reallaborforschung. In: Di Giulio A (ed) Transdisziplinär und Transformativ Forschen Eine Methodensammlung. Springer Fachmedien Wiesbaden GmbH, Wiesbaden, pp 143–154

Augenstein K, Bögel PM, Levin-Keitel M, Trenks H (2022a) Wie entfalten Reallabore Wirkung für die Transformation? Eine Embedded Agency Perspective zur Analyse von Wirkmechanismen in Reallaboren. GAIA Ecol Perspect Sci Soc. https://doi.org/10.14512/gaia.31.4.4

Augenstein K, Bögel PM, Levin-Keitel M, Trenks H (2022b) Wie entfalten Reallabore Wirkung für die Transformation? Supplementary Material. Das Realexperiment Dein BalkonNetz - Energie schafft Gemeinschaft. GAIA Ecol Perspect Sci Soc. https://doi.org/10.14512/gaia.31.4.4. https://www.oekom.de/_uploads_media/files/augenstein_et_al_wirkmechanismen_reallabore_supplementary_material_021142.pdf

Avelino F, Wittmayer JM (2016) Shifting power relations in sustainability transitions: a multi-actor perspective. J Environ Plann Policy Manag 18(5):628–649. https://doi.org/10.1080/1523908X.2015.1112259

Bauwens T, Schraven D, Drewing E, Radtke J, Holstenkamp L, Gotchev B, Yildiz Ö (2022) Conceptualizing community in energy systems: a systematic review of 183 definitions. Renew Sustain Energy Rev 156:111999. https://doi.org/10.1016/j.rser.2021.111999

Beecroft R, Parodi O (2016) Reallabore als Orte der Nachhaltigkeitsforschung und Transformation. TATuP Zeitschrift Für Technikfolgenabschätzung in Theorie Und Praxis 25(3):4–8. https://doi.org/10.14512/tatup.25.3.4

Beecroft R, Trenks H, Rhodius R, Benighaus C, Parodi O (2018) Reallabore als Rahmen transformativer und transdisziplinärer Forschung: Ziele und Designprinzipien. In: Di Giulio A (ed) Transdisziplinär und Transformativ Forschen Eine Methodensammlung. Springer Fachmedien Wiesbaden GmbH, Wiesbaden, pp 75–100

Bergmann M, Brohmann B, Hofmann E, Loibl MC, Rehaag R, Schramm E, Voß JP (2005) Quality criteria of transdisciplinary research: a guide for the formative evaluation of research projects

Bergmann M, Schäpke N, Marg O, Stelzer F, Lang DJ, Bossert M, Gantert M, Häußler E, Marquardt E, Piontek FM, Potthast T, Rhodius R, Rudolph M, Ruddat M, Seebacher A, Sußmann N (2021) Transdisciplinary sustainability research in real-world labs: success factors and methods for change. Sustain Sci 16(2):541–564. https://doi.org/10.1007/s11625-020-00886-8

Biddle BJ (1979) Role theory: expectations. Identities and behaviors. Academic Press, p 416

Biddle BJ (1986) Recent developments in role theory. Ann Rev Sociol 12(1):67–92. https://doi.org/10.1146/annurev.so.12.080186.000435

BMWI (2021) Reallabore als Testräume für Innovation und Regulierung: thematisches Screening für Experimentierklauseln in Technologie- und Innovationsfeldern

Bögel PM, Upham P (2018) Role of psychology in sociotechnical transitions studies: Review in relation to consumption and technology acceptance. Environ Innov Soc Trans 28:122–136. https://doi.org/10.1016/j.eist.2018.01.002

Bögel PM, Pereverza K, Upham P, Kordas O (2019) Linking sociotechnical transition studies and organisational change management: steps towards an integrative, multi-scale heuristic. J Clean Prod 232:359–368. https://doi.org/10.1016/j.jclepro.2019.05.286

Bögel PM, Upham P, Shahrokni H, Kordas O (2021) What is needed for citizen-centered urban energy transitions: Insights on attitudes towards decentralized energy storage. Energy Policy 149:112032. https://doi.org/10.1016/j.enpol.2020.112032

