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THE ROLE OF CITIZENS IN THE EUROPEAN ENERGY TRANSITION

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par

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ABSTRACT

Anthropogenic climate change has been widely recognized as one of the largest challenges that we face today. In consequence, the majority of nations have agreed to reduce their greenhouse gas emissions. This requires a rapid transition to an efficient energy system based on renewable energy technologies. However, as past energy transitions have shown, technological changes never occur in isolation but are always interlinked with significant social, cultural, economic and political changes. As such, the current energy transition also offers the opportunity to combat poverty and inequality and strengthen democratic decision-making processes, for instance.

Community Energy Initiatives (CEIs), broadly defined as initiatives for the energy transition, that are directly owned and democratically controlled by citizens, are regarded as important contributors to the achievement of these goals. A plethora of largely case-based studies suggest that CEIs could provide a variety of benefits, ranging from deploying and increasing acceptance for renewable energy to increasing local economic value creation, combatting energy poverty, increasing transparency and participation in the energy sector and strengthening community trust and cohesion.

At the same time, a smaller number of studies have contested this generally positive outlook, showing that some CEIs may not be as democratic and inclusive, or provide as many benefits, as often assumed. This begs the question, to what extent the impacts that individual examples of CEI evidently generate, materialize on the aggregate level across the European community energy sector. In view of the increasing support for CEI by European policy-makers, who hope that CEIs contribute to the achievement of the European energy and sustainability transition goals, there is a need for a better understanding of the aggregate level impacts of CEIs, allowing more evidence-based policy-making.

This thesis aims to address these issues by investigating the evolution of the European community energy sector and the associated aggregate level impacts. It builds on an inventory of over 10,000 European CEIs that was compiled as part of an EU funded research project. The thesis follows three objectives. First, to map the diverse community energy sector across Europe in terms of organizational forms, activities and historical evolution. Second, to investigate current challenges in managing CEI data that hinder systematic monitoring of the sector's development and impacts. Finally, to investigate how CEIs align with European energy policy goals, as well as different notions of the energy transition, ranging from a technological transition to a deeper societal sustainability transition.

On the European level, this thesis identifies five distinct phases of CEI development, each characterized by specific archetypical CEIs and policy contexts. Most important for the recent development of CEIs have been two contrasting policy approaches to supporting CEI, being universal feed-in tariffs and tailored mechanisms directly targeted at CEI. Yet, while these recent targeted support mechanisms emphasize the social nature of CEIs, in contrast to the more market-oriented CEIs established as a result of feed-in tariffs, this new approach also comes with new challenges. Chief among these is an increased need for monitoring and the associated reporting burden on CEIs, in order to ensure their adherence to the new requirements and consequently their eligibility for such support mechanisms. Overly complex administrative procedures have already been identified as a key barrier to the success of CEIs, indicating that the increased reporting requirements may negatively affect future activity within the sector.

RÉSUMÉ

Le changement climatique anthropique est présenté comme l'un des plus grands défis auxquels nous sommes confrontés. En conséquence, la majorité des pays ont convenu de réduire leurs émissions de gaz à effet de serre. Cela nécessite une transition rapide vers un système énergétique efficace basé sur des technologies énergétiques renouvelables. Cependant, comme l'ont montré les transitions passées, les changements technologiques ne se produisent jamais de manière isolée, mais sont toujours liés à des changements sociaux, culturels, économiques et politiques. À ce titre, la transition énergétique actuelle offre la possibilité de lutter contre la pauvreté et les inégalités et de renforcer des processus décisionnels démocratiques, par exemple.

Les initiatives énergétiques communautaires (IEC), définies au sens large comme des initiatives en faveur de la transition énergétique mises en place et contrôlées démocratiquement par les citoyens, sont vues comme des leviers à la réalisation de ces objectifs. De nombreuses études, largement basées sur des cas concrets, suggèrent que les IEC peuvent offrir divers avantages, allant de l'installation et l'acceptation croissante des énergies renouvelables à la création de valeur économique locale, la lutte contre la précarité énergétique, l'amélioration de la transparence et de la participation dans le secteur de l'énergie ou le renforcement de la confiance et de la cohésion au sein des communautés locales.

Dans le même temps, un petit nombre d'études ont contesté cet vision optimiste, montrant que certaines IEC ne sont peut-être pas si démocratiques et inclusives, ou n'apportent pas autant d'avantages. Cela soulève une question: dans quelle mesure ces impacts supposés des IEC spécifiques se concrétisent-ils au niveau de l'ensemble du mouvement des IEC ? Compte tenu du soutien croissant des décideurs politiques européens en faveur des IEC, dans l'espoir que celles-ci contribuent à la réalisation des objectifs de transition énergétique et de durabilité, il est nécessaire de mieux comprendre les impacts globaux de l'IEC, afin de permettre l'élaboration de politiques davantage fondées sur les faits réels.

Cette thèse vise à aborder ces questions en étudiant l'évolution du secteur européen des IEC et ses impacts globaux. Elle s'appuie sur un inventaire de plus de 10000 IEC de l'Europe, compilé dans le cadre d'un projet de recherche financé par l'UE. La thèse poursuit trois objectifs. Premièrement, cartographier ce secteur diverse de l'énergie communautaire à travers l'Europe en termes de formes organisationnelles, d'activités et d'évolution historique. Deuxièmement, examiner les défis actuels de la gestion des données des IEC qui entravent le suivi systématique des impacts du secteur. Enfin, comprendre l'alignement des IEC avec les objectifs européens ainsi que différentes conceptions de la transition énergétique, allant d'une transition technologique à une transition sociétale plus profonde vers la durabilité.

Au niveau européen, cette thèse identifie cinq phases de développement des IEC, caractérisée par des IEC archétypiques et des contextes politiques spécifiques. Deux approches contrastées de soutien ont joué un rôle déterminant dans le développement des IEC: des tarifs de rachat universels et des mécanismes ciblés sur les IEC. Cependant, si ces récents mécanismes de soutien ciblé mettent l'accent sur la nature sociale des IEC, contrairement aux IEC plus orientés vers le marché mises en place grâce aux tarifs de rachat, cette nouvelle approche s'accompagne également de nouveaux défis comme un besoin de suivi et la charge de travail accrus IEC, afin de contrôler leur conformité aux nouvelles exigences et leur éligibilité à ces mécanismes de soutien. Des procédures administratives complexes ont été identifiées comme un obstacle majeur au succès des IEC, ce qui indique que ces exigences pourraient avoir un impact négatif sur le secteur.

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LIST OF ABBREVIATIONS

- CEC Citizen Energy Community (EU definition)
- CEI Community Energy Initiative
- COMETS Collective Action Models for the Energy Transition and Social Innovation (Horizon 2020 project)
- DGRV German Cooperative and Raiffeisen Confederation
- ENBP Energy by the People (database with 10,000 CEIs across Europe, serving as main source for empirical data for this thesis)
- FiT Feed-In Tariff
- GHG Greenhouse Gas
- PV Photovoltaic
- REC Renewable Energy Community (EU definition)
- SDG Sustainable Development Goals
- SEAI Sustainable Energy Authority of Ireland
- SEC Sustainable Energy Community

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1. INTRODUCTION

1.1. THE NEED FOR A TRANSITION TO A SUSTAINABLE ENERGY SYSTEM

Anthropogenic climate change is widely recognized as one of the major challenges of the 21st century. This is based on overwhelming scientific evidence as summarized by the Intergovernmental Panel on Climate Change (IPCC, 2022, e.g. 2023). Addressing this challenge requires first and foremost a drastic reduction in anthropogenic greenhouse gas (GHG) emissions. Recent estimates suggest the current fossil fuel based energy system accounts for at least half of total anthropogenic emissions (Dhakal et al., 2023).

Beyond its carbon intensity, our current energy system has faces additional criticism. The large international supply chains that are particularly associated with oil and natural gas imports and exports are vulnerable to disruptions in trade routes (Tagliapietra, 2020), geopolitical conflicts (c.f. IEA, 2023), and create dependencies on the limited number of exporting countries (Bahgat, 2006; Sovacool, 2012a). Other authors have pointed out energy justice related aspects, such as the issue of energy poverty. While this issue is predominantly associated with developing countries, where a significant percentage of the population lacks access to modern energy sources (González-Eguino, 2015; Sovacool, 2012b), it also persists in developed countries such as the USA (Bednar & Reames, 2020), or in Europe (Bouzarovski et al., 2012; European Commission, 2025; Hills, 2012), and describes the inability of people to afford sufficient energy to fulfil basic needs. The current energy system has also been criticized for its undemocratic nature. As a result of its technological complexity and dependence on large scale projects such as international energy transmission infrastructure or large power plants (e.g. nuclear power), the management of and decision-making for the energy system is dominated by a relatively small group of technical experts and private and state-run companies. Most of society is simply a passive consumer with little influence on the system (McHarg, 2016; Pepermans, 2019; Szulecki, 2018; Thombs, 2019; Walker et al., 2007).

With the adoption of the sustainable development goals (SDGs) as part of the Paris Agreement in 2015, the global community has agreed, among other goals, to take action against anthropogenic climate change (United Nations, 2015). Crucial to this goal is the transition from a fossil fuel-based energy system to a sustainable energy system based on efficient and renewable energy technologies (IPCC, 2011).Thus far, nearly all member countries of the United Nations (UN) have included the goal of increasing the share of renewable energy in their nationally determined contributions to climate change mitigation (United Nations, 2023). However, the SDGs not only set goals regarding the shift to renewable energy technologies but also emphasize the need for affordable and reliable energy access (SDG 7), as well as the interconnectedness of the energy-related goals to the other SDGs, such as reducing poverty (SDG1) and inequality (SDG 10). The granular and decentralized nature of most renewable energy technologies, such as solar photovoltaics (PV) or wind power, has a number of benefits that help address the above-mentioned challenges. They are characterized, for example, by lower investment risks, lower complexity, and more equitable access (Wilson et al., 2020). Consequently, they have the potential to diversify the landscape of actors in the energy sector, reducing the dependence on large energy producers and suppliers. With the increasing concerns about energy security since the Russian invasion of Ukraine, renewable energy technologies have also been discussed as a means to lower dependence on international supply chains, due to their reliance on local energy sources (European Commission, 2022a; IEA, 2022a). However, the sustainable energy transition will have to be accelerated significantly if the goal of limiting global warming to 1.5°C or at least 2°C above pre-industrial levels is to be achieved (IPCC, 2023).

