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On the Future(s) of Energy Communities in the German Energy Transition: A Derivation of Transformation Pathways

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Abstract: Active participation of citizens in the sustainable energy transition—particularly in energy communities—is explicitly desired by the European Union and considered vital for a successful transformation of Europe's energy system. Currently, energy communities, i.e., citizen-led groups generating energy from renewable sources can be found across Europe, though current numbers are small. However, it is expected that the majority of EU households will be active in some form in the generation of energy by 2050. In order to understand how such a development could come about, and if desired, how it could be ensured, we developed and applied a quasi-dynamic model using the Cross-Impact Balance (CIB) approach and with it analyzed and assessed such a transition in detail. Data for the CIB model was derived from case studies, interviews, three surveys including two discrete choice experiments, expert workshops, and complementary secondary data. A central consideration of the model is a differentiated representation of the heterogeneity of actors in society and their interactions. Main results obtained from the application of the model are possible transformation pathways of citizen participation in the energy transition of Germany. A key finding was that if current trends continue, a citizen-driven energy transition based on energy communities will unlikely be successful. We conclude that several framework conditions must change simultaneously from the status quo so that different social groups in society can be active in the generation of energy. These include changes such as the abolition of hindering regulations and the expansion of financial support schemes with a focus on lower socioeconomic groups. Furthermore, only in a combination of conducive social factors such as neighborhood cohesion and conducive social influence, as well as favorable economic conditions, can energy communities become an important player in Germany's future energy system.

Keywords: energy transition; citizen participation; local energy communities; renewable energy; energy cooperatives; cross-impact balance analysis

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1. Introduction

Active and collaborative participation of citizens, particularly within energy communities, i.e., citizen-led groups generating renewable energy, is considered a vital pillar for a successful and sustainable energy transition as envisioned by the European Union (EU). This is explicitly reflected, among other, in the recent EU "Clean energy for all Europeans package" of 2019 [1], and especially in two of its recast directives [2]: the Renewable Energy Directive (Directive (EU) 2018/2001; RED II) [3] and the Internal Electricity Market Directive (Directive (EU) 2019/944; IEMD) [4].

From a policymaker's perspective, such citizen participation is vital as it is expected to further increase public acceptance of renewable energy projects and the sustainable energy transition [2,5]. Citizen participation is also expected to attract private investments in the sustainable energy transition [2], that is, close the investment gap in renewable energy

developments in the EU [6], and it bears the potential for advancing renewable energy technologies [7]. Energy communities have been shown to increase awareness, knowledge, and intention to adopt low-carbon technologies and other sustainable measures [8–10]. More broadly, the potential for spillover effects resulting in the adoption of further energy-relevant or sustainable measures and behaviors is also high in energy communities [11].

Key to success, however, is large-scale participation in such energy communities irrespective of socio-economic circumstances, as this is the only way to involve large segments of the population and geography, thus helping to ensure a just energy transition [12]. Energy communities do indeed hold the potential for such social inclusion of lower-income social groups [3]. This includes tenants and people who do not have the option to install individual renewable energy systems because of their situation or location (e.g., position of the house, restrictions due to national heritage laws). Additionally, energy communities have the potential to provide a platform for individuals with limited financial means [13] and debt aversion to become involved in the energy transition because of lowered financial entry hurdles (for an exploration of the detrimental effect of debt aversion on energy-relevant investments using the example of adoption of retrofit measures by homeowners, see [14]). To an extent, energy communities (and individually-owned renewable energy systems) might offer protection from future energy price uncertainty.

Currently, energy communities can be found across Europe and beyond [15]. Though present numbers are very small, Germany has a comparatively large number of energy communities in the EU, with approximately 1750 [16]. Furthermore, Germany also shows a considerable variety of energy communities [17] and a large share in renewable electricity generation capacity owned by private citizens (30.2% in 2019) [18]. Going forward, it is estimated that renewable energy systems (RES) owned by citizens could cover up to 45% of the EU's electricity demand by 2050 [19], of which 37% could be produced in energy communities [19]. (Data on the share of citizens and energy communities that provide heat from renewable energy sources are harder to come by. Overall, the share of renewable energy sources in the heating (and cooling) sector is lagging behind compared with their share in electricity generation in Europe [20]. This varies significantly among the EU member states. Germany currently ranks among the last in Europe in terms of heating generated from renewable energy sources [20]. In 2019, only 14.7% of overall heating and cooling was based on renewable energy in Germany, while 42.1% of the electricity demand was covered by renewables [21].) Kampman et al. [22] estimated that more than 80% of EU households (individually or in energy communities) could be active in the generation of energy (this is based on data of people's attitudes and their financial capabilities to act upon them) [22]. Current research, however, does not specify what such a transition would look like in detail, and if desired, how this shift toward energy communities could be supported.

At present, no studies exist that identify transformation pathways for citizens' participation in general, and energy community participation in particular, for an entire country's society that does not focus on one specific renewable energy technology. Some agent-based modeling (ABM) approaches exist that identify specific cases of photovoltaic systems (PV) adoption by single households or as a community (e.g., [23–26]), or the formation of thermal energy communities [27]. In a recent study [28], transformation pathways for one German bioenergy town were described on an aggregated level using cross-impact balance (CIB) analysis.

To address this research gap, we developed a quasi-dynamic model using a CIB approach to identify scenarios and transformation pathways of citizen participation in the sustainable energy transition in Germany up to 2040. This approach allowed us to develop future scenarios in a model that includes different actions of heterogeneous actors, framework conditions, and mutual influences of all these factors. CIB as such is not dynamic [29], since it does not consider a time dimension. However, we further developed the CIB method for this study to make it quasi-dynamic by considering several points in time and stringing together scenarios.

A central consideration of our model is a differentiated (albeit simplified) representation of the heterogeneity of citizens in society. Studies [30–35] that seek to characterize currently active individuals in the sustainable energy transition attest to the fact that those actively involved in the energy transition and especially in energy communities are a clearly definable group that represents only part of society. High levels of engagement have been associated with a green and alternative milieu, i.e., social group, characterized by, among others, pronounced environmental concern [35]. Furthermore, financial demands of active participation exclude some socio-economic groups. Thus, current conditions for participation in the energy transition are not favorable to all socio-economic groups. The predicted numbers of participation, however, would suggest that more, if not all, milieus will (or should) become active in the future to meet the EU-envisioned participation.

Overall, our study aimed to identify future scenarios and possible transformation pathways regarding citizen participation in the sustainable energy transition. To do so, we linked empirical data and the systematic qualitative scenario construction method CIB with concepts to characterize society. We sought to address the following research questions in this paper:

(1) Which factor constellations affect the formation of energy communities?
(2) What are possible scenarios that characterize the future of energy communities in Germany?
(3) What are possible transformation paths that characterize the development process toward these futures?

This paper is organized as follows. The next section provides an in-depth overview of the study design, data sources, and methodology applied. Section 3 outlines the results, followed by a discussion of the results in Section 4. Conclusions are outlined in Section 5.

2. Study Design, Data Sources, and Methods

In our analysis, we combined the CIB method (see Section 2.1) with several qualitative and quantitative data collection methods to construct a model which closely resembled the complex system under consideration. Traditionally, CIB has been employed to assess one single point in the future, and not the transition processes (e.g., [36]). We extended the CIB method to a quasi-dynamic model which allows the identification of viable future scenarios as well as transformation pathways.

We selected this method as we required a scenario construction approach, which enabled us to take dynamic aspects into consideration whilst allowing us to pay close attention to consistent settings of parameters and non-linearities (resulting, e.g., from tipping points). We also required our approach to be flexible enough to take micro-level factors (individuals' actions) and macro-level aggregates (actions by social groups) along with framework conditions into consideration. Furthermore, we needed an approach that could map the different scopes of action resulting from the heterogeneity of actors. Our quasi-dynamic CIB meets these needs.

Figure 1 illustrates the overall research design, the methodologies used, and steps taken within the CIB analysis. The following section and its four subsections discuss CIB's traditional steps (indicated in the center of Figure 1) and our approaches to them. The data sources we used are discussed within these sections, particularly Section 2.1.2. The CIB analysis usually ends with the selection of future scenarios. As indicated in Figure 1, we expanded the CIB methodology and went on to identify transformation pathways. Section 2.2 details this process.

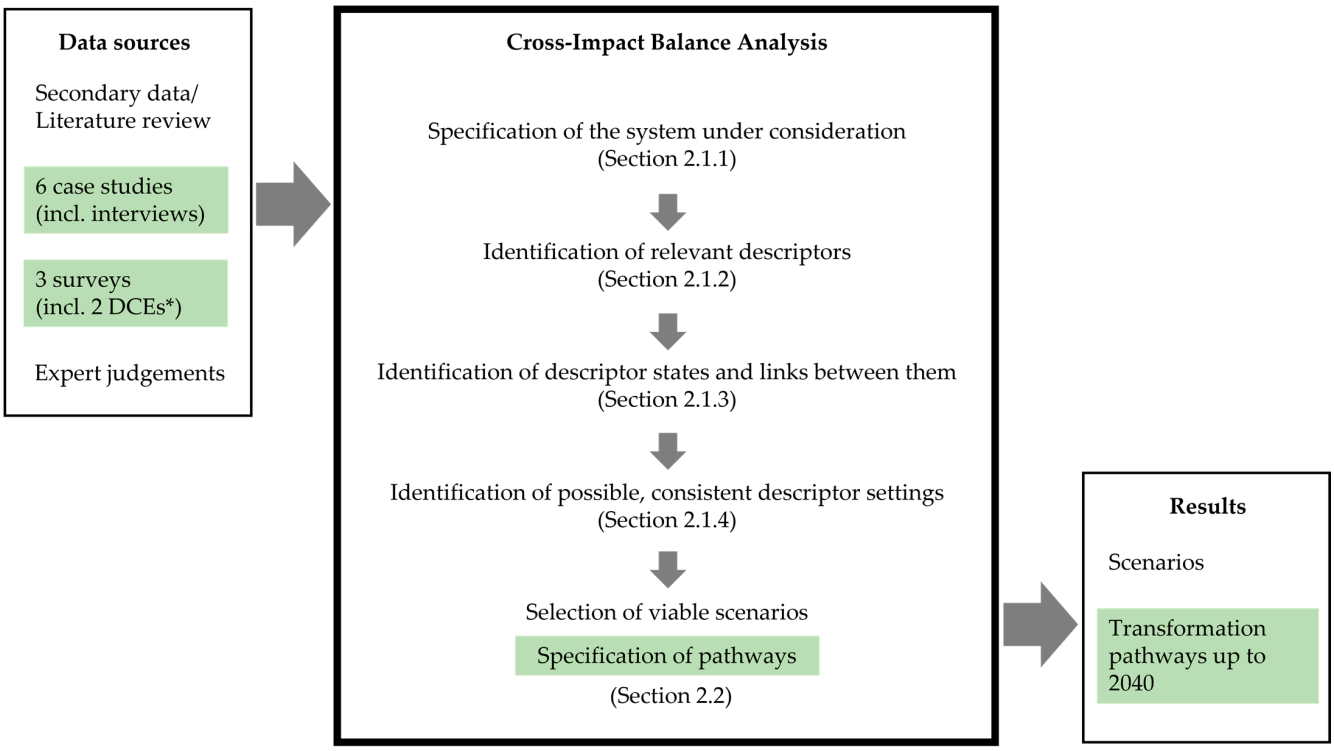

Figure 1. Research design and methodological approach.