Bögel PM, Augenstein K, Levin-Keitel M, Upham P (2022) An interdisciplinary perspective on scaling in transitions: connecting actors and space. Environ Innov Soc Trans 42:170–183. https://doi.org/10.1016/j.eist.2021.12.009

Bögel PM, Trenks H, Upham P, Sauter H, Albiez M, Stelzer V, Laborgne P (2023) Diversifying power in action: A socio-psychological approach to inclusive energy transition experiments. Energy Res Soc Sci 48:103070

Bohnsack R (2014) Narratives interview. In: Ralf Bohnsack (ed) Rekonstruktive Sozialforschung. Einführung in qualitative Methoden, 9th ed. Opladen, Verlag Barbara Budrich, pp 93–105

Burke MJ, Stephens JC (2017) Energy democracy: goals and policy instruments for sociotechnical transitions. Energy Res Soc Sci 33:35–48. https://doi.org/10.1016/j.erss.2017.09.024

Carter MAT, Cook K (1995) Adaptation to retirement: role changes and psychological resources. Career Dev Quar 44(1):67–82. https://doi.org/10.1002/j.2161-0045.1995.tb00530.x

Charli-Joseph L, Siqueiros-Garcia JM, Eakin H, Manuel-Navarrete D, Shelton R (2018) Promoting agency for social-ecological transformation: a transformation-lab in the Xochimilco social-ecological system. Ecol Soc. https://doi.org/10.5751/ES-10214-230246

Coenen L, Benneworth P, Truffer B (2012) Toward a spatial perspective on sustainability transitions. Res Policy 41(6):968–979. https://doi.org/10.1016/j.respol.2012.02.014

Colasante A, D'Adamo I, Morone P (2022) What drives the solar energy transition? The effect of policies, incentives and behavior in a cross-country comparison. Energy Res Soc Sci 85:102405. https://doi.org/10.1016/j.erss.2021.102405

de Roeck F, van Poeck K (2023) Agency in action: towards a transactional approach for analyzing agency in sustainability transitions. Environ Innov Soc Trans 48:100757. https://doi.org/10.1016/j.eist.2023.100757

DeHaan FJ, Rotmans J (2018) A proposed theoretical framework for actors in transformative change. Technol Forecast Soc Change 128:275–286. https://doi.org/10.1016/j.techfore.2017.12.017

Elliott R, Wattanasuwan K (eds) (1998) Consumption and the symbolic project of the self. Association for Consumer Research, Provo

Fischer L-B, Newig J (2016) Importance of actors and agency in sustainability transitions: a systematic exploration of the literature. Sustainability 8(5):476. https://doi.org/10.3390/su8050476

Frick J, Kaiser FG, Wilson M (2004) Environmental knowledge and conservation behavior: exploring prevalence and structure in a representative sample. Pers Indiv Differ 37(8):1597–1613. https://doi.org/10.1016/j.paid.2004.02.015

Geels FW (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res Policy 31(8–9):1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels FW (2011) The multi-level perspective on sustainability transitions: responses to seven criticisms. Environ Innov Soc Trans 1(1):24–40. https://doi.org/10.1016/j.eist.2011.02.002

Groß M (2015) Realexperimente. Ökologische Gestaltungsprozesse in der Wissensgesellschaft. Bielefeld, transcript

Hamann KRS, Bertel MP, Ryszawska B, Lurger B, Szymański P, Rozwadowska M, Goedkoop F, Jans L, Perlaviciute G, Masson T, Fritsche I, Favaro T, Hofer A, Eisenberger I, Gutschi C, Grosche C, Held J, Athenstaedt U, Corcoran K (2023) An interdisciplinary understanding of energy citizenship: integrating psychological, legal, and economic perspectives on a citizen-centred sustainable energy transition. Energy Res Soc Sci 97:102959. https://doi.org/10.1016/j.erss.2023.102959