1.2. EXPECTED CONTRIBUTIONS OF COMMUNITY ENERGY INITIATIVES TO THE SUSTAINABLE ENERGY TRANSITION

Community Energy Initiatives (CEIs), broadly defined as any entity that is democratically controlled and directly owned by citizens and engages in the energy transition (see also Section 3.2 for a more detailed definition), seem uniquely positioned to holistically address the various challenges of our energy system. First and foremost, CEIs directly contribute to the deployment of renewable energy technologies through various activities such as installing and operating renewable energy facilities, as well as electricity and district heating grids, investing in renewable energy projects owned by other stakeholders, and providing mobility services such as electric vehicle charging stations or car and bike sharing solutions (Schwanitz, Wierling, et al., 2023; Wierling, Zeiss, et al., 2022). Pons-Seres De Brauwer and Cohen (2020) estimate that by 2030 CEIs could mobilize significant financial investment into renewable energy technologies. Beyond direct investments, CEIs could also contribute to the energy transition by inspiring behaviour change among citizens, such as reducing their energy consumption (Becker & Kunze, 2014; Burchell et al., 2014), as well as providing consulting services and discounted bulk purchases of renewable energy equipment to anyone considering renewable energy investments (Viardot, 2013). CEIs are also often credited with increasing the acceptance of renewable energy technologies (Huybrechts & Mertens, 2014; Musall & Kuik, 2011; Tarhan, 2015; Warren & McFadyen, 2010), as their democratic decision-making model allows for more participation by local communities in the planning process, and they tend to share the benefits among local stakeholders. Furthermore, it is stated that they increase transparency regarding the origin and pricing of energy and reduce dependence on large incumbent actors, while countering monopolistic market structures (Huybrechts & Mertens, 2014). Through conducting awareness raising campaigns and providing a variety of education and training options, CEIs could also increase energy literacy among the public (Berka & Creamer, 2018; Bielig et al., 2022; Huybrechts & Mertens, 2014). Finally, it has been claimed that CEIs reduce energy poverty, for instance, by providing lower energy prices or supporting low-income households in conducting energy efficiency upgrades (Bielig et al., 2022; Huybrechts & Mertens, 2014).

In line with the idea that all the SDGs are interlinked and cannot be addressed in isolation, CEIs are also credited with providing various other social and economic benefits beyond the above-mentioned contributions to SDG 7 (clean and affordable energy) and 13 (climate action). Several literature reviews on the benefits of CEIs have summarized the evidence suggesting that CEIs may be generating a variety of benefits beyond purely financial profits for their members or shareholders (Berka & Creamer, 2018; Bielig et al., 2022; Brummer, 2018; Tarhan, 2015). CEIs could generate social capital in the areas in which they operate, for instance, by strengthening local social networks and social cohesion, while also being a source of pride when projects initiated by CEIs succeed, leading to a stronger sense of community. Through their participation in CEIs, local citizens may gain new technical or administrative skills, thereby contributing to the empowerment of the local community, as well as potentially leading to new technical, social or business innovations. Due to their participatory nature, CEIs also offer a platform for citizens to actively engage in the energy sector, increasing political representation, involvement in energy planning, and changing power structures. Finally, CEIs could contribute to local economic value creation by generating and reinvesting profits into further local projects and creating job opportunities.

The benefits associated with CEIs are also echoed by various umbrella organizations and networks. On the European level, the European REScoop Federation of Citizen Energy Cooperatives points out the advantages of CEIs (REScoop, 2025b), while the same takes place on the national level by organizations such as Énergie Partagée (Énergie Partagée, n.d.-b) and Centrales Villageoises (Centrales Villagoises, n.d.) in France, Bündnis Bürgerenergie (Bündnis Bürgerenergie, n.d.) in Germany or HIER opgewekt (HIER opgewekt, 2025) in the Netherlands.

The EU funded COMETS project, on which this thesis builds (see Section 2.2.1), identified a number of examples of especially innovative initiatives emphasizing some of the benefits outlined above, which are presented in the 'Power to & by the People' documentary (Bellier et al., 2023). These range from designing self-sufficient island communities in Croatia, children's cooperatives in Belgium, homeowner initiatives helping each other install solar PV facilities in Switzerland, to cooperatives in Ireland that combat energy poverty though supporting citizens in energy efficiency retrofitting their homes. Such examples show that CEIs actually have the potential to address numerous challenges related to our current energy system.

Recently, with the official recognition of 'renewable energy communities' (RECs) (Directive 2018/2001) and 'citizen energy communities' (CECs) (Directive 2019/944), the EU has also acknowledged the potential role that CEIs can play in the energy transition. The Directive (EU) 2019/944, recital 43 specifically states that:

> *'By directly engaging with consumers, community energy initiatives demonstrate their potential to facilitate the uptake of new technologies and consumption patterns, including smart distribution grids and demand response, in an integrated manner. Community energy can also advance energy efficiency at household level and help fight energy poverty through reduced consumption and lower supply tariffs. Community energy also enables certain groups of household customers to participate in the electricity markets, who otherwise might not have been able to do so. Where they have been successfully operated such initiatives have delivered economic, social and environmental benefits to the community that go beyond the mere benefits derived from the provision of energy services.'*

1.3. LIMITED EVIDENCE-BASE FOR CONTRIBUTIONS OF COMMUNITY ENERGY INITIATIVES TO THE SUSTAINABLE ENERGY TRANSITION ON AN AGGREGATE LEVEL

As Section 1.2 has shown, CEIs are credited with a variety of contributions to the sustainable energy transition, as well as wider societal transformation, yet the actual evidence base for their aggregate impact remains fragmented and less conclusive. While the CEI literature has been growing in recent decades, employing a variety of theoretical approaches ranging from transition studies to sociological and economic investigations (van der Schoor, 2019), there is a lack of generalizable empirical data beyond investigations of individual or small samples of CEIs (Berka & Creamer, 2018; Bielig et al., 2022; Holstenkamp & Radtke, 2018; Schwanitz, Wierling, et al., 2023; Seyfang et al., 2012; Walker, 2011). Such case-based investigations are also often focused on highly successful cases or best practice examples (Seyfang et al., 2013). Furthermore, the literature – and empirical investigations in particular – tend to focus on the drivers and barriers for CEI development, while their positive impact (benefit) is often simply taken as granted without further reflection (Creamer et al., 2019). The literature is also geographically concentrated, not only on Europe, but specifically on only a few countries in Europe. While concepts related to community energy have been investigated, for instance, under the terms of 'Bürgerenergie' in Germany or 'Énergies partagées' in France (Becker & Kunze, 2014), the literature has traditionally been dominated by studies on the UK community energy sector (Becker et al., 2017; Bielig et al., 2022; Brummer, 2018; Hewitt et al., 2019; van der Schoor, 2019). Even though the UK community energy sector is very diverse (Seyfang et al., 2013), community development trusts, community interest companies and community benefit societies have been prominent forms of CEIs, particularly in Scotland (Hewitt et al., 2019) where, in terms of capacity, the most CEI activity has taken place (Harnmeijer et al., 2018). These legal forms have a clear community benefit orientation, often even being legally banned from distributing surplus profits to their members (Coalfields Regeneration Trust, 2020; Hewitt et al., 2019). In contrast, the legal form of cooperative, which has traditionally been a more common form of CEIs in other countries (Savaresi, 2019), may exhibit more market-oriented characteristics, focusing on providing financial benefits for its members (Dilger et al., 2017). The diverse nature of this 'pluralistic sector' (see also Bauwens et al., 2022; Seyfang et al., 2014, p. 25) poses the question to what degree findings from a specific context, such as the UK, can be generalized to the phenomenon of CEIs as a whole.

The above factors are underpinned by existing evidence that contests the overwhelmingly positive narrative around CEIs. Huybrechts and Mertens (2014) and Hanke et al. (2021), for instance, find examples of CEIs that charge either higher or lower electricity prices compared to national averages. Walker et al. (2010) show that some initiatives labelled CEIs are actually more similar to traditional enterprises focused on profit maximization. Other authors (e.g. Simcock, 2013, 2016; Van Veelen, 2018) have also pointed out that CEIs are not always as democratic as often assumed. There seems to be a tendency for CEIs to be run by a small group of 'usual suspects' (Van Veelen, 2018, p. 652), with a large percentage of the member base not actively participating in decision-making processes, meaning that such cases may even lead to an increase in local resistance and social conflict. Rommel et al. (2018) also find a trend that active participation of members declines in larger CEIs. A study of 71 European CEIs also finds that there is limited involvement of vulnerable groups in the decision-making of CEIs (Hanke et al., 2021).

2. RESEARCH OBJECTIVE AND DESIGN

2.1. RESEARCH OBJECTIVE

As pointed out in the previous section, numerous case study investigations have shown that individual CEIs provide a variety of benefits, contributing to both the energy transition and a wider transformation to a sustainable society. However, evidence of the extent to which these manifest at the aggregate level is lacking (Berka & Creamer, 2018; Bielig et al., 2022). The issue of limited aggregate level evidence is based on the lack of systematic collecting and managing of CEI data (Schwanitz, Wierling, et al., 2023; Wierling et al., 2018, 2023). Consequently, the limited number of previous aggregate level studies have been focused on individual or small groups of countries (e.g. Hewitt et al., 2019; Seyfang et al., 2013). In order to avoid biased generalizations based on small samples and individual case studies, more quantitative, large sample studies have been recommended (e.g. Bielig et al., 2022).

With the acknowledgement of international treaties such as the Agenda 2030 on Sustainable Development and the Paris Agreement on Climate Change, the participating countries have committed to fulfilling the goals contained therein. In order to measure their respective progress towards reaching the targets, the countries have agreed to undertake regular assessments and reporting (United Nations, 2014; United Nations Development Group, n.d.). The official acknowledgement of CEIs by the EU (Directive 2018/2001; Directive 2019/944) and the considerable EU funding provided to projects aimed at investigating and/or supporting the development of CEIs (European Commission, 2022b, 2023b, e.g. 2024a, 2024b; European Energy Communities Facility, 2025a; Interreg Europe, 2025) show that there is significant political interest in CEIs as potential contributors to the achievement of these goals. This has led to a number of existing or planned support mechanisms directly targeted at CEIs (BMWE, 2024; Energy Communities Repository, 2024; European Energy Communities Facility, 2025a; Directive 2018/2001; Directive 2019/944). Thus, building on the concept of evidence-based policy-making requiring the ability to evaluate the effectiveness of enacted policies (Sanderson, 2002), the EU is calling for a more systematic and continuous monitoring of CEI contributions to the European energy transition (Energy Communities Repository, 2024). Consequently, the overarching objective of this thesis is to investigate whether CEIs constitute a phenomenon that goes beyond the impact that single, isolated projects could achieve. The thesis addresses the following research questions:

- RQ 1: How has the community energy sector developed across Europe in the past and what is its current state?
- RQ 2: What are the current challenges related to the monitoring of CEI activities and impact in Europe?
- RQ 3: How do CEI activities contribute to the energy transition on an aggregate level and how do these contributions align with European energy policy objectives?