2.1. CIB—The Methodology

CIB analysis is a method for the systematic construction of traceable qualitative and semi-quantitative scenarios, but also for qualitative network analysis [37,38]. CIB has been applied to a broad range of research questions, including the analyses of energy system transitions (see, e.g., [39–41]), studies on sustainability aspects [42], innovation [43], health care [44], and on climate change policies (e.g., [45,46]).

The conventional CIB approach is based on literature reviews and then expert judgments deciding on the selection of factors, i.e., descriptors that are relevant for the system under consideration, the possible states of descriptors, and the direct influences each state has on another state. In this study, however, we used results from case studies, surveys, and discrete choice experiments (DCE) for the selection of relevant descriptors, their states, and identification of interdependencies. Expert consultations assisted in the research and data collection. Any remaining data gaps were closed with secondary data identified via literature reviews. As a last step, expert judgements were employed as relevance and quality checks.

2.1.1. Specification of the System under Consideration

The part of the energy system of interest in this study was focused on the active roles of citizens in the energy system as depicted in the socio-technical energy system diagram in Figure 2. Thus, at the center of this study are citizens and their participation in the energy system and the energy system's transformation.

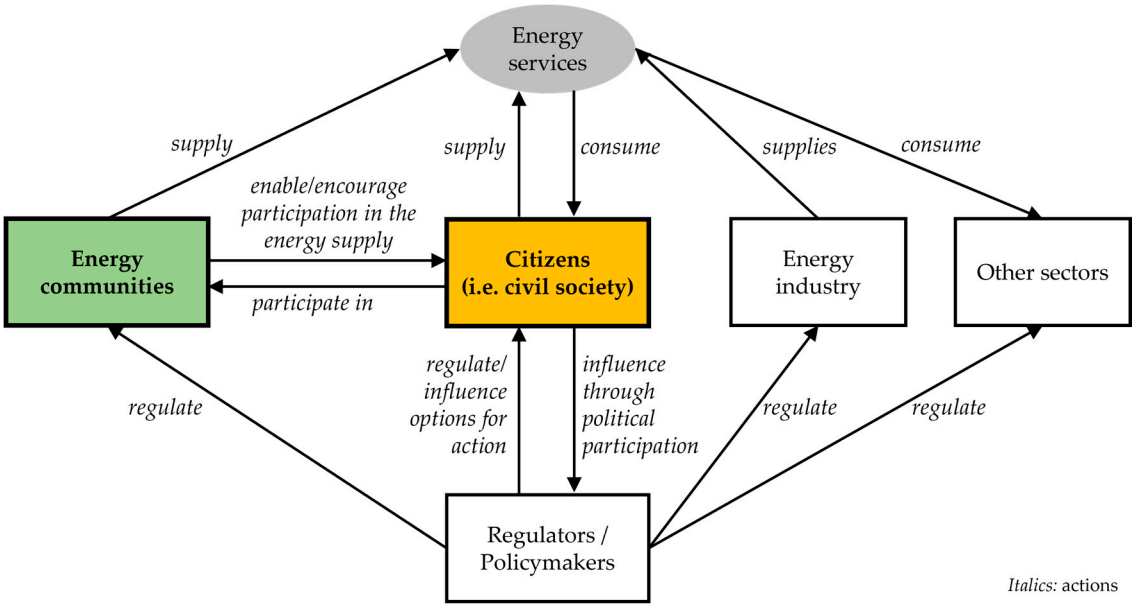

Figure 2. Citizens in an energy system.

As Stern [47] highlights, citizens interact with the energy system in various ways. They act as consumers of energy, as producers of energy, as citizens participating politically in the policy and regulatory environment of energy systems, as members of organizations, and as passive individuals that are affected by the energy system. In this study, we focused on citizens as prosumers, i.e., producers and consumers of energy, either individually or as members of prosuming energy communities. The decision to become a prosumer is that of an individual citizen (though it is probably influenced by others), but prosuming impacts their entire household. Therefore, the two terms are used somewhat interchangeably in this text.

Citizens can be prosumers by owning and operating their own energy system, e.g., a photovoltaic system. However, this requires homeownership, financial means, and favorable spatial conditions (e.g., a roof facing south, unobstructed). Energy communities make it possible for every citizen to be a co-owner of a renewable energy-generating system irrespective of financial, spatial, and other factors. Although we included in our analysis the possibility of citizens to be active alone, our particular interest was in joint activities, i.e., energy communities.

Furthermore, we narrowed the focus of the study down to local energy communities. Therefore, we excluded supraregional energy communities from our model.

A **local energy community** is defined here as an association of private households in a neighborhood (i.e., in each other's immediate vicinity) that jointly operate and use a spatially limited energy system based on sustainable energy sources (i.e., renewables).

EU directives RED II [3] and IEMD [4] define three types of collective forms of active citizen participation in the energy system: renewable energy communities, jointly acting renewable self-consumers, and citizen energy communities. Our definition includes aspects of all three. That is, the first two include the local aspect as well as the generation of heat and not just electricity, while the latter—citizen energy communities—focuses only on the electricity sector but is not restricted to generation of energy alone [48]. We refrained from using the energy community definitions by the EU as they were deemed too restrictive. Moreover, they were not adopted into German legislature [49] and do not reflect the realities of energy communities in Germany (cf. [11]), many of which were in existence before the EU's definitional differentiation was introduced (cf. [16]).

The focus on the local level is necessary; as Balest et al. [50] pointed out, a delimited territory is characterized by its local natural environment, technological development, economy, legislature, and social system. Through these subsystems, local territories play a

large role in shaping local energy systems. Likewise, actions by local citizens are influenced by their local territorial context (e.g., [51,52]). Consequently, different challenges arise for households when it comes to the sustainable transformation of their electricity and heat supply. At the local neighborhood level, however, these situations are more homogeneous. Neighborhoods are characterized by a similar building structure, similar ownership structures (or a dominant type of ownership), and they are shaped by certain milieus and have the same infrastructure and spatial conditions.

We focused on Germany for several reasons. First, Germany has well-established energy communities and a large share of privately owned renewable systems in the EU (as discussed in Section 1). Second, the CIB model needed to be kept operational by limiting the number of attributes, whilst at same time preventing the model from becoming too generic. Third, the diverse composition of energy communities in Germany ensures that findings are relevant beyond Germany. Results are, however, particularly relevant for other EU countries given the EU-wide regulatory framework. The approach developed and employed in this paper can be easily adapted to specifics (e.g., legislature, policies, and societal characteristics) of another country where the data allow.

2.1.2. Identification of Relevant Descriptors

To identify the relevant descriptors for the CIB model i.e., factors required to describe the system (see Section 2.1.1), we used primary and secondary data. We conducted case studies and interviews for qualitative data, and three surveys including two discrete choice experiments for quantitative data. We augmented this with information from the literature and with expert judgements by members of the practitioners advisory board of the project REsCO [53], consisting of consumer organizations for consumer protection, citizen-led local energy transitions, and for citizens active in solar energy, a state energy agency and an energy cooperative. Table 1 gives an overview of our main data sources. Through this process, we identified 28 descriptors, which can be grouped into two categories: citizens' actions and effects on different societal levels (category 1), as well as context factors (category 2). The two categories are described in the following two sections.

Table 1. Main data sources.

Source Type	Topic and Main Research Question(s)	Publications
Study A: 6 case studies incl. interviews (n = 31), May–November 2019	**Sustainable community projects in Germany:** What motivates people to participate? Why and how does a broad sustainability transformation come about?	[11]
3 surveys Study B: Quota sample German population (n = 3.043), January–Feburary 2020 Study C: Quota sample German population, incl. DCE (n = 1.500), October–November 2020 Study D: Quota sample German homeowners, incl. DCE (n = 1.600), March 2021	**Willingness to participate in a local energy community:** What predictors are relevant? **Characteristics of local energy communities:** Which characteristics are particularly relevant for the choice between different energy communities? **Individual prosumers vs. energy communities:** What type of participation is preferred? What factors are particularly relevant?	
Expert judgements	**Evaluation of factors' importance for the CIB model** by members of the practitioners advisory board of the project REsCO [53], consisting of consumer organizations for consumer protection, citizen-led local energy transitions, and for citizens active in solar energy, a state energy agency, and an energy cooperative	
Complementary secondary data (important external studies)	**Systematization of heterogeneity in society:** Social milieus framework by Sociodimensions **Value change and future values of German society**	[54,55] [56]

Remarks: Studies A–D were conducted in part to inform this study. Some results are already published, and others will be published in due course.