Hauck J, Omann I, Thronicker I, Spekkink W, Díaz Ayude A, Maricchiolo F, Mock M, Quist J, Pandur V (2020) Understanding actor roles in sustainability initiatives: An exploratory study in five European countries. Helmholtz-Zentrum für Umweltforschung (UFZ), Leipzig. UFZ Discussion Paper No. 2/2020. http://hdl.handle.net/10419/214913

Hewitt RJ, Bradley N, Baggio Compagnucci A, Barlagne C, Ceglarz A, Cremades R, McKeen M, Otto IM, Slee B (2019) Social innovation in community energy in Europe: a review of the evidence. Front Energy Res. https://doi.org/10.3389/fenrg.2019.00031

Hilbert RA (1981) Toward an improved understanding of 'role.' Theory Soc 10(2):207–226

Hilger A, Rose M, Wanner M (2018) Changing faces—factors influencing the roles of researchers in real-world laboratories. GAIA Ecol Perspect Sci Soc 27(1):138–145. https://doi.org/10.14512/gaia.27.1.9

Hilger A, Rose M, Keil A (2021) Beyond practitioner and researcher: 15 roles adopted by actors in transdisciplinary and transformative research processes. Sustain Sci. https://doi.org/10.1007/s11625-021-01028-4

Huning S, Räuchle C, Fuchs M (2021) Designing real-world laboratories for sustainable urban transformation: addressing ambiguous roles and expectations in transdisciplinary teams. Sustain Sci 16(5):1595–1607. https://doi.org/10.1007/s11625-021-00985-0

Huttunen S, Kaljonen M, Lonkila A, Rantala S, Rekola A, Paloniemi R (2021) Pluralising agency to understand behaviour change in sustainability transitions. Energy Res Soc Sci 76:102067. https://doi.org/10.1016/j.erss.2021.102067

Jenkins K, McCauley D, Heffron R, Stephan H, Rehner R (2016) Energy justice: a conceptual review. Energy Res Soc Sci 11:174–182. https://doi.org/10.1016/j.erss.2015.10.004

Kampfmann T, Bernert P, Lang DJ (2022) Toward a modular evaluation approach of real-world laboratories: findings from a literature review. Res Eval. https://doi.org/10.1093/reseval/rvac029

Kaufman S, Saeri A, Raven R, Malekpour S, Smith L (2021) Behaviour in sustainability transitions: a mixed methods literature review. Environ Innov Soc Trans 40:586–608. https://doi.org/10.1016/j.eist.2021.10.010

Köhler J, Geels FW, Kern F, Markard J, Onsongo E, Wieczorek A, Alkemade F, Avelino F, Bergek A, Boons F, Fünfschilling L, Hess D, Holtz G, Hyysalo S, Jenkins K, Kivimaa P, Martiskainen M, McMeekin A, Mühlemeier MS, Nykvist B, Pel B, Raven R, Rohracher H, Sandén B, Schot J, Sovacool B, Turnheim B, Welch D, Wells P (2019) An agenda for sustainability transitions research: state of the art and future directions. Environ Innov Soc Trans 31:1–32. https://doi.org/10.1016/j.eist.2019.01.004

Kok KPW, van der Meij MG, Wagner P, Cesuroglu T, Broerse JEW, Regeer BJ (2023) Exploring the practice of Labs for sustainable transformation: the challenge of 'creating impact.' J Clean Prod 388:135994. https://doi.org/10.1016/j.jclepro.2023.135994

Kuckartz U, Rädiker S (2022) Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung: Grundlagentexte Methoden, 5th edn. Beltz Juventa, Weinheim/Basel

Lang DJ, Wiek A, Bergmann M et al (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci 7(Suppl 1):25–43. https://doi.org/10.1007/s11625-011-0149-x

Liedtke C, Baedeker C, Hasselkuß M, Rohn H, Grinewitschus V (2015) User-integrated innovation in Sustainable LivingLabs: an experimental infrastructure for researching and developing sustainable product service systems. J Clean Prod 97:106–116. https://doi.org/10.1016/j.jclepro.2014.04.070