RQ 1 investigates the development of the landscape of European CEIs, identifying several distinct phases of CEI development. RQ 2 investigates the current monitoring and reporting procedures for CEI activities and impact in Europe, discussing the main challenges associated with existing practices in terms of data availability and measurement methods. RQ 3 then investigates how CEIs contribute on an aggregate level to the different aspects of the energy transition, ranging from a purely technological transition to a more substantial societal transition beyond the energy sector, in line with broader sustainability transitions (see Section 3.1). The findings in RQ 3 will then be put into context with the European energy policy objectives.

2.2. RESEARCH DESIGN

2.2.1. Thesis context

The thesis is linked to the Horizon 2020 project 'COMETS - COllective action Models for the Energy Transition and Social innovation (grant agreement ID: 837722) (European Commission, 2024a). The COMETS project ran from 2019 to 2022, with the goal of investigating the development of Collective Action Initiatives for the energy transition[1] on an aggregate European level. The COMETS project set out to compile a Europe-wide inventory of CEIs, to be able to better understand the drivers, barriers and motivations for establishing CEIs as well as their aggregate level impact. It further strived to develop and test tools to support CEIs. The present author was involved in the COMETS project throughout its duration, contributing to the data collection for the inventory of European CEIs. The resulting open-access 'Energy by the People' (ENBP) inventory (Wierling, Schwanitz, et al., 2022) serves as the main data basis for this thesis.

2.2.2. Geographical focus

CEI are a global phenomenon and exist outside of Europe, for example, in the USA, Canada and New Zealand (e.g. Brummer, 2018; Gilcrease et al., 2022; Holstenkamp & Radtke, 2018). This thesis, however, is limited to the EU, plus Norway, Switzerland and the United Kingdom, mainly due to its connection to COMETS, an EU-funded research project. Beyond this practical reason, several additional factors speak for a focus on Europe. First, the EU has a clear commitment to the energy transition on a supra-national level (European Commission, 2010, 2019b, 2022a). Second, the significant political interest in the concept of community energy in Europe (cf. Energy Communities Repository, 2024; Directive 2018/2001; Directive 2019/944) highlights the need for a better understanding of the impact of CEIs to ensure evidence based policy-making. Third, Europe is also characterized by relatively homogenous governmental systems and legal traditions (Glenn, 2004; Metin & Ünal, 2022). Lastly, European countries also face similar energy transition challenges (c.f. IEA, 2023). At the same time, variations in terms of available renewable energy resources, cultural context or national transpositions of the overarching European goals allow for a discussion of the influence of such factors on CEI development and their impact under otherwise similar conditions.

[1] Note that the term "Collective Action Initiatives for the energy transition" used in the COMETS project is the same as the term "Community Energy Initiatives" that is used in this thesis. The choice to switch from "Collective Action Initiative" to "Community Energy Initiative" was made to ensure terminological consistency with the recent EU definitions of Energy Communities (European Parliament, 2018, 2019), that have not been in force at the time of writing the proposal for the COMETS project.

2.2.3. Overall theoretical approach

Bielig et al. (2022) have recommended promoting mixed-methods approaches for the study of CEI impact as these have the potential to combine the strengths of both qualitative and quantitative methods. As such they allow for causal inferences that are typical for large sample quantitative studies while maintaining the depth of qualitative methods. Common mixed-methods approaches initially use qualitative methods during an exploratory phase to develop assumptions and hypotheses on a research topic, which are then tested quantitatively in large-sample studies during the second confirmatory phase (Flynn, 2021). While often dominated by qualitative studies, the exploratory phase is otherwise comparably open to a variety of concepts, and theoretical and methodological perspectives. In contrast, the latter confirmatory phase is characterized by a narrowing towards a more standardized and rigid research approach, for the sake of generalizability and comparability (Flynn, 2021; Stebbins, 2001; Stockemer, 2019). In the past, CEI research has been dominated by qualitative case studies, employing a variety of different theoretical perspectives and definitions of CEIs (Bauwens et al., 2022; van der Schoor, 2019) that are typical for exploratory research. Recent calls for more systematic monitoring of the community energy sector (e.g. Energy Communities Repository, 2024) and initial efforts to formalize the concept of CEIs with the two EU definitions of RECs and CECs by the EU (Directive 2018/2001; Directive 2019/944) indicate a shift from the previous exploratory phase to a confirmatory phase. This thesis is therefore situated within the second of the two phases common in mixed-methods approaches. Using a large sample of 10,000 CEIs across Europe, this thesis investigates the extent to which previous statements that were mainly derived from case studies apply to the community energy sector in general. The large-sample statistical investigation of the community energy sector also has the advantage of depicting the dynamic historical development of CEIs, which is crucial for RQ 1. The large sample with broad inclusion criteria (See Section 4.1.1) also captures a variety of borderline CEI cases in terms of organizational form or activities, which have seen less focus in previous case-study-based investigations. The openness in terms of inclusion criteria also allows for a discussion of the extent to which different types of CEIs align with the narrower definitions proposed by the EU.

While RQ 1 is simply investigated through the use of descriptive statistics regarding the historical development and current state of the community energy sector in Europe, RQ 2 and RQ 3 use a separate theoretical framing, respectively. Two aspects are of importance regarding the challenges in the current monitoring of CEI activities and impact (RQ 2). First an understanding of the existing process of compiling CEI-related data and second, a discussion of the quality of the indicators used to assess CEI impact derived from the collected data. For the first aspect, the FAIR data principles (Wilkinson et al., 2016) are used as a frame of reference. While they are oriented towards research data, the core concepts are also helpful when assessing the availability and quality of non-academic data such as in official governmental registers or privately operated databases. The FAIR principles propose that data should be (I) Findable, meaning they come with detailed metadata and are uniquely identifiable, (II) Accessible, meaning they should be openly accessible to the extent that, for example, data protection regulations allow it, (III) Interoperable, meaning they adhere to common standards and vocabularies allowing for easy integration of the data with other data sources, and (IV) Reusable, meaning the data are clearly licensed and have information of origin. Adherence to the FAIR principles therefore increases the transparency and shareability of data. Given that data are increasingly handled by machines through (partially) automated processes, the FAIR principles also specifically emphasise their applicability to both human- and machine-driven data collection, -curation and analysis processes. The second aspect, being the quality of CEI impact indicators, builds on the workflow for indicator quality evaluation that was developed in Paper VII of this thesis (see Section 4.2.5). This workflow uses insights from the literature on impact assessment (Bodem-Schrötgens & Becker, 2019; Ebrahim & Rangan, 2014; e.g. Niemeijer & De Groot, 2008; Vanclay, 2002) and indicator development (European Commission, 2023a; Eurostat, 2014; Gebara et al., 2024; e.g. Joumard & Gudmundsson, 2010) to guide the evaluation of the accuracy, usability, interpretability, and understandability of CEI impact indicators.

RQ 3 investigates the impact of CEIs and how these align with different perspectives of the energy transition and related energy policy objectives. For this purpose, Section 3.4 initially outlines how different definitions of CEIs, perspectives of the energy transition and European energy policy objectives align with each other. The conceptualization of the energy transition builds on the literature on green growth and degrowth (Belmonte-Ureña et al., 2021; Demaria et al., 2013; Hickel & Kallis, 2019; Latouche, 2009; e.g. Parrique et al., 2019) to envision the energy transition as a spectrum ranging from a purely technological shift on the one hand to a more fundamental societal shift on the other. Applying the green growth concept to the energy transition implies a mostly technological shift towards renewable energy. While technological shifts may lead to profound socio-cultural changes, green growth does not actively seek to break with the current growth-oriented paradigm. Degrowth, on the other hand, represents a fundamental shift towards a more just and democratic society with 'an emphasis on quality of life rather than quantity of consumption' (Research & Degrowth, 2010, p. 524) (see also Section 3.1). Using this framing, RQ 3 investigates whether CEIs predominantly contribute to the technological transition towards renewable energy or whether they contribute to a deeper societal change, and how these contributions align with European energy policy objectives.

Previous studies have referred to the social, environmental and economic effects that CEIs generate as 'contributions' (e.g. Schwanitz, Wierling, et al., 2023; Wierling, Zeiss, et al., 2021), 'impact' (e.g. Berka & Creamer, 2018; Okkonen & Lehtonen, 2016) or 'benefits' (e.g. Brummer, 2018; Ceglia et al., 2022). For the sake of terminological consistency, in the following, the term 'benefits' will be used to describe the positive effects of CEIs, 'impact' will be used when discussing both the positive and negative effects of CEIs on a more general level, while 'contributions' (to the energy transition/ European energy policy objectives) will be used when specifically discussing the impact off CEIs in relation to the different conceptualizations of the energy transition or the European energy policy objectives.

2.2.4. Overall approach to data collection

The publications included in this thesis are mainly based on the data contained in the ENBP inventory (see also Section 4.1.1). The ENBP inventory is the result of a three-year data collection conducted as part of the COMETS project. While the COMETS project also conducted several interview- and survey-based exploratory case studies, as is typical for this research field (c.f. Bielig et al., 2022; Holstenkamp & Radtke, 2018), a different approach was adopted for the compilation of the ENBP inventory. Instead, preexisting but at this point highly fragmented data were aggregated from national business registers, databases on renewable energy facilities, CEI umbrella organizations, as well as individual CEI websites and media articles. This approach allowed for a high coverage of CEIs across Europe, identifying more than 10,000 cases. The detailed data collection approach is summarized in Paper I (Section 4.1.1) and is therefore not discussed further here. While the decision to rely on pre-existing data limited the depth of data that could be collected for each CEI, it allowed for far greater coverage in terms of sample size, which serves the purpose of this thesis to investigate the community energy sector on an aggregate level. A further added benefit of the chosen approach was the possibility of gaining a detailed understanding of the systems for CEI data reporting and monitoring that are currently in place across Europe. This is crucial to answer RQ 2.