Descriptor Category 1: Actions and Effects on Different Societal Levels

Actors (i.e., citizens) and their actions are the central part of the model, as discussed in Section 2.1.1. Our data collection efforts resulted in two key findings regarding actors and their energy system-related activities. First, individuals' activities in energy systems are social, i.e., they are influenced by others and they in turn influence others with their actions, opinions, and recommendations (peer effects) (see studies A and D noted in Table 1, and also [11,57,58]). Second, studies A and B in Table 1 indicated that those currently already active in the energy system are a clearly definable part of society. Citizens active in local energy communities, as considered in study A, are predominantly upper-middle class, or older and have amassed the necessary funds, and have ecological values. Thus, as other studies have also shown (e.g., [35]), high levels of engagement are associated with a green and alternative milieu.

To identify future scenarios of citizen participation in the German energy transition, it is necessary to model the process of social influences through society and determine primary actor groups in society. We included three levels in society in our model: individuals, neighborhoods, and social milieus. Individuals, i.e., citizens, influence others around them in their neighborhoods by their actions (as has also been shown in empirical studies on adoption of renewable energy systems in neighborhoods, e.g., [59]). This in turn propagates from the individual level to the neighborhood level and from the neighborhood level to the milieu (social group) level. We limit the meaning of neighborhoods to the spatially limited area in which a local energy community can form, in line with our definition in Section 2.1.1. Other levels superordinate to these neighborhoods were abstracted in our model and reduced to the level of milieus.

Thus, activity in the sustainable energy transition will spread from the micro to the macro level. Perceived actions on higher levels, in one's neighborhood or social group, also influence a citizen's actions. We consider such feedback loops at a later stage when interdependencies between descriptors are identified (see Section 2.1.3).

To incorporate heterogeneities of society in the model, while keeping it manageable in terms of the number of descriptors and descriptor states, the social milieu framework by Sociodimensions [54,55] was used as a basis to identify relevant ideal type actor groups. Milieus are social groups characterized by similar living conditions, formal power, financial means, education, prestige, housing conditions, socio-historical experiences of each generation, as well as similar lifestyles, fundamental attitudes, and value orientations [55,60]. According to Sociodimensions' framework, German society consists of eight milieus.

For our model, we specify five ideal type actor groups (henceforth referred to as actor groups), loosely based on these eight milieus, grouped together according to characteristics relevant to activities in the energy system. Table 2 distinguishes the ideal type actor groups according to their relevant socio-demographic and attitudinal characteristics.

Table 2. Characterization of the ideal type actor groups.

Ideal Type Actor Group.	Approx. Share in Society (in %) [1]	Short Characterization [2]	Predominant Housing Type/Ownership Structure [4]	Income	Environmental Attitude	Social Attitudes	Relevance as an Actor in the Energy System (i.e., Readiness to Act [6]/Willingness to Participate [7])
A	9	Medium to high level of formal education. Value tolerance, respect and diversity. Post-materialistic orientation. Strive for self-realization and independence from norms and conventions. Self-image as critical conscience of society with sustainability and environmental awareness as essential components. Great interest in social and cultural issues. Voluntary and professional work frequently socially and ecologically oriented.	house/owner-occupier	high	high	social justice & community activities important	high willingness to act: either in an energy community or individually installing a renewable energy system
B	9		tenant	middle	high	social justice & community activities important	high willingness to act: esp. in an energy community setting
I	—	A possible initiator [3] (in the case of private citizens, characteristics similar to A or B),	—	middle/high	very high	social attitudes strongly pronounced; central role in personal social network (including many contacts) [5]	very high willingness to act: esp. in an energy community setting; potential initiator of a community, or co-founding member
C	23	Medium to high level of formal education. See themselves as high achievers in society. Professional success and a high standard of living are important to them. Consider economic growth and competitiveness necessary to ensure good social conditions. Extensive consumer habits.	house/owner-occupier	very high	skeptical, trust in technology and government measures, ready to take action in the energy transition as a sign of modernity	no pronounced social attitudes	Willingness to act if advantageous (social norms/prestige, financial benefits): Individual system preferred
D	26	Typical middle class with medium level education and medium income. Private and family life are priority. Longing to feel protected. Consumption defined by comfort, convenience, and value for money. Self-image as the center of society. Willing to perform to maintain social status, but increasingly fearful of social decline.	—	middle	recognition of the problem; positive valuation of environmental action	longing for a functioning community	Willingness to act if no disadvantages (financial): prefer to join an energy community
E	32	Consists of two distinct groups: Older people with different social positions united by a desire for order, stability, and to preserve the familiar. They are thrifty and willing to do without. People with little formal education, low incomes, simple jobs. Many are unemployed. Their participation in consumption and social life is severely limited. See themselves as losers of modernization and are pessimistic about the future.	tenant	low	acknowledge the problem, but in an abstract manner; critical of measures previously taken by the government	among the young of the group, social justice is a priority, otherwise distant from political and social issues	hardly any willingness to act

[1] Based on [54,55]; [2] Based on [54,55]: A and B loosely resemble the "critical creative milieus" and "young idealists", C—the "established milieus" and "young pragmatists", D—the "middle-class mainstream", E–the "traditional milieus", "precarious milieus", and "young distanced milieu"; [3] Relevance of initiators in energy communities were identified in study A (cf. Table 1) and [61–63]. Studies B, C, and D in Table 1 illustrated that the majority of people willing to participate are not looking to found an energy community themselves. In theory, initiators do not have to be natural persons. Legal entities could also take on the role. However, our study is limited to grassroots innovations and thus citizen-initiators; [4] Set by authors, loosely based on information from [64,65]; in case D no predominant housing tenure could be identified since it strongly depends on where the household is located (city, or countryside), in case I defining a predominant housing tenure was deemed infeasible; [5] Characteristics of innovators based on Rogers [66] (see also [67]); [6] Loosely based on information from [55], mainly relates to energy-related renovation measures; [7] Inferred from [55] and adjusted according to results from studies A and B (see Table 1).

Descriptor Category 2: Context Factors

After the actor groups were specified, we identified, selected, and defined context factors that affect (and might be affected by) citizen's actions in the energy system. We focused particularly on context factors that hindered or supported the formation of energy communities. Table A1 lists and defines all context factors. The immediate social context is depicted in factors such as "neighborhood cohesion" and "recommendations from personal social network". The wider external context is also of utmost relevance. Financial characteristics of the options available to citizens in active participation in the energy transition are of central importance (e.g., [68]). Financial factors are summarized in descriptors "saving potential" and "incentives" (see Table A1). Technical design is also crucial in the adoption of renewable technologies. The fact that technical advances can occur is particularly crucial when modeling future scenarios and is reflected in descriptor "degree of innovation". The regulatory framework defines the scope of action for citizens and is presented in several descriptors: "administrative/legal barriers for energy communities", "regulatory requirements", and "incentives".

2.1.3. Identification of Descriptor States and Links between Descriptors

Once all descriptors were identified for the model, we defined their possible and relevant states and links between these states. All descriptors' possible states are also summarized and defined in Table A1. Descriptor states reflect possible alternative future developments. The number of states for each descriptor ranges from 2 to 4 depending on the descriptor. For example, individuals in any of the five actor groups, defined in Table 2, can take three possible actions: they can be active in an energy community, they can install their individual renewable energy system, or they can be inactive.

Interdependencies between descriptor states were determined and revised with the help of expert judgements. The interdependencies are qualitative information on whether a certain descriptor state promotes or hinders the development of another descriptor in reaching a certain state of its own. The coding of this information in CIB usually has seven degrees of influence: −3 (strongly restricting), −2, −1, 0 (no influence), 1, 2, 3 (strongly promoting). For example, positive saving potential of prosuming renewable energy (F1 in Table S1 in Supplementary Materials) strongly promotes positive recommendations regarding prosuming (J1 in Table S1 in Supplementary Materials).

To include actor groups' differing evaluations of the various descriptors, we weighted the influences of the descriptor states for the different actor groups by using actor-specific information from [55] and studies A and B. These weightings are summarized in Table A2. The resulting data on all influences between all descriptor states form the cross-impact matrix (see Tables S3 and S4 in Supplementary Materials).

2.1.4. Identification of Possible, Consistent Descriptor Settings

As mentioned above, for each set, all positive and negative influences of the selected state on each of the other descriptors' states must be summed up. A selected set of states is considered consistent if the selected state(s) is not supported more strongly by any of the other states of the descriptors than the selected one(s). Thus, the interdependencies between the descriptors regulate which combinations of descriptors' states can be regarded as consistent scenarios.

Table 3 summarizes the steps taken to identify possible consistent descriptor settings: In the case of 28 descriptors with each splitting into three states on average, approximately 3^{28} sets would need to be checked. This would challenge the CIB software (ScenarioWizard) and, moreover, would not be realistic.

The influence of a single individual becoming active in the energy transition is highly unlikely to result in an immediate rise in activities on the neighborhood level and actor group level. To address this, a time lag was introduced by splitting the CIB matrix into two matrices. Furthermore, there are some context factors that, while potentially influencing

other descriptors in our model, are not in turn influenced by them. We separate out and predefine these before calculating the consistent descriptor settings in our two-step CIB approach. We termed these predefined descriptors framework sets (see Table A3 in the Appendix A). They specify some possible combinations of those descriptors that shape the realization of other descriptors without being influenced in return. The framework sets' influences (see Table S1 in Supplementary Materials) were taken and added up (see Table S2 in Supplementary Materials).

Therefore, a single framework set is reduced to basically one descriptor state, one number. In our approach we include a single descriptor called "framework set" in the first matrix. Its states are the aggregated values of the framework sets. The first CIB matrix (Table S3 in Supplementary Materials) includes the neighborhood level and the actor group level, but not the individual level. Because of the limited number of framework sets that can be included at one time, the algorithm needs to run multiple times on the first matrix to determine all consistent descriptor settings.