Loorbach D (2007). Transition management. New mode of governance for sustainable development: nieuwe vorm van governance voor duurzame ontwikkeling = Transitiemanagement. Zugl.: Rotterdam, Erasmus-Univ., Diss., 2007. Utrecht, Internat. Books

Loorbach D (2010) Transition management for sustainable development: a prescriptive. Complex-based govern framework. Governance 23(1):161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x

Lowitzsch J (2019) Introduction: the challenge of achieving the energy transition. In: Lowitzsch J (ed) Energy transition. Springer International Publishing, Cham, pp 1–26

McCrory G, Schäpke N, Holmén J, Holmberg J (2020) Sustainability-oriented labs in real-world contexts: an exploratory review. J Clean Prod 277:123202. https://doi.org/10.1016/j.jclepro.2020.123202

Meyer-Soylu S, Parodi O, Trenks H, Seebacher A (2016) Das Reallabor als Partizipationskontinuum. TATuP Zeitschrift Für Technikfolgenabschätzung in Theorie Und Praxis 25(3):31–40. https://doi.org/10.14512/tatup.25.3.31

Miller CA, Iles A, Jones CF (2013) The social dimensions of energy transitions. Sci Cult 22(2):135–148. https://doi.org/10.1080/09505431.2013.786989

Nevens F, Frantzeskaki N, Gorissen L, Loorbach D (2013) Urban transition Labs: co-creating transformative action for sustainable cities. J Clean Prod 50:111–122. https://doi.org/10.1016/j.jclepro.2012.12.001

Parodi O, Albiez M, Meyer-Soylu S, Waitz C (2016) "District future—urban lab" a real urban transition lab. In: Albiez M, Banse G, Lindeman KC et al (eds) Designing sustainable urban futures : concepts and practices from different countries. KIT Scientific Publishing, pp 45–65

Parodi O, Beecroft R, Albiez M, Quint A, Seebacher A, Tamm K (2017) The ABC of real-world lab methodology—from "action research" to "participation" and beyond. Trialog, pp 74–82

Parodi O, Steglich A, Bylund J (2023a) Real-world lab. In: Thorsten P, Tobias S (eds) Handbook transdisciplinary learning. Transcript Verlag, Bielefeld

Parodi O, Schwichtenberg R, Stelzer F, Rhodius R, Schreider C, Wirth T von, Lang DJ, Marg O, Wagner F, Egermann M, Bauknecht D, Wanner M (2023b) Stellungnahme des Netzwerks Reallabore der Nachhaltigkeit zur Reallabore-Gesetz-Initiative. GAIA 32/4(2023):399–401. https://doi.org/10.14512/gaia.32.4.14

Pesch U (2015) Tracing discursive space: agency and change in sustainability transitions. Technol Forecast Soc Chang 90:379–388. https://doi.org/10.1016/j.techfore.2014.05.009

Radtke J, Drewing E (2020) Technokratie oder Gemeinschaftswerk? TATuP Zeitschrift Für Technikfolgenabschätzung in Theorie Und Praxis 29(3):36–42. https://doi.org/10.14512/tatup.29.3.36

Räuchle C, Stelzer F, Zimmer-Hegmann R (2021) Urbane Reallabore im Kontext von transdisziplinärer Stadtforschung und

Planungswissenschaft. Raumforschung Und Raumordnung Spatial Research and Planning 79(4):287–290. https://doi.org/10.14512/rur.139

Ryghaug M, Skjølsvold TM, Heidenreich S (2018) Creating energy citizenship through material participation. Soc Stud Sci 48(2):283–303. https://doi.org/10.1177/0306312718770286

Schäfer M, Bergmann M, Theiler L (2021) Systematizing societal effects of transdisciplinary research. Res Eval. https://doi.org/10.1093/reseval/rvab019

Schäpke N, Bergmann M, Stelzer F, Lang DJ (2018a) Labs in the real world: advancing transdisciplinary research and sustainability transformation: mapping the field and emerging lines of inquiry. GAIA Ecol Perspect Sci Soc 27(1):8–11. https://doi.org/10.14512/gaia.27.S1.4