2.3. OVERVIEW OF PAPERS

The thesis builds on seven journal articles and one book chapter and includes 6 co-author and 2 first-author papers (see Table 1). Papers I and II summarize the compilation of the ENBP inventory on European CEIs and the main aggregate findings for the complete sample of CEIs contained in the database. These serve as the overarching papers providing an overview of the community energy sector in Europe. The ENBP inventory also serves as the data basis for the following papers. Papers III – VIII represent focus papers that go into more detail on specific thematic or geographic areas. Papers VII and VIII, in which the doctoral student is the first author, expand on the previous results to specifically discuss the current approaches to CEI impact monitoring (RQ 2) and the extent to which CEIs go beyond current green growth narratives focused on technological change, aiming for more fundamental societal change (RQ 3). Table 1 links the papers to the respective research questions of this thesis. Note that the papers are not listed in chronological order, but follow a logical structure, with Papers I and II being listed as the first papers as they describe the ENBP inventory that is also used in the other papers. While each paper differs in the detailed theoretical foundation and methodological approach, the papers are generally situated in the second phase of mixed-methods approaches characterized by large sample, quantitative investigations, as outlined in Section 2.2.3. Where necessary, more details on the respective research approaches of each paper will be provided in Section 4.

Table 1: Overview of publications and link to research questions

Publication Nr.	Topic/ Research Question of the paper	Link to research questions of the thesis
I	Presentation of the process of compiling the ENBP inventory, a Europe-wide inventory of over 10,000 Community Energy Initiatives across 29 countries	Presentation of data used as the basis for the following papers **RQ 2:** Challenges in the monitoring of the community energy sector
II	Key statistics on European Community Energy Initiatives derived from the ENBP inventory, estimating the people involved, renewable energy capacities installed, and finances invested	**RQ 1:** Historical development and current state of the community energy sector in Europe **RQ 2:** Challenges in the monitoring of the community energy sector **RQ 3:** CEI contributions to the energy transition
III	Investigation of the development of energy cooperatives in Austria, Germany, Denmark and the UK	**RQ 1:** Historical development and current state of the community energy sector in Europe **RQ 3:** CEI contributions to the energy transition
IV	Historical development of energy cooperatives in Europe and investigation of their inclusivity in terms of the demography of members and steering committees	**RQ 1:** Historical development and current state of the community energy sector in Europe **RQ 3:** CEI contributions to the energy transition
V	Investigation of aggregate statistics, development barriers and geographical distribution of German and Italian Community Energy Initiatives active in solar photovoltaic energy	**RQ 3:** CEI contributions to the energy transition
VI	Investigation of the evolution of business models that are deployed by German energy cooperatives active in the solar photovoltaics sector	**RQ 1:** Historical development and current state of the community energy sector in Europe **RQ 3:** CEI contributions to the energy transition
VII	Development and application of a workflow for the evaluation of the quality of indicators used to assess CEI impact	**RQ 2:** Challenges in the monitoring of the community energy sector
VIII	Investigation of the alignment of Community Energy Initiatives with the core ideas of degrowth	**RQ 3:** CEI contributions to the energy transition

Paper I summarizes the data collection and final ENBP inventory (Wierling, Schwanitz, et al., 2022), which is available open source to the public. The ENBP inventory contains data on over 10,000 CEIs in the EU plus Norway, the UK and Switzerland. For each entry, it covers four main categories: (I) administrative data, (II) data on the CEI's activities, (III) data on tangible assets, and (IV) time-resolved data. The data described in this paper serve as the basis for the following papers. The supplementary material for the paper provides a detailed overview of the available data sources on CEIs for each included country, thereby contributing to the discussion of RQ 2.

Paper II provides aggregate statistics for the total sample of CEIs in the ENBP inventory, including the number of projects conducted, number of people involved, renewable energy capacities installed, and finances invested by CEIs in Europe. The paper allows for an overarching understanding of the community energy sector in Europe, showing its historical development and where CEIs are/have been especially active. Given the inconsistency of reporting in the various European countries, the paper develops strategies to estimate missing data in order to generate aggregate values for the above indicators. The paper offers detailed supplementary material containing information on the exact method of estimation for each country. The paper contributes to the research questions by mapping the landscape of CEIs across Europe (RQ 1) and quantifying the contribution of CEIs to the energy transition in terms of the above-mentioned indicators (RQ 3). To a lesser extent it also contributes to RQ 2 by providing information on the feasibility and reliability of estimating the mentioned contributions.

Paper III represents the first of the following papers focused on more specific thematic or geographical areas. Specifically, Paper III investigates in more detail the development of energy cooperatives in Austria, Germany, the UK and Denmark. These are among those countries with the highest level of CEI activity in Europe. However, the paper focuses exclusively on energy cooperatives, which are only one form of CEIs, even though they represent the most common form. The paper describes in detail the historical development of such CEIs in the four countries, linking it to important regulatory and policy developments. With its investigation of the historical development of CEIs and the associated drivers, it mainly addresses RQ 1. To a lesser extent, the investigation of membership dynamics conducted in this paper is also linked to RQ 3 as this relates to the contribution of CEIs to democratizing the energy sector.

Paper IV, which is a chapter in the book called 'Paradigms, Models, Scenarios and Practices for Strong Sustainability' (Diemer et al., 2020), investigates who participates in CEIs. Using statistical evidence from Denmark, Germany and Sweden, it re-evaluates claims about the inclusive and democratic control and ownership of CEIs. The chapter studies the spatial distribution of CEI members, the age distribution and gender ratio of members of CEI steering committees, as well as whether CEIs are predominantly located in areas characterized by higher or lower average household income. Thus, the chapter mainly provides insight into RQ 3, showing the extent to which CEIs are actually representative of a more substantial transformation to an inclusive, just and democratic society, beyond the technological energy transition to renewable energy. To a lesser extent, Paper IV also addresses RQ 1, as it also discusses the historical development of CEIs in Europe.

Paper V focuses specifically on CEIs in Germany and Italy that are active in the solar PV sector. The paper studies the role of CEIs in the upscaling of solar PV facilities in the two countries. It investigates the size of the PV facilities that CEIs predominantly install, as well as the geographical distribution of CEI activity. For this purpose, the paper compares CEI activity with regional population densities, income levels and structural characteristics (rural/ urban). The paper also tests a previous claim that CEIs face higher costs for installation, operation and maintenance of PV facilities compared to other incumbent actors. This claim was based on a far smaller sample of CEIs (IEA-RETD, 2016). In doing so, Paper V addresses RQ 3, providing evidence on how CEIs contribute to the European energy transition from a technological perspective.

Paper VI maps the different business models employed by German CEIs that are active in the PV sector. Using a business model canvas for CEIs (Dilger et al., 2017; c.f. Osterwalder & Pigneur, 2010), the paper identifies nine different commonly used business models. These are characterized by different activities, key partners and resources, revenue streams, and in terms of the value proposition for both customers and members. The paper investigates which of the nine business models are the most common and how CEIs have diversified their portfolio in response to regulatory changes. Thus, the mapping of business models and their evolution contributes to a better understanding of the community energy sector (see RQ 1). Showing that the studied CEIs tend to prioritize economic over social community benefit goals, this paper also provides more insight into RQ 3, as this indicates that they mainly operate within the current growth oriented economic paradigm instead of striving for more deep-rooted societal change.

Paper VII develops and applies a workflow to evaluate the quality of the indicators used to assess CEI impact. Various efforts to identify and measure the potential impact that CEIs could generate have been initiated by the scientific community, government actors, as well as CEIs and CEI umbrella organizations themselves. However, critical reflection on the quality of the indicators used to measure such impact is often missing. The developed workflow aims to facilitate a more systematic discussion of the accuracy, usability, interpretability and understandability of the indicators used in CEI impact assessments. The workflow was developed by translating the findings from the literature on impact assessment and indicator development (Eurostat, 2014; Gebara et al., 2024; e.g. Joumard & Gudmundsson, 2010; Niemeijer & De Groot, 2008; Vanclay, 2002) to the CEI domain. With the help of the developed workflow, the paper compares exemplary cases of CEI impact assessments conducted by the scientific community, government actors, as well as CEIs and CEI umbrella organizations. The paper specifically addresses RQ 2, by both identifying existing issues and best practices in CEI impact monitoring as well as presenting a potential frame of reference to guide a more systematic future monitoring.

Paper VIII investigates the extent to which CEIs align with five degrowth imperatives. For this purpose, an initial review of the degrowth literature identified the most common degrowth imperatives. These revolve around (I) reducing environmental impact, (II) re-orienting current economic priorities from economic growth to human well-being, (III) reducing inequalities in wealth and resource distribution, (IV) strengthening (direct) democratic decision-making, and (V) re-localization of production and consumption. While individual examples of CEIs are closely aligned with these imperatives, the extent to which the community energy sector is representative of these imperatives on an aggregate level is questionable. The paper aims to offer insight into this question by providing key statistics for the sample of CEIs from the ENBP inventory as well as a more in-depth comparison of French and German CEIs. As such, the paper directly addresses RQ 3, questioning whether CEIs are representative of a radical societal transformation as envisaged by the degrowth movement, or continue to operate within the current growth-oriented paradigm.

2.4. THESIS OUTLINE

In order to answer the research questions, the thesis is structured as follows: **Section 3** provides the background for the thesis. This section first conceptualizes the different aspects of the energy transition along a spectrum ranging from purely technological change to more fundamental societal change using insights from the green growth and degrowth literature. This serves as a guiding framework to discuss the transformative potential of CEIs. The background section then provides a more detailed conceptualization of CEIs. Third, an overview of the most relevant European energy policy objectives and the progress towards their achievement in given. The section concludes with a discussion about the extent to which the different perspectives on the energy transition align with European energy policy objectives and the different definitions of CEIs. **Section 4** summarizes the methods and main results of the papers included in this thesis. Note that the thesis does not contain a specific chapter on methodology. The general data compilation approach for the ENBP inventory, which serves as the basis for all included publications is summarized in Paper I (See Section 4.1.1). Furthermore, in line with mixed-methods approaches, the included publications investigate the CEI phenomenon from a variety of specific methodological perspectives. Hence, where necessary, the specific methodological approaches, beyond the general data collection, are described in the respective sections for each paper (Section 4). **Section 5** synthesizes the results of the papers to answer the three research questions. First, it provides an overview of the historical development and current state of CEIs in Europe (RQ 1). This is followed by a discussion on the current reporting and monitoring procedures for CEIs (RQ 2). The last subsection discusses CEI contributions to the different perspectives of the energy transition and European energy policy objectives. **Section 6** summarizes the findings of this thesis and discusses the associated policy implications. **Section 7** discusses the validity of the results and potential limitations, separated into conceptual and methodological validity. **Section 8** provides an outlook, in terms of both future research and monitoring needs, as well as how the currently changing political landscape may affect the future development of the community energy sector. Finally, **Section 9** concludes the thesis.