In a second step, the resulting consistent descriptor settings identified by conducting the CIB analysis were—much like the framework sets in the beginning—added up to states for a new descriptor called "NM set". This set becomes a descriptor in the second CIB matrix (see Table S4 in Supplementary Materials), which now focuses on the individual level of actors. Again, only six states can be put in at a time, making multiple runs necessary. Once all runs on this second CIB matrix were completed, all consistent descriptor settings of the model had been identified.

Table 3. Steps in the identification process of consistent descriptor settings summarized.

Step 1: Identification of consistent descriptor settings on the neighborhood and ideal type actor group level)	
(1)	Selection of framework setting
(2)	Aggregation of influences on other descriptors
(3)	Integration of descriptor "Framework set" in CIB matrix I (Table S3 in Supplementary Materials)
(4)	CIB Analysis I (Neighborhood and ideal type actor group level)
(5)	Identification of consistent descriptor settings
Step 2: Identification of consistent descriptor settings focusing on the individual level	
(1)	Aggregation of influences of neighborhoods and ideal type actor groups (results from step 1.5)
(2)	Integration of descriptor "NW set" in CIB matrix II (Table S4 in Supplementary Materials)
(3)	CIB Analysis II (Individual level)
(4)	Identification of consistent descriptor settings overall

2.2. Development of Transformation Pathways

The CIB analysis usually ends with the selection of viable scenarios for the future moment in time specified for the scenario beforehand; 2040 was selected as the endpoint for this study. As Vögele et al. [29] showed in a different context, it is possible to string together scenarios with stock variables, in which each of the resulting sequences of static scenarios represents a quasi-dynamic path. Therefore, to make our CIB approach quasi-dynamic, i.e., to identify interim scenarios that together depict the development process, we applied the approach put forth by Vögele et al. [29] and proceeded as follows:

1. We identify the consistent descriptor set that describes the current situation best (t_0).
2. We define the interval, in which we want to observe developments along a transformation path ($i = t_{n+1} - t_n$).
3. We assess whether all descriptors can change from the current state to all other possible states, or if there are certain sequences of changes from one state to another.

4. We consider whether all descriptors can change from one state to another within the defined interval.
5. Based on restrictions (1) to (4), we exclude improbable consistent descriptor sets for t_{n+1}, (t_{n+2}, t_{n+3}, . . .). As a result, we identify plausible sets in the next period (taking changes in stock variables into consideration).
6. Based on research question 2 and 3 (see Section 1), we define a path narrative to pursue when assembling a transformation pathway, e.g., extrapolation of current trends.
7. Under restrictions (1) to (6), we assemble likely and possible transformation pathways. At each point in time, the identified sets serve as chain links to the next possible sets in the next point in time as defined by i.
8. The linking of sets will end if the final period is reached or the number of possible developments becomes too large, i.e., uncertainty becomes unmanageable.

In step one, the year 2020 was set as the present; 2020 was marked by the COVID-19 pandemic, an extreme event (see Table A1). Next, we defined the interval to be 5 years, resulting in five time steps, including the present as starting point and 2040 as endpoint.

In step three, we assessed all sequences of states of a descriptor. Some sequences are highly unlikely. For example, if an individual has become active in the energy transition, either jointly or alone, it is unlikely that this person is no longer active within 5 years. The same holds for the share of people active in the energy transition in a neighborhood or in an entire actor group: if from t_n to t_{n+1} an increase in the share has been observed, a decrease in t_{n+2} compared to t_{n+1} is unlikely. Over longer periods of time the likelihood of such a "backwards" shift increases with purchased technologies aging and context factors changing, or with a switch between "active alone" and "jointly active". Similarly, the three states of value orientation represent a progression, in which sustainable materialism represents a mixed form between materialism and post-materialism. All other descriptors can be expected to change freely between states.

Step four asks whether the time needed for a descriptor to change from one state to another is less than the interval, i.e., $\Delta t_{change} \leq i$. Ordering descriptors according to possible speed of change from one descriptor state to another would be conjecture to a large extent. However, it is clear that extreme events occur with incredible speed, while a shift in dominant value orientation of large parts of society is a slow process. Changes in values usually occur because of societal developments [69], changed circumstances of existence (as can be observed now with humankind's increasingly felt impact on the environment) [69,70], or as the result of sudden (extreme) events [71]. However, while values can shift for a person over the course of a lifetime, they are marked by relative constancy [56]. Society-wide value shifts usually occur on a generational level [72]. Therefore, we decided to restrict only two descriptors in terms of their shift from state to state from one period to the next: the share of those active in the different ideal-type actor groups and changes in value orientation.

The exclusion of some consistent descriptor sets in step five is highly dependent on the set and sets determined to represent the observation period(s) before. This is particularly important in the case of stock variables. If in the period before there has been no or little citizen participation in the sustainable energy transition, be it alone or in an energy community, then the current period cannot be described by a scenario that shows no actions by individuals, but steep rises in shares of people active on the neighborhood or even social group level. Such scenarios could well be fitting in the context of another transformation pathway. Therefore, the choice of transformation pathway narratives is highly important.

As our approach in this study was explorative in nature, we defined two path narratives to pursue during the assembling process of transformation pathways in step six. We focused on: extrapolation of current (positive) trends, narrative 1, and changing values towards a worldview centering on sustainability in narrative 2.

Based on these narratives, two possible transformation pathways were developed consisting of the likely scenarios in the case of each narrative and for each observation period. The paths ended in 2040 or 2035 when uncertainty increased substantially so as to make the narrowing down of scenarios of the next point in time is impossible.

3. Results: CIB Scenarios and Transformation Pathways

This study identified scenarios of future citizen participation in the sustainable energy transition in Germany and possible transformation pathways. All in all, we identified 286 fully consistent descriptor sets for the selected 15 framework sets (see Table A3). After selecting the descriptor set best describing the present (2020) and following the steps described in Section 2.2, ten probable scenarios were selected (see Table 4) for the two transformation pathway narratives. Each path consisted of a series of scenarios (see Figure 3).

The following subsections outline the results, starting with a characterization of the present and current trends. We discuss the selected scenarios within the context of the transformation pathways as the choice of scenarios is highly dependent on the transformation pathways.

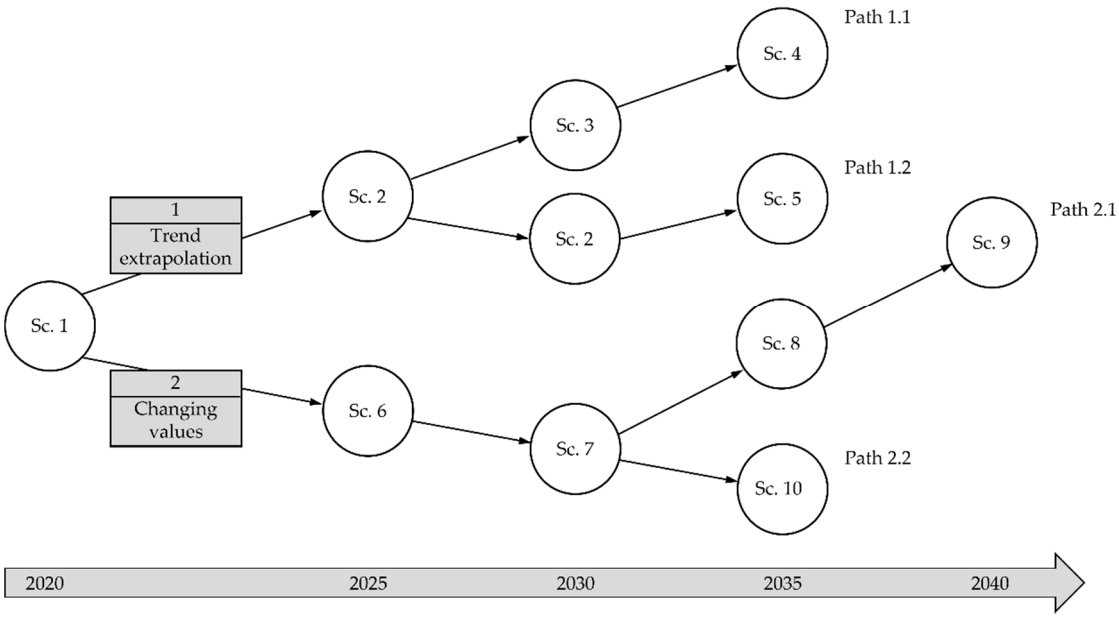

Figure 3. Constructed transformation pathways based on scenarios (Sc.) listed in Table 4.

Table 4. Overview of selected scenarios.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
I-IE. Individual level	I3 not active	I2 active alone		I1 jointly active	I2 active alone	I1 jointly active				
	A3 not active	A2 active alone				A1 jointly active				
	B3 not active		B2 active alone	B1 jointly active	B2 active alone	B1 jointly active				
	C3 not active			C2 active alone	C3 not active			C2 active alone		C1 jointly active
	D3 not active			D1 jointly active	D2 active alone	D1 jointly active				
	E3 not active							E1 jointly active		
G [I]. Perceived neighborhood cohesion	G2 neutral		G3 bad	G1 great						
J [I]. Recommendations from social network	J2 mixed			J1 positive		J2 mixed	J1 positive			
T [I]. Personal future outlook	T3 pessimistic		T1 optimistic							
NA-NE. Neighborhood level	NA4 CRE-low & RES-low	NA3 CRE-low & RES-high				NA2 CRE-high & RES-low			NA1 CRE-high & RES-high	NA2 CRE-high & RES-low
	NB4 CRE-low & RES-low		NB3 CRE-low & RES-high			NB2 CRE-high & RES-low				
	NC4 CRE-low & RES-low		NC3 CRE-low & RES-high		NC4 CRE-low & RES-low			NC3 CRE-low & RES-high		NC1 CRE-high & RES-high
	ND4 CRE-low & RES-low		ND3 CRE-low & RES-high				ND2 CRE-high & RES-low			
	NE4 CRE-low & RES-low							NE2 CRE-high & RES-low		
MAB-ME. Social group level/milieu level	MAB4 CRE-low & RES-low		MAB3 CRE-low & RES-high			MAB2 CRE-high & RES-low				
	MC4 CRE-low & RES-low		MC3 CRE-low & RES-high		MC4 CRE-low & RES-low			MC3 CRE-low & RES-high		MC1 CRE-high & RES-high
	MD4 CRE-low & RES-low		MD3 CRE-low & RES-high				MD2 CRE-high & RES-low			
	ME4 CRE-low & RES-low							ME2 CRE-high & RES-low		
G. General neighborhood cohesion	G2 neutral				G1 great					
J. Recommendations	J2 mixed		J1 positive			J2 mixed		J1 positive		
T. Future outlook	T3 pessimistic		T1 optimistic							
O. Trends in value orientation	O3 materialism		O2 sustainable materialism							O1 post-materialism
X. Degree of innovation	X3 little innovative		X2 innovative		X3 little innovative			X1 very innovative		X2 innovative
F. Saving potential	F2 neutral							F1 positive		F2 neutral
Q. Incentives	Q3 low incentives								Q1 financial	
R. Administrative / legal barriers for CRE	R1 high			R2 low	R1 high			R2 low		
Y. Regulatory Requirements	Y3 no	Y2 low				Y3 no	Y2 low		Y1 high	Y2 low
Z. Perceived extreme event	Z2 extreme event	Z3 no event						Z2 extreme event	Z3 no event	