Schäpke N, Stelzer F, Caniglia G, Bergmann M, Wanner M, Singer-Brodowski M, Loorbach D, Olsson P, Baedeker C, Lang DJ (2018b) Jointly experimenting for transformation? Shaping real-world laboratories by comparing them. GAIA Ecol Perspect Sci Soc 27(1):85–96. https://doi.org/10.14512/gaia.27.S1.16

Schimank U (2016) Handeln und Strukturen. Einführung in die akteur-theoretische Soziologie, 5th edn. Beltz, Weinheim

Schneidewind U (2014) Urbane Reallabore—ein Blick in die aktuelle Forschungswerkstatt. Pnd online III.

Schneidewind U, Augenstein K, Stelzer F, Wanner M (2018) Structure matters: real-world laboratories as a new type of large-scale research infrastructure: a framework inspired by Giddens' structuration theory. GAIA Ecol Perspect Sci Soc 27(1):12–17. https://doi.org/10.14512/gaia.27.S1.5

Schreuer A, Mert W, Bohunovsky L, Grünberger S, Omann I, Ninaus J, Punzenberger J (2020) BENE—BürgerEngagement für Nachhaltige Energie

Singer-Brodowski M, Beecroft R, Parodi O (2018) Learning in real-world laboratories: a systematic impulse for discussion. GAIA Ecol Perspect Sci Soc 27(1):23–27. https://doi.org/10.14512/gaia.27.S1.7

Steg L, Perlaviciute G, van der Werff E (2015) Understanding the human dimensions of a sustainable energy transition. Front Psychol. https://doi.org/10.3389/fpsyg.2015.00805

Tjørring L (2016) We forgot half of the population! The significance of gender in Danish energy renovation projects. Energy Res Soc Sci 22:115–124. https://doi.org/10.1016/j.erss.2016.08.008

Turner RH (1990) Role change. Ann Rev Sociol 16(1):87–110. https://doi.org/10.1146/annurev.so.16.080190.000511

van den Bosch S, Rotmans J (2008) Deepening, broadening and scaling up: a framework for steering transition experiments. Dutch Research Institute for Transition

van der Schoor T, Scholtens B (2019) The power of friends and neighbors: a review of community energy research. Curr Opin Environ Sustain 39:71–80. https://doi.org/10.1016/j.cosust.2019.08.004

van Veelen B, van der Horst D (2018) What is energy democracy? Connecting social science energy research and political theory. Energy Res Soc Sci 46:19–28. https://doi.org/10.1016/j.erss.2018.06.010

von Wirth T, Levin-Keitel M (2020) Lokale Nachhaltigkeitsexperimente als raumwirksame interventionen: theoretische grundlagen und handlungskonzepte. GAIA Ecol Perspect Sci Soc 29(2):98–105. https://doi.org/10.14512/gaia.29.2.7

Wahlund M, Palm J (2022) The role of energy democracy and energy citizenship for participatory energy transitions: a comprehensive review. Energy Res Soc Sci 87:102482. https://doi.org/10.1016/j.erss.2021.102482

Wanner M, Hilger A, Westerkowski J, Rose M, Stelzer F, Schäpke N (2018) Towards a cyclical concept of real-world laboratories. disP Plan Rev 54(2):94–114. https://doi.org/10.1080/02513625.2018.1487651

WBGU (2011) Welt im Wandel. Gesellschaftsvertrag für eine Große Transformation ; Hauptgutachten. 2nd ed. Berlin, Wiss. Beirat der Bundesregierung Globale Umweltveränderungen (WBGU)

WBGU (2016) Der Umzug der Menschheit. Die transformative Kraft der Städte ; Hauptgutachten. Berlin, Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen

Weik E (2012) Introducing "the creativity of action?" Into institutionalist theory. Management 15(5):564. https://doi.org/10.3917/mana.155.0564

Wittmayer JM, Avelino F, van Steenbergen F, Loorbach D (2017) Actor roles in transition: Insights from sociological perspectives. Environ Innov Soc Trans 24:45–56. https://doi.org/10.1016/j.eist.2016.10.003