3. BACKGROUND

3.1. CONCEPTUALIZING ENERGY TRANSITIONS

In its simplest conceptualization, ‘Energy Transition’ describes the shift of an energy system that is reliant on one dominant energy commodity to a new system that largely utilizes a different energy commodity (Fouquet & Pearson, 2012; Laird, 2013; Sciullo et al., 2020). Energy transitions can occur at various temporal and spatial scales (Sovacool, 2016). At the global level, two significant historical energy transitions have been the shift from traditional biomass to coal and the subsequent introduction of oil into the energy system (Smil, 2016; Solomon & Krishna, 2011). However, as history shows, each of the past energy transitions has not only been a technological shift, but has been accompanied by drastic cultural, economic, social and political changes (Fischer-Kowalski et al., 2019; Fouquet & Pearson, 2012; T. Mitchell, 2009). Similarly, the current ongoing transition to a sustainable energy system based on renewable energy technologies is conceived as more than simply a technological shift. Unsurprisingly then, various authors have criticized the technocentric approach to studying energy transitions, arguing for a stronger focus on the social aspects of energy transitions (Hirsh & Jones, 2014; Laird, 2013; Miller et al., 2013; Sovacool, 2014). This has led to new conceptual approaches to studying energy transitions (Grubler, 2012; Sovacool, 2016; Sovacool & Hess, 2017), most notably socio-technical transitions (Geels, 2002; Geels & Schot, 2007). Socio-technical transition studies aim to better understand the interplay between technological innovation and societal change. While this research field not only encompasses energy transitions but all kinds of socio-technical transitions, the study of energy transitions is a key component, given the importance of energy systems to the modern economy (Miller et al., 2013).

However, when comparing previous energy transitions with the current transition, a key difference emerges. Previous energy transitions were driven by opportunity, through new technological innovations, which provided the same energy service in a less costly or more efficient fashion or with additional benefits (Fouquet, 2010). However, the current energy transition is driven by a need to move to a more sustainable energy system. As stated by Grubler (2012, p. 8), 'the need for the "next" energy transition is widely apparent as current energy systems are simply unsustainable on all accounts of social, economic and environmental criteria'. The current energy transition's 'fundamental raison d'etre is the prevention of excessive rise of average tropospheric temperature' (Smil, 2016, p. 195). Contrary to previous energy transitions, the current transition has a defined goal and is driven by purposeful decision-making (Markard et al., 2012; Smith et al., 2005). As such, there is a need to define the envisioned end-state of the transition process, allowing for goal-oriented coordination. Consequently, in the field of socio-technical transition studies, two research streams have emerged, an analytical-descriptive stream, and a normative stream (Sovacool & Hess, 2017). The first stream aims to understand the processes and dynamics of socio-technical transitions, while the second stream aims to envision the characteristics of the end-state of the transition process. Those transitions that are guided by a normative imperative to move to a more sustainable society are commonly referred to as 'sustainability transitions' (Markard et al., 2012).

However, what actually constitutes such a new, more sustainable society remains a point of contention. As a framing for the discussion in this thesis on how CEIs contribute to the energy transition, this discourse will be conceptualized as a spectrum ranging from green growth on the one end to degrowth on the other, as shown in Figure 1 (Haberl et al., 2020; cf. Khmara & Kronenberg, 2020). Green growth[2] represents a techno-optimist perspective, arguing that current challenges in the energy system (most notably the associated GHG emissions) can be addressed (almost) exclusively through technological change. While, as pointed out earlier, every technological change also encompasses some degree of social change, green growth continues to adhere to the core characteristics of our capitalist and growth-oriented society (Faccer et al., 2014). Supported by international institutions such as the OECD, the World Bank and the UN the

[2] There are various other terms that describe similar discourses, such as Eco-modernization (Martínez-Alier et al., 2010; Polewsky et al., 2024) or the incremental/reformist/transformative discourse (Belmonte-Ureña et al., 2021; Faccer et al., 2014)

concept of green growth emerged in earnest in the early 2000s as response to the imminent environmental crises, such as global warming, biodiversity loss and pollution (Hickel & Kallis, 2019; Ossewaarde & Ossewaarde-Lowtoo, 2020). While the OECD (2011), the World Bank (2012) and the United Nations (2011) use somewhat different definitions, they can be collectively paraphrased as meaning 'fostering economic growth, while avoiding environmental impact'. Green growth assumes that absolute decoupling is possible, meaning that economic growth can be separated from resource use and environmental degradation through efficiency improvements and increased recycling and reuse, as well as shifting to less resource-intensive and environmentally-harmful economic activities such as the service economy (Haberl et al., 2020; Polewsky et al., 2024; Vadén et al., 2020). As evident in the development narratives of international institutions (European Commission, 2019b; e.g. World Bank, 2012), the required technological advancements are also regarded as an opportunity to foster economic growth which, in turn, will improve the living conditions and wellbeing of global society at large. Following its emergence on the global stage, the green growth idea also became the dominant paradigm for sustainability transitions in the EU after the financial crises of the late 2000s and early 2010s (Ossewaarde & Ossewaarde-Lowtoo, 2020). In the context of the energy transition, green growth entails a shift towards renewable energy technologies and/or towards more energy-efficient technologies.

While there is evidence that a degree of decoupling is occurring in certain geographically confined regions, a common criticism argues that this is a result of an outsourcing of especially resource-intensive and environmentally-harmful economic sectors to other regions. As such, these findings do not indicate a decoupling at the global level but simply a geographical re-location of the environmental burden (Bithas & Kalimeris, 2018; Vadén et al., 2020). This is the starting point of the degrowth discourse, whose proponents argue that the absolute decoupling of economic growth from resource use and environmental impact is impossible (Hickel & Kallis, 2019; Parrique et al., 2019; Schneider et al., 2010). Thus, the degrowth discourse represents the other side of the sustainability transition spectrum. Its theoretical foundation is based on the works of Meadows et al. (1974), Daly (Daly, 1972, 1991) and Georgescu-Roegen (1977), who argue that continued economic growth is impossible in a closed system and is limited by the earth's planetary boundaries (Steffen et al., 2015). Consequently, the only option to achieving a sustainable society is to abandon the growth imperative and actively reduce economic throughput (Research & Degrowth, 2010; Trainer, 2012). As such, degrowth proponents also commonly criticize the currently dominating conceptualization of 'sustainable development', where 'development' is often equated with economic growth (Demaria et al., 2013; Martínez-Alier et al., 2010).

While originally focused on the fact that economic growth cannot be fully decoupled from environmental impact and resource use, the current degrowth movement is a far wider conglomeration of scientists and activists united in their critique of the economic growth paradigm (Ariès, 2005; Demaria et al., 2013; Kallis, 2018; Petridis et al., 2015). Beyond its environmental destructiveness, the degrowth movement also questions the fundamental importance of economic growth for future societal development and human well-being, as postulated by supporters of green growth. Instead, the degrowth movement sees the current growth-oriented economic system as the cause for various other ongoing crises, such as the erosion of democratic principles (Cosme et al., 2017; Demaria et al., 2013), increasing social inequality, especially between the global north and south (Cosme et al., 2017; Demaria et al., 2013; Latouche, 2009; Schneider et al., 2010), and loss of meaning to life and mental health (Ariès, 2005; Kallis, 2018). Thus, the degrowth movement not simply argues for a reduction in economic activity in the current economic and socio-political structures, akin to a recession (Hickel, 2020), but instead envisages a radical shift in our value system from the current consumerist society to a society that emphasizes the value of leisure, human well-being, collaboration, creative freedom and democracy (Cosme et al., 2017; Kallis, 2018; Latouche, 2009; Research & Degrowth, 2010). Based on a review of conceptualizations of degrowth found in the most commonly cited articles, books, and statements by degrowth initiatives, five degrowth imperatives can be identified (see Paper VIII for more details):

1. **An environmental impact reduction imperative**,
   focusing on reducing environmental impact to a level that can be sustained within the planetary boundaries (Degrowth.info, n.d.; Demaria et al., 2013; Hickel, 2020; Latouche, 2009; OPCD, n.d.; c.f. Research & Degrowth, 2010; Schneider et al., 2010).
2. **An economic re-orientation imperative**,
   focusing on transforming our value systems from an economic growth and consumerism based society to a society that values human well-being and focuses on fulfilling (basic) needs (Associazione per la Descrecita, n.d.; Hickel, 2020; Kallis, 2018; Latouche, 2009; Petridis et al., 2015; Sekulova et al., 2013; Trainer, 2012).
3. **A democracy imperative**
   focusing on strengthening elements of direct democracy (Degrowth.info, n.d.; Kallis, 2018; OPCD, n.d.; Schneider et al., 2010; Trainer, 2012; Weiss & Cattaneo, 2017)
4. **An inequality reduction imperative**
   focusing on reducing injustice in wealth and resource distribution within and across countries (Cosme et al., 2017; Degrowth Switzerland, n.d.; Demaria et al., 2013; Jarvis, 2017; Latouche, 2009; OPCD, n.d.; Schneider et al., 2010).
5. **A re-localization imperative**
   focusing on increasing local production and consumption as well as decision-making (Beling et al., 2018; Kallis, 2018; Latouche, 2009; Rede para o decrescimento, n.d.; Schneider et al., 2010; Trainer, 2012).