Remarks: Coloring indicates whether the descriptor settings are positive (green), neutral (yellow), or negative (red) for energy communities and their emergence. Abbreviations: CIB nomenclature: Letters represent descriptors (e.g., I = initiator), numbers represent the different states a descriptor can be in (e.g., I3 = possible initiator is not active), see also Table A1 for definitions of each descriptor and each state; CRE—community renewable energy (abbreviation and term used frequently in the literature on energy communities since the early 21st century, see [10]).

3.1. Framework Shaping the Specification of Transformation Paths

3.1.1. Characterization of the Present Situation

The present (2020) is marked by limited citizen participation in the sustainable energy transition (for both heating and electricity), particularly so in energy communities (cf. [16,18]). Overall, current context factors are not conductive for energy communities. The general value orientation among Germans is marked by mixed materialistic and post-materialistic values (see Table A1 for definitions), with the former dominating (cf. [56,73]). Renewable energy technologies used in households are well-established and little innovation is seen here [74]. The present is also marked by extreme events, i.e., the COVID-19 pandemic (cf. [75]) and recent floods and storms in parts of Germany (cf. [76]).

Context factors directly linked to renewable energy technologies and prosuming citizens are also not ideal for a broad uptake of renewable energy solutions among German citizens. Saving potential across all renewable energy sources and technologies is neutral on average. That is, while running costs for renewable energy technologies are lower compared with fossil-fuel based sources (cf. [77]), other costs, such as investment costs, need to be included in the decision-making process (cf. definition in Table A1). There are some support schemes for installing renewable energy technologies in residential homes, which equally apply to single households and groups of households in Germany (e.g., [78]). The impact and public awareness of such schemes, however, seem limited [79]. While some German states require a small minimum share of renewable energy to be part of the energy supply of households or buildings [80], no such requirements exist on the national level.

Germany's overall positive regulatory conditions for energy communities compared to other EU countries have been noted (e.g., [49]). However, it seems that only some types of energy communities are supported by the regulations in Germany. Administrative processes for classic renewable energy cooperatives are standardized [81]. Energy cooperatives are citizen-led renewable energy initiatives that usually generate electricity, which are frequently not place-based and usually do not self-consume the electricity they generate but feed the electricity into the grid. Their main support came from feed-in tariffs, as a result of which, a fair amount of such energy communities came into existence [16]. In 2014, financial support via feed-in tariffs was partially replaced by market-based support schemes for renewables [81]. Consequently, growth of renewable energy cooperatives slowed down markedly [81].

Furthermore, large-scale self-consumption is restricted and excluded from (financial) support schemes in Germany [82], despite the fact that the EU's RED II [3] explicitly demands the support for self-consumption in energy communities. A legal opinion [83] of the recently (July 2021) amended German Renewable Energy Sources Act [84] provides clarity on these restrictions. Self-consumption of solar power, for instance, is exempted from all levies, charges, and fees only for systems with an output power of up to 30 kilowatts peak. However, for energy communities only larger photovoltaic systems are sensible. Furthermore, self-consumption must be proven. That is, the owner of the system and user of the generated energy need to be identical—the same person or legal entity. In many cases, legally proving that operator and user are identical is impossible.

This is the case in housing cooperatives, for instance. Germany has a strong tradition of cooperatives supported by the Cooperative Act [85] and cooperative housing accounts for around 10% of the 24 million tenements in Germany [86]. Their potential for sustainability measures in the building sector is recognized [87]. Housing cooperatives that are active in the field of renewable energies are, by definition (see Section 2.1.1), local energy communities. More and more of such sustainable housing cooperatives exist in Germany (e.g., [88,89]). Members of housing cooperatives are at the same time co-owners and tenants (e.g., [11]). Therefore, the required self-consumption cannot be proven. In cases where the landlord supplies electricity to tenants, the Tenant Electricity Act [90] takes effect, which sets out to support such legal arrangements of energy communities. However, since the introduction of these laws, no significant uptake in the number of energy communities

active in photovoltaics can be seen in Germany. This may be due to the law's complexity and overly bureaucratic nature perceived as barriers [91,92]. Only specialized service providers seem to be equipped to handle these legal barriers. Small energy community projects seem to be economically not interesting to those providers (this was explicitly identified by an interviewee in study A).

The recent move away from feed-in tariffs and the subsequent slow-down in the formation of energy cooperatives alone illustrate how impactful the regulatory framework is for energy communities. If the administrative barriers for local prosuming energy communities are added, the picture of Germany's enabling environment reverts into a restricting environment. This is reflected in the configuration of Scenario 1, which represents the present (see Table 4).

3.1.2. Current Trends

The "Future of values" study [56] found that German society is shaped by the desire for a solidary and just society. This is reflected in the rise of voluntary work. The study also found that on the societal level there are fault lines which hinder the realization of these social and solidarity values and desires: income inequality, increasing selfishness and performance orientation, a perceived drifting apart of values, and a perceived decline in cohesion. Against this backdrop, citizens' engagement in the sustainable energy transition, both by acting alone or as an energy community, is equally likely to slowly increase in the future.

While in the 1970s post-materialist values were seen to grow in importance and were expected to overtake materialist values [93], recent years have seen a shift back towards materialism [73,94,95]. Thus, while the present is marked by pluralism of values, which of the two will dominate in the upcoming decades remains unclear. Both directions are seen as possible in [56].

Environmental values and attitudes are vital for an actual realization of pro-environmental actions (cf. [96–98]). Environmental values are considered part of the post-materialist value set [93,99]. Among the younger generation environmental concern seems to be increasing [100], exemplified by the Fridays for Future movement lead by Greta Thunberg. While stronger environmental attitudes have been observed among the young [99,101], the Greta Thunberg effect seems to work across age groups [102]. Overall environmental attitudes seem to be strongly affected by perception of environmental issues, extreme events, and media discourse about them (see e.g., the environmental agency's environmental awareness study [103] which evidences the correlation between environmental attitude and environmental disasters). Given that extreme events are expected to increase in frequency and severity due to climate change [104,105], it can be expected that awareness of environmental issues and climate change will further increase. That raises the likelihood of a value shift towards sustainability making sustainable materialism the dominant value orientation in German society (cf. [41,56]).

3.2. Specification of Transformation Paths

3.2.1. Transformation Path 1: Extrapolation of Current Trends

In line with transformation pathway 1 (see Figure 3 and Table 4), the following outlines how the next two decades could unfold:

Within the next five years the COVID-19 pandemic will have loosened its grip on Germany, i.e., *Z. Perceived extreme event* (last row in Table 4) will change from *extreme event* (Z2) in Scenario 1 (data column 1 in Table 4) to *no event* (Z3) in Scenario 2 (data column 2 in Table 4). Changes in the legal framework, happening already on the state-level (see Section 3.1.1), will be expanded to the federal level, resulting in the introduction of low regulatory requirements of renewable energy as part of households' energy supply nationwide (cf. Y3 in Sc. 1 → Y2 in Sc. 2, in Table 4). A slow rise in the numbers of citizens active alone will follow—initially among environmentally conscious homeowners (actor group A). This will occur predominantly with a slow shift in value orientation towards a more sustainable worldview (cf. O3 in Sc. 2 → O2 in Sc. 3 and Sc. 5, in Table 4). How fast

that shift occurs, however, depends on what direction the transformation follows after the split of the transformation pathway (cf. Figure 3).

On path 1.1 (see Figure 3) by 2030, activities in the development of new and evolved renewable energy technologies might result in innovation breakthroughs (X2 in Sc. 3, in Table 4). This would result in increased activity by other groups, initially acting alone. Later there could be a shift of some actors towards being active in energy communities (B1 and D1 in Sc. 4, in Table 4), in part due to lowered administrative and legal barriers for energy communities (cf. R1 in Sc. 3 → R2 in Sc. 4, in Table 4). These developments in innovation and reduced legal barriers influence recommendations by other people regarding renewable energy technologies and energy communities (cf. J2 in Sc. 2 → J1 in Sc. 3 and Sc. 4, in Table 4). This in turn will boost citizen participation even more. Similarly, this will result in a more positive view of the future (cf. T3 in Sc. 2 → T1 in Sc. 3 and Sc. 4, in Table 4).

Alternatively on path 1.2 (see Figure 3), the previous trajectory characterized by increasing numbers of citizens in some form active alone in the energy transition could continue (Sc. 5, in Table 4). However, not all actor groups will become active. Especially citizens with lower socio-economic status will be left out entirely in both path 1.1 and 1.2 (cf. E3, NE4, ME4 in Sc. 4 and Sc. 5, in Table 4).

3.2.2. Transformation Path 2: Changing Values towards Sustainability

The second transformation pathway takes into consideration a fast (or at least faster than assumed in path 1) societal change towards a more sustainable worldview.

With growing awareness of the need for sustainability in lifestyle design and economic activities, citizens will become active in the sustainable energy transition fast, predominantly in energy communities (A1, B1, D1 in Sc. 6, in Table 4). This will positively affect their outlook (cf. T3 in Sc. 1 → T1 in Sc. 6, in Table 4). The German state will introduce requirements for renewables in the energy supply of residential buildings; however, requirements will remain low (cf. Y3 in Sc. 6 → Y2 in Sc.7, in Table 4 and Figure 3). Further increases in environmental values and citizens active in energy communities will follow (ND3, MD3 in Sc.6 → ND2, MD2 in Sc. 7, in Table 4).

Around 2035 and onwards, innovative breakthroughs become increasingly likely (X1 in Sc. 8 or X2 in Sc. 10, in Table 4). If path 2.1 (see Figure 3) is followed and renewable energy technologies become very innovative (X1 in Sc. 8), financial benefits will grow markedly (cf. F2 in Sc. 7 → F1 in Sc. 8, in Table 4). These factors will influence people's experiences of being active in the energy transition and will lead to predominantly positive recommendations regarding the adoption of renewable energy technologies and the participation in energy communities (cf. J2 in Sc. 7 → J1 in Sc. 8, in Table 4). In a best-case scenario (Sc. 9 in Table 4), all context factors shift to be favorable for action by all actor groups in society. For example, the required share of renewable energy in residential energy supply will be increased (cf. Y2 in Sc. 8 → Y1 in Sc. 9, in Table 4). All this might well be the result of a post-extreme-event awakening (cf. Z2 in Sc. 8, in Table 4), which are predicted to increase in frequency and impact severity (see Section 3.1.2). In that case, a substantial number of citizens from most actor groups will become members of energy communities, some will be active alone (cf. C2, NC3, MC3 in Sc. 9, in Table 4).

Then again, an extreme event is not an essential factor to expedite citizen participation in the energy transition. On path 2.2 a further change in values, away from the materialist paradigm to post-materialism (cf. O2 in Sc.7 → O1 in Sc. 10, in Table 4), could also result in positive changes among context factors. This could be a change in the policy environment, which might lead to fewer legal and administrative barriers for energy communities (cf. R1 in Sc. 7 → R2 in Sc.10, in Table 4) and/or financial state support (cf. Q3 in Sc. 7 → Q1 in Sc. 10, in Table 4). These changes will further encourage the formation and growth of energy communities towards being the predominant form of citizen participation across all actor groups.

In both path 2.1 and 2.2, those less well-off will have a chance to be active in the energy transition (cf. E1, NE2, ME2 in Sc. 9 and Sc.10, in Table 4). This will be due to an inclusive policy environment, in which extensive financial support schemes are implemented, for instance (Q1 in Sc. 9 and Sc. 10, in Table 4).

4. Discussion

4.1. Discussion and Implications of Results

In this study, we set out to identify and assess what citizen participation in the energy transition might look like in Germany in the upcoming decades. We created a quasi-dynamic model using the CIB approach and identified transformation pathways that depict possible developments up to 2040.

In research question one, we asked: Which factor constellations affect the formation of energy communities?

Our analysis resulted in factor constellations that influence citizen participation. Tables S3 and S4 in Supplementary Materials depict positive and negative influences between these factors' states in detail. Key beneficial factors are regulatory and state support context factors (e.g., low legal barriers, incentives), but also economic determinants like technological innovation and financial gains.

At the same time, social factors (cf. Table A1)—first and foremost social influence—play a decisive role. Individuals influence their neighbors by installing a visible solar PV system or by recommending them to their neighbors and acquaintances, for example. Individuals also have different degrees of influence, and this can be crucial. For example, someone initiating an energy community plays a preeminent role. Furthermore, the resulting scenarios highlight that social factors, like cohesion among neighbors, can be important on an individual level.

If neighborhood cohesion is bad, an individual is unlikely to become a member of an energy community (as seen in Scenario 3, Table 4). On the contrary, there is Scenario 5, calling attention to the fact that social factors, such as neighborhood cohesion, recommendations from others in an individual's social circle, and values, have limited sway when economic and regulatory framework conditions are unconducive to energy communities.

Questions two and three asked: What are possible scenarios that characterize the future of energy communities in Germany? And what are possible transformation paths that characterize the development process toward these futures?

Under the premise of two transformation pathway narratives and based on CIB scenarios, two transformation paths have emerged, each with two strands of development. Extrapolating current trends, such as increasing environmental concern and to-and-fro shifts in dominance of materialist and post-materialist values, we found that increased active citizen participation in the (national) energy system would likely characterize the future. However, the majority of citizens will most likely stay in a passive role. Under the premise of a strong shift of values towards sustainability and post-materialism, a more successful proliferation of citizen participation, especially in groups, might take place if, at the same time, regulatory framework conditions for energy communities improve.

Our results showed that only in a combination of conducive social factors and economic framework conditions or state regulations (including the abolition of hindering regulations) can active citizen participation become an important player in Germany's future (sustainable) energy system. Conducive social factors are difficult to strengthen. Van den Berg et al. [106] suggested some possibilities for policy makers to strengthen perceived neighborhood cohesion, but whether this will lead to success remains unclear. Economic and regulatory conditions are largely determined by policy makers. Therefore, policy makers can support energy communities by reducing administrative and legal barriers (discussed in Section 3.1.1) and by expanding financial support schemes (they should particularly focus on the socially disadvantaged).

Technology innovation support of renewable energy technologies, which are particularly suitable for use in the residential sector, can be an equally important support measure,

especially if this increases financial savings potential. Among the most powerful tools policy makers have at their disposal are regulatory requirements demanding of owner-occupiers and landlords that at least a share of a housing unit's energy supply comes from renewable energy sources.

Our analysis was purposefully kept vague in terms of technology design and whether heating or electricity is meant. The technology-mix available to choose from depends heavily on the context of a housing unit. Furthermore, to predict or make an educated guess what renewable energy technology options will be available in 20 years is beyond the scope of this research.

During the data collection process, the following became evident: neither energy communities nor individually owned renewable energy systems are necessary in order to provide households with electricity from renewable sources—or, conversely from the households' perspective, to promote renewable electricity. A contract with a green power provider is also effective in this regard. Of critical relevance, however, seems to be the active participation of citizens in the area of heat supply. In heating, the expansion of renewables is proceeding sluggishly (cf. [21]). A high dependence on natural gas and heating oil can be observed (cf. [107]). Here, the installation of a single system, such as a single-house woodchip stove, is even more context-dependent (e.g., requires extensive storage space). Energy communities providing heat to households in a neighborhood with a small pipeline system for district heating (for examples of such communities see [11]) seems to be the most promising solution in most cases.

4.2. Discussion of the Methodological Approach's Viability

Potential estimations, such as those carried out by Kampman et al. [22], provide information about the socioeconomic and technical potential of active citizen participation in the energy transition but are not helpful when it comes to showing how to fully exploit the potential. Barriers that prevent the potential in Germany from being exploited must be considered not only separately, but also in their interaction. For this, the CIB analysis is the ideal method. So, our study provides a holistic and thus close-to-reality picture of the possible futures for citizen participation in the German energy transition and thereby closes a significant research gap in the field. Assessments based on potentials are an important starting point for scenario studies, while transformation pathways show holistically how to potentially get there. However, they also show that things can turn out quite differently. Thus, our results are particularly relevant for policy makers. At the same time, our results are in line with the results of the potentials for citizen participation in Germany by Kampman et al. [22]. Thus, potential analyses also function as a verification tool of accuracy for scenario studies.

Compared with other methodological approaches dealing with development processes, the approach chosen here has some particularities of advantage for the topic of active citizen participation. In terms of methodology, Witt et al.'s [28] study is the closest to ours. However, while they used the CIB to map steady linear developments, we took full advantage of CIB's applicability to include complex dynamics and nonlinearities. In doing so, we expanded the usual framing of the CIB to include heterogeneous actor behavior at the micro, meso, and macro levels. Traditionally, CIB shows the perspective of only one actor. This can be at the micro level, from the perspective of just one individual [108], or at the aggregate macro level, for example from a macroeconomic perspective [41]. However, the CIB methodology easily allows for an extension to include multiple actors. Modeling of multiple actors' behavior is core to agent-based modeling (ABM) and has been applied in some studies of individual or collective adoption of renewable energy technologies [24–27]. ABM represents dynamic aspects and interactions well but does so under predetermined rules that specify the internal dynamics [109,110]. Nonlinearities that occur suddenly and unexpectedly due to exogenous stimuli are not taken into account. Here, again, lies the strength of our extended CIB analysis: external factors that provide an impetus for action are considered in a consistent framework just as internal dynamics are. In order to establish

scenarios and transformation paths for future developments, both aspects, actor behavior and exogenous factors and dynamics, are important. Thus, in this study, aspects of actors and actor behavior were taken from the ABM and integrated into the CIB.

Similar to ABM, system dynamics (SD) is an approach that is based on numerical and often complex equations [111]. In contrast to CIB analysis, which, as its name suggests, is a pure balancing approach, SD and ABM put higher demands on the input data in terms of their measurability and quantifiability. Aspects like impacts of neighborhood cohesion and social influence on action are difficult to be quantified. Hence, the application of the CIB approach has advantages over the others. Another important aspect is the consideration of micro, meso, and macro aspects. Usually, SD models focus on one specific system level (micro, meso, or macro) and do not emphasize overlapping aspects and interactions [109]. Again, the extended CIB approach presented here included these interrelations.

The exogenous stimuli or contextual factors constitute the sociotechnical regime and, more importantly, the socio-technical landscape of the multi-level perspective [112]. However, the multi-level perspective (MLP) approach, as an example for a widely used approach employed for the assessment of technology diffusion processes, has a different focus compared with our study. The MLP is about how a new technology gradually diffuses from the niche into the regime. Actors were included here but were not the focus. Our work, on the other hand, focused on actors and their active acceptance and implementation of mature technologies. Furthermore, the assessment of active citizen participation development in the future does not call for the precise technical design to be included, since as Fouladvand et al. [27] found, the technology options in citizen participation in energy communities are secondary in relevance. Ultimately, the focus is on the deployment process in a broad contextual framework where actors and the deployment of sustainable energy supply in the residential sector generally are at the center of attention.