It is important to note that the conceptualization of green growth and degrowth as two opposing views is not a binary one, but a continuous spectrum. On the one hand, green growth strategies such as the European Green Deal (European Commission, 2019b) or strategies by the World Bank (2012) emphasize inclusivity, thereby resonating with some of the core goals of the degrowth movement of creating a fairer, more equal, and democratic global society. Similarly, the SDGs, while being criticised by degrowth proponents as another growth-oriented development strategy (Demaria et al., 2013; Martínez-Alier et al., 2010), also strongly emphasize such social aspects. On the other hand, while taking a critical stance on technological development, the degrowth movement does not inherently condemn any technological advancement. In fact, the question of which technological advancements are in line with the degrowth idea remains an ongoing debate in the movement, with examples such as cargo-bikes, open source digital solutions or small scale wind turbines being described as technologies that are consistent with the degrowth idea (c.f. Vetter, 2018). Furthermore, the degrowth movement does not aim to abandon economic growth entirely, instead acknowledging, for example, that developing countries should be allowed a measure of economic growth (Hickel, 2020; Kallis, 2018; Research & Degrowth, 2010; Schneider et al., 2010).

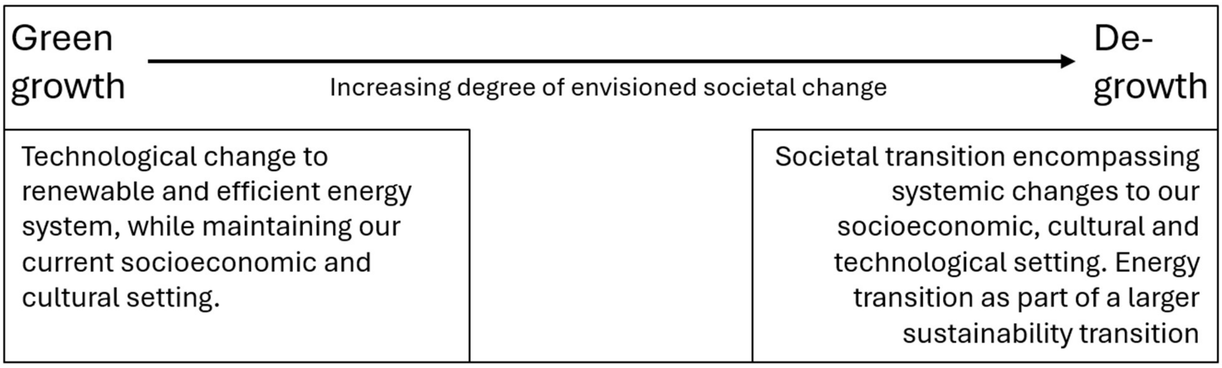

Figure 1: The energy transition spectrum

3.2. CONCEPTUALIZING COMMUNITY ENERGY INITIATIVES

Community Energy as a concept lacks a unified definition (Seyfang et al., 2012; Tarhan, 2015; Walker & Devine-Wright, 2008). In fact, a recent literature review found 183 definitions of Community Energy (Bauwens et al., 2022). The terminology currently being used ranges from 'citizen energy community' (Directive 2019/944) and 'renewable energy community' (Directive 2018/2001) to 'collective action initiatives for the energy transition' (Gregg et al., 2020), 'local renewable energy cooperatives' (Hufen & Koppenjan, 2015) and 'grassroots energy initiatives' (Kooij et al., 2018). The terminology is further expanded when moving beyond the English language, for example, with terms such as 'Energiegenossenschaft' (e.g. Holstenkamp & Müller, 2013) and 'Bürgerenergie' (e.g. Radtke, 2016) for Germany and 'Énergie citoyenne' for France (e.g. Énergie Partagée, n.d.-b). In this thesis, all these terms will be summarized as 'Community Energy Initiatives (CEIs)'. In addition, a separate literature stream exists that commonly employs terms such as 'community energy'. However, this literature stream is dominated by engineering scholars and focuses on 'the material connection between actors as embodied by an infrastructure, such as a microgrid or a network, and much less on the social dimension of the community' (Bauwens et al., 2022, p. 3).

Each of the concepts may emphasize certain characteristics of community energy, showing the difficulty of finding a single definition for CEIs. The following provides an overview over the characteristics that are commonly used to describe CEIs with respect to two main aspects. First, the question arises what constitutes the term *community* from an organizational perspective. Second, there is a need to narrow down the activities that a CEI may conduct for it to be understood as a community *energy* initiative.

First and foremost, the community nature of a CEI inherently excludes any projects by individual private citizens, for instance, homeowners installing a solar PV facility on their roof. Beyond such cases of private citizens, there is no universal definition regarding the minimum number of people required to be counted as a 'community'. As an example, Germany's Renewable Energy Act has recently increased the minimum member requirement for energy communities ('Bürgerenergiegesellschaften') from 10 to 50 members (c.f. EEG 2023, §3; EEG 2021, §3).

Next, this thesis restricts its scope to the investigation of formal initiatives. These include all initiatives that are officially registered as legal entities. In principle, this encompasses everything from associations, cooperatives and charities to shareholding companies or private limited enterprises. However, there are also informal initiatives such as neighbourhood initiatives, social movements or online communities, for instance, on social media platforms (Hewitt et al., 2019). Informal initiatives were excluded from the ENBP inventory primarily for practical reasons, as such initiatives are far more difficult to identify, given that they are generally not listed in national public registers.

Having narrowed down the potential candidates to formally registered legal entities, precisely situating CEIs within this space becomes more challenging. Four conceptualizations will be used in the following to establish a set of criteria to guide the definition of a CEI. First, Walker and Devine-Wright (2008) suggested one of the earliest conceptualizations of CEIs, which has been widely adopted in numerous studies (Creamer et al., 2019). Second, the recently established definitions of RECs and CECs by the EU represent the policy perspective (Directive 2018/2001; Directive 2019/944) on defining CEIs. Third, the definition used during the compilation of the ENBP inventory is included as this inventory serves as the basis for the empirical investigations related to this thesis.

Walker and Devine-Wright (2008) define CEIs along the process and outcome dimensions. The former describes the governance and decision-making structure and the latter describes the benefits that a CEI generates. The process dimension covers a spectrum from 'closed and institutional' to 'open and participatory', describing in essence how democratically a CEI is governed. The outcome dimension ranges from 'distant and private' to 'local and collective' and describes in essence who benefits from a CEI. Thus, the ideal CEI is one that is run democratically by citizens with the purpose of providing collective benefits to the wider community beyond its members. Diametrically opposed to this would be an entity like a shareholding company or a private limited company in which most of the decision-making power is in the hands of a few people and their primary focus is the maximization of profits for their shareholders. Foundations and charities are a typical example of entities characterized by a clear community benefit purpose, while not necessarily being governed in a democratic way, instead. being tied, for example, to the ideas of the founder. Typical examples of democratic control, but not necessarily any focus on community benefit, are traditional cooperatives which are run democratically but which focus (almost) exclusively on benefits for their members (c.f. Bauwens & Defourny, 2017). Note, however, that Walker and Devine-Wright (2008) combine two distinct features in each respective dimension. The process dimension consists of the aspects of 'closed-open' and 'institutional-participatory' governance, while the outcome dimension consists of the aspects of 'distant-local' and 'private-collective' benefits.

The EU defines RECs and CECs as initiatives that are 'based on open and voluntary participation, […] effectively controlled by shareholders or members' and the 'primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits' (Directive 2018/2001, Article 2(16); Directive 2019/944, Article 2(11)). Furthermore, both definitions restrict membership to natural persons, SMEs and local authorities, with the definition of an REC additionally requiring members to be located 'in proximity', as well as not engaging in the energy sector as their primary economic activity. Furthermore, a CEC is restricted to activities in the electricity sector but not exclusively to renewable energy technologies. An REC, on the other hand, is restricted to renewable energy production, consumption and selling, but may engage in other sectors than electricity (e.g. renewable heating) (CEER, 2019). The two directives were intended to be transposed into national laws by 2020 and 2021, respectively. Both academics (Krug et al., 2023) and the European Federation of Citizen Energy Cooperatives (REScoop, 2024) have tracked the transposition of the two EU directives into national legislation, reaching the conclusion that the EU member states are at various stages in this process. Based on the last update provided by the REScoop tracker in April 2024, Italy is the only country to have transposed the definitions of RECs and CECs into national law, as well as implemented enabling frameworks and support schemes for these entities. Other countries such as Belgium, Czech Republic, Denmark, France and Ireland have transposed the definitions into national law, but their efforts in implementing an enabling framework for energy communities is still considered lacking in some respects. Countries such as Austria and the Netherlands, on the other hand, lack a transposition of the definitions, but have implemented regulatory conditions that can also benefit such entities. On the other end of the spectrum, the efforts of countries such as Estonia, Finland, and Sweden are deemed insufficient.

Finally, the ENBP inventory defined three selection criteria for a potential CEI to be included in the database. These are an engagement in the energy transition, the initiative being led by citizens, and the initiative striving for social or environmental benefits beyond pure economic interest (see Section 4.1.1 for further details).

From these definitions, the following definitional criteria can be drawn:

1. An engagement in energy-related activities as the primary or secondary purpose
2. A restriction on sustainable energy technologies and activities
3. A focus on economic, environmental or social benefits beyond pure financial profits
4. A democratic and participatory mode of governance
5. An inclusive, open and voluntary membership
6. A focus on providing collective benefits
7. A limit of the geographical scale at which the CEI operates

Table 2 summarizes which criteria are present in the definitions mentioned above. As can be seen, the EU definition of RECs in particular is among the most demanding of the four definitions. The definition employed in the ENBP inventory, on the other hand, sets fewer requirements, which is in line with the intended goal of capturing as broad a picture as possible.

Table 2: Overview of the representation of CEI definitional criteria in selected definitions. + = criterion is present in definition; - = criterion is not present in definition; * = special cases that are discussed in the text below

Definitional Criteria for CEIs		Primary energy activity	Sustainable energy technologies	Focus on non-monetary benefits	Participatory governance	Inclusive membership	Public benefit orientation	Local geographic focus
CEI Definitions	Walker and Devine-Wright, 2008	*	*	-	+	+	+	+
	ENBP inventory (Paper I)	-	+	*	+	-	-	-
	EU REC	+	+	+	+	*	*	+
	EU CEC	+	-	+	+	+	*	*

Defining precise boundaries when a criterion is regarded as being fulfilled is often a case of individual interpretation. As such, the following will discuss how these criteria can be operationalized in practice.

Criterion 1

In terms of the activities that CEIs may engage in, the ENBP inventory provides a list ranging from the production and distribution of energy and the provision of energy services (energy consulting, building retrofitting, mobility services, …) to conducting information and awareness raising activities. A full list of activities can be found in Paper I (see Section 4.1.1). CECs, as defined by the EU, may engage in a similarly wide variety of activities, which the exception of being restricted to the electricity sector. As such, it is somewhat unclear whether information and awareness raising activities are included. RECs on the other hand, are restricted to the production, consumption and selling of energy (CEER, 2019; Directive 2018/2001). Lastly, Walker and Devine-Wright (2008) do not discuss specific activities in their conceptualization of CEIs.

A crucial aspect of this criterion relates to the question of whether the above-mentioned activities are part of the primary purpose of a CEI, or a secondary activity. For example, housing or banking cooperatives operating solar PV facilities on their own roofs, or agricultural cooperatives engaging in bioenergy generally have a main purpose not related to the energy sector. Such entities with a secondary energy-related activity are often referred to as ‘prosumers’, a concept that has received more attention among EU policymakers in the last decade (EEA, 2022; e.g. EPRS, 2016). The term ‘prosumer’ is a merging of the terms ‘producer’ and ‘consumer’ and refers to entities that are primarily energy consumers but also generate a certain amount of energy. The ENBP inventory specifically includes such cases. In contrast, both definitions by the EU exclusively refer to energy-related activities that CEIs may engage in. Walker and Devine-Wright (2008) do not provide any specifications in this regard. However, it can be inferred from the text that they likely only see such initiatives as CEIs that engage in energy activities as their primary purpose.

Criterion 2

In terms of the technological focus, the ENBP inventory considers all renewable energy and energy efficiency technologies to be relevant, as well as sustainable modes of transport such as electric vehicles and bicycles. However, CEIs engaging in both renewable and non-renewable energy technologies were also included. This is, for instance, occasionally the case for Finnish, Austrian or Italian district heating cooperatives that operate both biomass-based and fossil fuel-based heating plants. Furthermore, options such as car sharing using combustion engine cars were included as they are considered more sustainable than private transport. CECs, in contrast, may engage in both renewable and non-renewable energy technologies, but are restricted to the electricity sector (including e-mobility). RECs, in turn, may engage in other energy sectors, such as heating, but are restricted to renewable energy technologies (CEER, 2019; Directive 2018/2001; Directive 2019/944). Lastly, Walker and Devine-Wright (2008) do not state specific technologies, but generally refer to renewable energy. It can therefore be assumed that entities engaging in non-renewable technologies have been excluded.

Criterion 3

The third criterion is present in the ENBP inventory and in the EU definitions, specifying that CEIs should strive for economic, social or environmental benefits beyond simply generating financial profits. As such, CEIs should be akin to non-profit organizations. Salamon and Anheier (1992) provide a detailed description of the definitional challenges of precisely separating the non-profit, for-profit and public sectors. For the purpose of this thesis, the for-profit sector will be defined along Milton Friedman's (1962) classical view of a business' social responsibility being solely the generation of profits. The opposing side of the spectrum can then be defined by a focus on fulfilling a real or perceived need without a focus on profit generation (c.f. Gawell, 2013; Peredo & McLean, 2006). As discussed in Gregg et al. (2020), such cases are similar to the conceptualization of social movements by Tilly (1978), that are formed to address issues neglected by the private (for-profit) and public sector. While using different terminology, a similar connotation can be found, for instance, in Magni et al. (2024) who describe CEIs as 'value-based' instead of 'profit-driven'. The notion of 'purpose-driven' similarly describes the idea that an organization has a social purpose other than simply generating profits (c.f. George et al., 2021; Rey et al., 2019). As such, CEIs can be seen as drivers of social innovation (Gregg et al., 2020). Social innovation can be understood as innovation that aims to address a societal need, which contrasts with business innovation that is driven by private, for-profit enterprises with a focus on profit maximization (Gregg et al., 2020; Hubert et al., 2011; Mulgan et al., 2007). However, typical for-profit enterprises increasingly also present themselves as being driven by a social purpose (George et al., 2021; Rey et al., 2019). As such, an organization often displays characteristics of both non-profit/value-/purpose-driven and for-profit oriented entities, leaning more towards one or the other side. From an operational perspective, one of the most straightforward criteria is whether a CEI distributes financial surplus to its members. For example, in Latvia the transposed EU directives forbid CEIs from paying dividends to their members, while in Slovakia, they are allowed to distribute 50% of their profits as dividends (Energy Communities Repository, 2024). Note, however, that in contrast to the examples above that provide specific requirements for CEIs to fulfil this criterion, it was not operationalized in the ENBP inventory with clear requirements that would allow a testing the fulfilment of the criterion on the level of individual CEIs. Instead, for practical reasons, the criterion was seen as being fulfilled for specific types of organizational forms (e.g. cooperatives, associations) typically associated with a focus on generating non-monetary benefits (see Section 4.1.1 for more details on the selection process of CEIs for the ENBP inventory). The resulting large spectrum of CEIs included in the ENBP inventory allows for a more complete overview of the CEI landscape with all its potential forms.

Criterion 4

An emphasis on democratic and participatory decision-making processes is present in all the discussed definitions. A comparably straight forward method to operationalize this criterion is the presence of the one member-one vote principle. This principle, commonly employed in cooperatives (c.f. ICA, n.d.-b), dictates that every member has equal voting power, regardless of the share of the cooperative that they own. The one member-one vote principle is commonly regarded as more democratic than other forms of governance such as the One Share – One Vote principle (Yildiz et al., 2015). For example, in countries such as Ireland and Greece, the transpositions of the EU directives exclusively allow the one member-one vote principles regardless of the shares held by the individual member. However, there are also less strict requirements. In Germany, for example, voting rights may be tied to the amount of shares held, as long as no member holds more than 10% of the votes.

Criterion 5

The question of who may participate in a CEI is specifically referenced in Walker and Devine-Wright (2008) and the EU directives. The former specifies that participation in a CEI should be open to all, while the latter additionally states that participation should be voluntary. Interestingly, the EU directives also set requirements that arguably infringe on the idea of open participation. The provisions regarding the proximity of members of RECs restrict membership to a specific area (see criterion 7). The ENBP inventory, on the other hand, does not specify this criterion, also including initiatives that, for instance, restrict membership to specific audiences.

Criterion 6

Bauwens and Defourny (2017) provide a definition of collective benefit by distinguishing between mutual and public benefit organizations. In simple terms, they define mutual benefit organizations as organizations in which the stakeholders who own the decision-making power are also the primary beneficiaries of the organization's value creation. Public benefit organizations are organizations in which the primary beneficiaries are not equal to the stakeholders holding the decision-making power. Shareholding companies or cooperatives would be examples of mutual benefit organizations, with a main focus on providing benefits for their members or shareholders. Charities, on the other hand, typically aim to provide public benefits to external stakeholders. Here, Walker and Devine-Wright (2008) clearly regard CEIs as public/collective benefit organizations. Note, however, that the authors do not provide specific criteria to determine when a focus on providing public benefits is present. While the ENBP inventory does not specifically state this aspect in the definition, it does refer to the conceptualization by Walker and Devine-Wright (2008). The definitions of CECs and RECs state that such initiatives should provide 'community benefits for its shareholders or members or for the local areas where it operates' (Directive 2018/2001, Article 2(16); Directive 2019/944, Article 2(11)), which is somewhat contradictory, as it emphasizes 'community benefits' while simultaneously allowing for a focus on 'shareholders or members'.

Criterion 7

As pointed out by Bauwens (2016), CEIs may be 'communities of place' or 'communities of interest'. The former are characterized by the geographical proximity of their members, while the latter are characterized by a common narrative or thematic interest, but not necessarily by spatial proximity. Walker and Devine-Wright (2008) describe the ideal CEI as one that generates local benefits, thereby leaning towards the 'community of place' conceptualization. Similarly, the CEC and REC definitions also state that CEIs should focus on providing 'community benefits for its shareholders or members or *for the local areas where it operates*' (Directive 2018/2001, Article 2(16); Directive 2019/944, Article 2(11)). The definition of RECs goes even further, restricting members to those located 'in proximity' to the project (CEER, 2019; Directive 2018/2001). Some transpositions of the directives into national law specify this further. For example, the German Renewable Energy Law (EEG) restricts membership in 'Bürgerenergiegesellschaften' to natural and legal persons located within a 50km radius of the CEI. In France membership is restricted to citizens with a residence in the département of the CEI or a neighbouring one. In Italy membership in RECs is restricted to prosumers connected to the same medium voltage station. In contrast, Ireland allows each individual RECs to define the geographic boundaries themselves (Energy Communities Repository, 2023b, 2024). The ENBP inventory sets no boundaries in terms of spatial scale.

3.3. European Energy Policy

At the top level, 'EU energy policy is based on the principles of decarbonisation, competitiveness, security of supply and sustainability.' (Babiker & Ciucci, 2025a, p. 1). The European Energy Union defines the following five objectives for European energy policy: Ensuring energy security, increasing energy efficiency, removing technical and regulatory barriers for a fully integrated European energy market, decarbonizing the economy, and supporting research and innovation to drive the energy transition and improve competitiveness. Achieving these objectives is also expected to provide new job opportunities, as well as foster economic growth (Babiker & Ciucci, 2025a; European Commission, n.d.-b).

In terms of environmental sustainability, in 2020 the EU celebrated the achievement of its 20-20-20 targets. Enacted in 2007, the 20-20-20 targets encompassed a 20% reduction of GHG emissions compared to 1990 levels, achieving a share of at least 20% renewable energy in final energy consumption and reducing final energy consumption by 20% compared to projections (EEA, 2021; European Commission, 2010). Achieving the goal of 20% renewable energy in the final energy consumption is largely a result of a comparably high share of renewables in electricity production, with the biggest share of renewables coming from wind power. However, the share of renewables used in the transport sector and for heating and cooling are significantly below the 20% goal (IEA, 2020). Furthermore, the goal of a 20% energy saving could only be achieved due to the reduction in economic activity as a result of the enforced lockdowns during the COVID-19 pandemic (EEA, 2021).