5. Conclusions

Active citizen participation is considered a key pillar for a sustainable energy transition. Particularly important here is the generation of renewable energy by energy communities. This allows for socially inclusive participation in the energy transition. As a result of their potentially inclusive nature, energy communities also increase public acceptance of renewable energy projects and the sustainable energy transition. They are also expected to help close the investment gap in renewable energy developments in the EU. However, such energy communities are currently limited in practice. This is despite of such communities being considered a vital pillar for a successful and sustainable energy transition as envisioned by the EU.

We developed a quasi-dynamic CIB model and identified transformation pathways of citizen participation in the energy transition in Germany up to 2040. This allowed us to explicitly assess how citizen participation might evolve and how energy communities could be fostered if desired. Not only will a continuation of current trends not lead to active citizens from different socioeconomic groups playing a relevant role in the energy transition, but energy communities will not become widespread but stay a niche phenomenon. In order for that to change, several framework conditions need to improve simultaneously (e.g., hindering regulations need to be abolished and financial support schemes with a focus on the less well-off introduced). Additionally, the results showed that only in a combination of conducive social factors such as social influence and favorable economic conditions can active citizen participation become important in Germany's future energy system.

We showed that CIB is a versatile method that is ideal to generate transformation pathways depicting possible development processes while at the same time taking heterogeneous actors, multiple levels, nonlinearities and dynamics into consideration. CIB's application and scenario generation approach were expanded and further developed by basing the study on a wide range of self-collected data, making it quasi-dynamic, and by accounting for multiple actor perspectives and considering actors on the micro, meso, and macro level. By splitting and recombining the CIB matrix, we demonstrated how the

list of descriptors can be extended without a great increase in the workload. As a result, this approach allows for incorporation of a broader range of qualitative and quantitative descriptors. In contrast to agent-based models and system dynamics approaches, which focus on quantitative factors and require a level of accuracy that usually is not given by the data, the CIB approach takes inexactness into consideration and adjusts data with the help of experts. This study shows the suitability of CIB for carving out pathways for consistent constellations of socio-economic factors. Thus, the CIB approach could support the development of advanced Shared Socioeconomic Pathways (SSPs). Additionally, the study brings significant methodological improvements for the scientific community working with CIB: it illustrates how to include larger numbers of descriptors, how to include several actor perspectives, weightings of descriptor state interactions, and different aggregation levels and their interplay. It also highlights how CIB scenarios can be used to derive nonlinear transformation paths. In terms of content, the study shows the possible development of energy communities into the future and thus represents a complement to potential estimations.

The model presented is characterized by the following advantages, which make it universally applicable to citizen participation in the sustainable energy transition: it includes all types of citizen participation, there are no restrictions in renewable energy technology, there are no restrictions in type of energy (electricity or heat), and it includes the portrayal of citizens as heterogeneous actors, represented in a simplified way by means of ideal type actor groups.

Future research efforts should advance the methodological approach introduced here, i.e., how to recombine and analyze data when large CIB matrices are split in two or more. Furthermore, in future research, the transformation paths obtained could be subjected to a macroeconomic analysis in order to make a correct assessment of the economic relevance of various developments. An input-output analysis, for example, would be suitable for this purpose. The same could also be done regarding a sustainability assessment, for example, via life cycle assessment.

Whether values will significantly shift in the upcoming decades among the majority of German citizens remains unclear. The transformation pathway narrative suggesting such changes simply shows a best-case scenario in which energy communities spread successfully and consequently highlights what factors need to change. Only a combination of several factors conducive to the formation of energy communities could lead to such a best-case. Herein also lies the analysis' main limitation: to generate even more transformation pathways would in principle be possible but is beyond the scope of this study. Additional transformation path narratives would have to be generated and substantial knowledge gain is uncertain if not to be doubted. The geographical focus on Germany in the study is just as much a limitation because the topic is so highly complex and context-specific that the adaptation of the model for other countries, even within the European Union, would involve significant effort. Like the results of other studies, our results strongly depend on the quality of the information integrated into the model. By using information gained by conducting discrete choice experiments and surveys, as well as empirical data from case studies we tried to maximize the realism of the assumptions. However, we are aware that there are still uncertainties regarding data used for the CIB analysis.

Our results suggested that a successful citizen-driven energy transition by 2040 is not achievable following current trends. A significant step change would be necessary. For a majority of society to become active, changes in several framework conditions are necessary, for example, administrative and legal conditions for energy communities and saving potential from renewable energy technologies. Taking along the less well-off remains a key issue in the energy transition. However, while energy communities bear the potential to include all socio-economic groups, policy support is necessary to make them universally accessible. A key implication we identified is, therefore, that policymakers in Germany should improve their current support for energy communities or, at the very least, simplify administrative processes and reduce legal barriers. This would be achieved by meticulously

incorporating the objectives and recommendations from the EU directives RED II [3] and IEMD [4] into national laws and regulations.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14063169/s1, Table S1: Impacts of the framework set descriptors, Table S2: Example for the aggregation of the framework sets' impacts (with framework set P1), Table S3: Example for CIB matrix I focusing on the neighborhood level and ideal type actor group level (with framework sets P1–F5), Table S4: Example for CIB matrix II focusing on the individual level of actors (incl. NM Sets P1-1–F1-3, the aggregated first six consistent descriptor settings resulting from CIB matrix I).

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Appendix A

Table A1. Definition of descriptors and their states.

Descriptor Category	Descriptor	Definition of Descriptor	Descriptor's States and Their Definitions	Sources
Actions and Effects on Different Societal Levels (Micro to Macro)				
Individual level	I. Action taken by possible initiator in the neighborhood	Action taken by an actor, most likely belonging to ideal type actor group A or B, who might be a possible initiator of an energy community, lives in the neighborhood, and occupies a central role in the social network of the neighborhood of A, B, C, D, or E	(1) jointly active—the actor starts to *found* an energy community, (2) active alone–the actor installs an individual RES, (3) not active—the actor neither becomes active in an energy community, nor do they adopt an individual RES	Own conceptualization, based on studies A and D
	IA/IB/IC/ID/IE. Action taken by a citizen of type A (B, C, D, or E)	Action taken by one actor belonging to ideal type actor group A (B, C, D, or E)	(1) jointly active—the actor starts to participate in an energy community, (2) active alone—the actor installs an individual RES, (3) not active—the actor neither becomes active in an energy community, nor do they adopt an individual RES	Own conceptualization, based on studies A and B, [55]
Neighborhood level	NA/NB/NC/ND/NE. Share of citizens active in IA's (IB, IC, ID, IE)'s neighborhood	Share of neighbors in IA's (IB, IC, ID, IE)'s neighborhood active in the energy transition by either participating in an energy community (CRE) or owning an individual renewable energy system (RES)	(1) CRE-high and RES-high—of the neighborhood, 20% and more are members of the energy community & 20% and more own an individual RES (2) CRE-high and RES-low—of the neighborhood, 20% and more are members of the energy community & less than 20% own an individual RES (3) CRE-low and RES-high—of the neighborhood, less than 20% are members of the energy community & 20% and more own an individual RES (4) CRE-low and RES-low–of the neighborhood, less than 20% are members of the energy community & less than 20% own an individual RES	Own conceptualization, based on studies A and B, [55]
Actor group (milieu) level	MAB. Share of type A and B citizens active	Share of German citizens belonging to actor group A and B, who are already active in the energy transition by either participating in an energy community (CRE) or owning an individual renewable energy system (RES)	(1) CRE-high and RES-high—of German citizens, belonging to the actor group, 10% and more are members of an energy community & 10% and more own an individual RES (2) CRE-high and RES-low—of German citizens, belonging to the actor group, 10% and more are members of an energy community & less than 10% own an individual RES	Own conceptualization, based on studies A and B, [55]
	MC/MD/ME. Share of type C (D or E) citizens active	Share of German citizens belonging to actor group C (D or E), who are already active in the energy transition by either participating in an energy community (CRE) or owning an individual renewable energy system (RES)	(3) CRE-low and RES-high—of German citizens, belonging to the actor group, less than 10% are members of an energy community & 10% and more own an individual RES (4) CRE-low and RES-low—of German citizens, belonging to the actor group, less than 10% are members of an energy community & less than 10% own an individual RES	

Table A1. *Cont.*

Descriptor Category	Descriptor	Definition of Descriptor	Descriptor's States and Their Definitions	Sources
		Context factors		
G. Neighborhood cohesion	Generally cohesive relationships among inhabitants of a neighborhood and no interpersonal conflicts among neighbors (dimensions of neighborhood (social) cohesion are: social interaction, perceived degree of connection, personal identification, amount of trust, value consensus, willingness to intervene for the common good)		(1) great—particularly close interrelations among neighbors and no interpersonal conflicts; at least 4 out of 6 dimensions of neighborhood cohesion are high among the majority of the neighborhood, (2) neutral—no close interrelations among neighbors, insignificant frictions occur from time to time; few dimensions of neighborhood cohesion are pronounced, but neither are they low among the majority of the neighborhood, (3) bad—no interrelations among neighbors and frequent interpersonal conflicts; most of the dimensions of neighborhood cohesion are low among the majority of the neighborhood	Own conceptualization, based on: Concept/definition: [113–115] In (energy) communities: [58,106,116,117]
G [I]. Perceived neigh-borhood cohesion	Evaluation of neighborhood cohesion at the individual level (see G. for a detailed definition of neighborhood cohesion)		(see G.)	(see G.)
J. Recommendations	Recommendations of citizens in energy communities or of owners of individual RES (propagated in their own social networks)		(1) positive—the majority of citizens with experiences have had only positive experiences with either an energy community or an individual RES, (2) mixed—the majority of citizens with experiences have had positive and negative experiences with either an energy community or an individual RES, (3) negative—the majority of citizens with experiences have only had negative experiences with either an energy community or an individual RES	Own conceptualization, based on study C and study D, [118,119]
J [I]. Recommendations of citizens in (personal) social network	Recommendations of citizens in the social network of IA, IB, IC, ID, or IE regarding either an energy community or an individual RES (The social network likely includes close acquaintances of the individual's neighborhood, but also family, friends, and acquaintances from beyond.		(1) positive—citizens in the actor's social network have only had positive experiences with either an energy community or an individual RES, (2) mixed—citizens in the actor's social network have had positive and negative experiences with either an energy community or an individual RES, (3) negative—citizens in the actor's social network have only had negative experiences with either an energy community or an individual RES,	(see J.)
T. Future outlook	Expectations for the future, i.e., how hopeful citizens are of a stable future awaiting them (contains expectations about economic (e.g., employment, job security, own-income growth), societal, and particularly environmental developments (incl. their children's future))		(1) optimistic—generally high expectations for the future, (2) uncertain—ambivalent expectations for the future, (3) pessimistic—low expectations for the future	Own conceptualization, based on [120–123]

Table A1. *Cont.*

Descriptor Category	Descriptor	Definition of Descriptor	Descriptor's States and Their Definitions	Sources
T [I]. Personal future outlook	IA's (IB, IC, ID, or IE) expectations for the future (see T. for a detailed definition of future outlook)		(see T.)	(see T.)
O. Trends in value orientation	Values describe ideas of what is desirable and are part of the symbol systems regulating interactions within a society. They influence the objectives of the economic system, and change in the course of social and cultural change.		(1) post-materialism—Post-materialistic values such as self-fulfillment, friendship, leisure gain importance; economy is marked by qualitative growth, i.e., development of prosperity without expanding material production, (2) sustainable materialism—Material consumption still plays a role as a target, but is subordinate to the concept of sustainability, reflected in people's ideas about economic design, which should develop in the direction of material growth with decreasing environmental pollution, (3) materialism—Material consumption plays a major role as a target and wealth is primarily defined by it; objective of economic design is mainly conventional material growth stimulated by competition	Concept/definition adapted from: [41,124]; Application: [56,125,126]
X. Degree of innovation	Characterizes the innovativeness of the RESSuccessful innovations' key attributes are: (1) perceived **relative advantage** in terms of economic and social-prestige factors, convenience, and satisfaction; (2) **compatibility** with existing values, past experiences, and needs (or requires a prior adoption of a new value system); (3) **complexity** (adoption occurs more slowly when not readily understood by most members of a social system); (4) **trialability** (decreases uncertainty); (5) **observability**		(1) very innovative—RES is characterized by all 5 attributes of successful innovations, (2) innovative—RES is characterized by 2 to 3 attributes of successful innovations, (3) little innovative—RES is characterized by 1 or less of the attributes of successful innovations	Concept/definition adapted from: [66,67]; In energy communities/Application: [16,127–129]
F. Saving potential	Savings in monthly costs for electricity and heating in a household (incl. annualized investment cost), due to either being "jointly active" or "active alone"		(1) positive—at least a 5% decrease in monthly costs of electricity and heating, (2) neutral—no changes in monthly costs of electricity and heating, (3) negative—5% increase in monthly costs of electricity and heating	Own conceptualization, based on study D and study C
Q. Incentives	Financial incentive schemes by public organizations, banks etc., such as investment grants, low-interest loans; non-financial incentives such as information campaigns (The existence and number of incentives are a result of the political strategy regarding the energy transition.)		(1) financial—significant and well-known financial incentive schemes by public organizations, banks etc., such as investment grants, low-interest loans, (2) non-financial–non-financial incentives such as information campaigns (reports and/or advertising campaigns on the radio, television, the internet, in newspapers or magazines) that attract a lot of attention (3) low incentives–financial and/or non-financial incentives exist for CRE or RES, but are insignificant and little known/perceived	Own conceptualization, based on: Financial incentives: [68,130] Financial vs. non-financial incentives: [131]

Table A1. *Cont.*

Descriptor Category	Descriptor	Definition of Descriptor	Descriptor's States and Their Definitions	Sources
R. Administrative/legal barriers for energy communities	Legal/administrative hurdles, which greatly affect the organization of energy communities (e.g., restrictions to energy sharing among neighbors), and might be a result of a lacking political strategy)		(1) high–laws and regulations hindering the easy creation of energy communities, (2) low–few minor administrative hurdles, which have an effect on the creation process of energy communities	Own conceptualization, based on study A, [132]
Y. Regulatory Requirements	Regulations requiring that some form of renewable energy provides a minimum share of the energy supply of a household or building. They can apply to new buildings, those undergoing refurbishment or cases, in which the heating system is being replaced. They can even be a blanket obligation for buildings.		(1) high—majority of households and buildings need to have at least half of their energy demand (heating and electricity) covered by renewable energy sources, (2) low—majority of households and buildings need to have a small share of their energy demand (heating and electricity) covered by renewable energy sources, or certain types of buildings (e.g., new buildings) are required to cover some of their energy demand by renewable energy sources, (3) no—the inclusion of renewable energy sources in the energy supply of households is entirely voluntary	Own conceptualization, based on expert recommendations from the REsCO practitioners advisory board [53] Concept/definition adapted from: [80,133]
Z. Perceived extreme event	Both the perceived extreme event and the perceived likelihood of extreme events are encompassed. The following definition is the basis of what is understood to be an extreme event: "An extreme event is a dynamic occurrence within a limited timeframe that impedes the normal functioning of a system or systems" [134].		(1) extreme energy event—an extreme event with effect on the energy supply is perceived or deemed highly likely to occur in the near future, (2) extreme event—an extreme event without effect on the energy supply is perceived or deemed highly likely to occur in the near future, (3) no event—no extreme event takes place or is deemed very unlikely to occur in the near future	Own conceptualization, based on study D, [134]

Remarks: CIB nomenclature: Letters represent descriptors (e.g., I = initiator), numbers represent the different states a descriptor can be in (e.g., I3 = possible initiator is not active); CRE–community renewable energy (abbreviation and term used frequently in the literature on energy communities since the early 21st century, see [10]); RES–renewable energy system.

Table A2. Weightings.

Descriptor	I.	A.	B.	C.	D.	E.
I. Action taken by possible initiator	1.00	2.00	2.00	1.63	2.00	1.56
IA. Action taken by a citizen of type A	1.00	1.00	1.13	1.00	1.00	1.00
IB. Action taken by a citizen of type B	1.00	1.17	1.00	1.00	1.00	1.00
IC. Action taken by a citizen of type C	1.00	1.00	1.00	1.00	1.00	1.00
ID. Action taken by a citizen of type D	1.00	1.00	1.00	1.00	1.00	1.00
IE. Action taken by a citizen of type E	1.00	1.00	1.00	1.00	1.00	1.00
NA. Share of citizens active in A's neighborhood	1.17	2.00	1.25	1.00	1.00	1.00
NB. Share of citizens active in B's neighborhood	1.17	1.33	2.00	1.00	1.00	1.00
NC. Share of citizens active in C's neighborhood	1.00	1.00	1.00	1.88	1.00	1.00
ND. Share of citizens active in D's neighborhood	1.17	1.00	1.00	1.00	1.86	1.00
NE. Share of citizens active in E's neighborhood	1.17	1.00	1.00	1.00	1.00	1.67
MAB. Share of type A and B citizens active	1.83	1.67	1.50	1.25	1.29	1.00
MC. Share of type C citizens active	1.00	1.00	1.00	1.63	1.29	1.00
MD. Share of type D citizens active	1.00	1.17	1.13	1.00	1.43	1.00
ME. Share of type E citizens active	1.00	1.00	1.00	1.00	1.00	1.33
G [I]. Perceived neighborhood cohesion	2.00	1.83	1.75	1.63	1.86	1.67
J [I]. Recommendations of citizens in (personal) social network	1.50	2.00	1.75	1.88	1.86	1.67
T [I]. Personal future outlook	1.67	1.67	1.50	1.50	1.71	1.56
O. Trends in value orientation	1.33	1.33	1.25	1.50	1.43	1.67
X. Degree of innovation	1.17	1.33	1.00	1.25	1.14	1.00
F. Saving potential	2.00	2.00	1.75	2.00	2.00	2.00
Q. Incentives	1.17	1.00	1.00	1.25	1.29	1.11
R. Administrative/legal barriers for energy communities	1.33	1.33	1.25	1.50	1.43	1.67
Y. Regulatory requirements	1.67	2.00	1.13	2.00	1.43	1.11
Z. Perceived extreme event	1.67	1.67	1.50	1.38	1.43	1.22

Remarks: I = initiator. The weightings were derived by a pre-evaluation of the importance of each descriptor by experts on a scale from 1 to 10. To avoid an overestimation of the effects, the values were scaled down to a scale of 1 to 3.

Table A3. Framework sets.

Descriptor	Framework Sets														
	P1	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
O. Trends in value orientation	O3	O3	O3	O3	O3	O1	O2	O2	O1	O2	O2	O3	O2	O2	O2
X. Degree of innovation	X3	X3	X2	X3	X3	X2	X1	X2	X2	X3	X1	X3	X3	X3	X2
F. Saving potential	F2	F2	F2	F1	F3	F2	F1	F2	F1	F3	F1	F2	F2	F2	F2
Q. Incentives	Q3	Q3	Q1	Q3	Q3	Q1	Q1	Q3	Q1	Q2	Q3	Q3	Q3	Q3	Q3
R. Admin./legal barriers for CRE	R1	R1	R1	R1	R1	R2	R2	R2	R1	R2	R2	R1	R1	R1	R1
Y. Regulatory requirements	Y3	Y2	Y2	Y3	Y3	Y2	Y1	Y2	Y2	Y3	Y2	Y3	Y3	Y2	Y2
Z. Perceived extreme event	Z2	Z3	Z1	Z3	Z3	Z3	Z3	Z3	Z1	Z1	Z2	Z1	Z3	Z3	Z3

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