Following the 2020 targets, the EU established the European Green Deal with the goal of transforming the economy towards 'no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use' (European Commission, 2019b, p. 2). This goal, as well as the intermediary goal of reaching a 55% reduction of GHG emissions by 2030 (compared to 1990), was enforced in the European climate law in 2021 (European Commission, n.d.-c). The European Green Deal also increased the 2030 goal for renewable energy shares from

the previous 32% (Directive 2018/2001) to 40% of final energy consumption (European Commission, n.d.-e). Furthermore, a new energy efficiency target of a 9% reduction by 2030 compared to the 2020 projections was introduced (European Commission, n.d.-a)
Since the Russian invasion of Ukraine, the issue of energy security has received increased attention. The REpowerEU plan, enacted in 2022, aims to drastically reduce the dependence of the European energy system on Russian fossil fuels (IEA, 2022a). This goal rests on three main pillars: lowering total energy consumption, accelerating the shift to renewable and clean energy technologies and diversifying the remaining energy imports (European Commission, 2022a). Thus, the REpowerEU plan further increased the renewable energy deployment goal from 40% to 45% of final energy consumption by 2030 and the energy efficiency target from a 9% to a 11.7% reduction in total energy consumption by 2030 compared to the 2020 predictions.

In the past, feed-in tariffs have been a common tool among EU member states to encourage the deployment of renewable energy technologies (C. Mitchell et al., 2011). Cointe and Nadaï (2018) summarize the development of FiTs in Europe. Firstly, they point out that FiTs are not actually a renewable energy support tool by the EU but are rather enacted individually by the member states. As such, their design varies from one country to the next. Yet, they are often based on similar core principles. FiTs are typically long-term contracts tied to a specific production unit that obligate utility companies to purchase renewable energy from producers and guarantee the producers a fixed price over the duration of the contract, thereby reducing the financial risk associated with renewable energy investments. Interestingly, Cointe and Nadaï (2018) point out that the stance of the EU regarding FiTs was somewhat controversial. On the one hand, they were seen as state level subsidies for specific industries, which are generally condemned by the EU for their potential to create one-sided competitive advantages for certain industries in some countries. On the other hand, FiTs clearly supported the EU's goals of expanding renewable energy deployment, as well as diversifying the energy market. FiTs were first officially introduced in Germany[3] and Denmark in the early 1990s and were then adopted by other countries and, by 2010, most European countries had introduced FiTs (Cointe & Nadaï, 2018; C. Mitchell et al., 2011). Due to the reduction in the cost of renewable energy technologies such as solar PV (c.f. Wirth, 2025), most countries continuously reduced their FiTs, as renewable energy technologies were increasingly seen as being able to compete with the costs of other energy technologies. The OECD provides data on the development of FiTs for the EU member states since 2000 (OECD, 2020), clearly showing a common trend of declining FiTs in the second half of the 2010s.

A crucial step towards an integrated energy market was its liberalization in the 1990s, with the goal of increasing the diversity of actors, competitiveness, transparency and consumer-friendliness (Babiker & Ciucci, 2025b; Pepermans, 2019). Prior to the liberalization, the European energy market was highly monopolized and vertically integrated, meaning a single entity was potentially in charge of all major roles associated with the supply of energy (both gas and electricity). These roles encompass energy generation, transmission, distribution and retail (Pepermans, 2019; Rotaru, 2013). The process of liberalizing the energy market started with a separation of the electricity and gas market, followed by the unbundling of the actors involved in

[3] See also Paper V, supplementary material, for a detailed overview of the evolution of FiTs in Germany

the different roles in the two energy markets. Individual actors were no longer allowed to be active in more than one role in the energy market. Furthermore, consumers were guaranteed free choice of their energy retailer. Recent data on energy market indicators provided by the EU show that the extent to which these measures have led to a diversification of energy market actors varies greatly from country to country. Table 3 shows the evolution of the number of electricity market actors and their respective market share in two exemplary EU countries. As can be seen in the case of Sweden, the diversity of electricity producers increased drastically from 2009 to 2021, with the largest actor losing significantly in its market share. France, on the other hand, has seen little change, with electricity production still being dominated by a single actor. Interestingly, the French retail market has seen some degree of diversification. While the total number of retailers has not changed, the main retailers have individually lost a significant market share, with one main retailer accounting for 85.5% in 2009 while three retailers account for 74.3% percent in 2021.

Table 3: Evolution of market share of electricity market actors in Sweden and France. Data source: European Commission, Directorate-General for Energy (2024)

	SWE_2009	SWE_2021	FRA_2009	FRA_2021
Producers, Representing 95% Total [No.]	11	132	>5	5
Main Producers, >5% Total [No.]	3	5	1	2
Cumulative Market Share Generation, Main Entities [%]	79	60	87	84
Cumulative Market Share Capacity, Main Entities [%]	74	20	83	63
Market Share Largest Producer [%]	44	19	87	79
Retailers to Final Consumers [No.]	75	210	177	177
Main Retailers, Sales >5% Total [No.]	3	6	1	3
Cumulative Market Share, Main Retailers [%]	49.6	55.3	85.5	74.3

While the policies discussed above mainly focus on technological aspects and the competitiveness of the European energy market, social aspects of the energy transition, such as energy justice and energy democracy, are also occasionally considered. The ‘Clean Energy for all Europeans’ package also acknowledges the issue of energy poverty, pointing out that from 2004 and 2014, the percentage of total income that low-income households had to spend on energy had risen by 50% (European Commission, 2016). On the other hand, data from Eurostat (2024b) show that energy poverty, measured in the share of households not able to keep their homes adequately warm, has been constantly declining since 2012. However, this trend has reversed in 2021, when a stark increase in households suffering from energy poverty was observed. This reversal is likely a result of the significant increase in energy prices in recent years (Eurostat, 2024a), largely caused by the onset of the war between Russia and Ukraine. Initiatives such as the European Social Climate Fund have attempted to address this issue by specifically supporting vulnerable groups in energy efficiency retrofitting, the integration of renewable energy sources, or switching to sustainable modes of transport (European Commission, n.d.-f; Widuto, 2023).
Starting with the aforementioned liberalization of the energy market, there has been increasing focus on aspects of consumer protection as well as allowing new actors to engage in the energy market. Initially, consumers were guaranteed free choice of their energy provider (Babiker & Ciucci, 2025b; Pepermans, 2019). The ‘Clean Energy for all Europeans’ package, which was first

proposed in 2016 and finally adopted in 2019 as part of the European Green Deal (European Commission, 2019a), also aims to provide better and more transparent information regarding energy prices and energy sources, reduce barriers for consumers to invest in small-scale private renewable technologies (e.g solar PV), and provide more control to consumers by simplifying the switching of energy providers and rolling out smart meters (European Commission, n.d.-d, 2016). The aforementioned EU directives (Directive 2018/2001; Directive 2019/944), which also define RECs and CECs, further strengthen the rights of new actors such as energy communities or self-consumers (prosumers).

3.4. LINKING EUROPEAN ENERGY POLICY, CONCEPTUALIZATIONS OF ENERGY TRANSITIONS AND DEFINITIONS OF CEIS

Table 4: Alignment of degrowth imperatives, CEI definitional criteria and EU energy policy objectives

Degrowth imperatives	CEI definitional criteria	EU energy policy objectives
Imperative 1: Environmental impact reduction	Criterion 1 & 2: Restriction to sustainable activities and technologies	Renewable energy deployment, energy efficiency, GHG emission reduction
Imperative 2: Economic re-orientation	Criterion 5: Focus on fulfilling needs instead of generating financial profits	Economic growth and competitiveness
Imperative 3: Strengthening democratic/participatory decision-making processes	Criterion 6 & 7: Participatory decision-making and open & voluntary membership	Strengthening consumer rights, citizen participation in the energy transition
Imperative 4: Reducing inequality in wealth and resource distribution	Criterion 4 & 7: Focus on generating collective benefits and open & voluntary membership	'Fair and inclusive transition', combatting energy poverty
Imperative 5: Re-localization of production and consumption	Criterion 3: local geographic focus	Reducing dependence on international energy exports, but also establishing new energy import sources e.g. for liquified natural gas and hydrogen

Table 4 summarizes how CEI definitional criteria (see Section 3.2) and European energy policy principles (see Section 3.3) align with the conceptualization of the energy transition as a radical societal transformation along the degrowth imperatives (see Section 3.1). A comparison between the degrowth imperatives and the CEI definitional criteria shows a striking similarity. The first degrowth imperative of reducing environmental impact closely aligns with the first two criteria for CEI definitions, being a primary engagement in sustainable energy activities and technologies. The only exception is the definition of CECs that allows the use of non-renewable energy technologies. The second imperative of an economic reorientation from a society oriented towards economic growth and consumerism to one that values human well-being and focuses on fulfilling (basic) needs is represented in the common emphasis of CEI definitions on the generation of economic, social or environmental benefits beyond generating financial profits (criterion 5). The third degrowth imperative emphasizes the need to increase democratic and participatory decision-making processes. This is represented in the criteria of participatory governance and open and voluntary membership in the CEI definitions (criterion 6 and 7). The fourth degrowth imperative focuses on reducing inequality, pointing out the need to redistribute wealth and resources both within and across countries. The CEI definitions align with this imperative through a combination of the collective benefit and open & voluntary membership criteria (criterion 4 and 7). Finally, CEI definitions such as the one proposed by Walker and Devine-Wright (2008) or the EU Directive introducing RECs (Directive 2018/2001) emphasize the local anchoring of CEI, which correlates with the fifth degrowth imperative of re-localizing production and consumption.

In terms of European energy policy, targets regarding GHG emission reductions, deployment of renewable energy technologies and energy efficiency improvements put a strong emphasis on environmental impact reduction. Additional degrowth imperatives are represented to a varying extent in the European energy policy. Statements regarding citizens being ‘a driving force of the energy transition’ (European Commission, 2019b, p. 22) resonate with the third degrowth imperative of strengthening democratic and participatory processes. Accordingly, some authors have also identified a shift to more deliberative forms of citizen participation in European energy policy-making (Buzogány et al., 2025). Other authors, however, point out that citizen engagement in the energy transition, while commonly emphasized in EU energy policy documents, tends to be limited to their role as consumers or producers (or prosumers, as a combination of both) of energy. In the meantime, existing power structures dominated by a small number of established actors remain intact (Ossewaarde & Ossewaarde-Lowtoo, 2020). The focus on citizen participation in their role as consumers is evident in previous efforts to strengthen consumer rights (Babiker & Ciucci, 2025b; Pepermans, 2019), or in statements that ‘consumers are at the centre of the Energy Union’ (European Commission, 2016, p. 10). Proclamations that projects such as the European Green Deal ‘can only succeed if it is conducted in a fair and inclusive way’ (European Commission, 2019b, p. 16), as well as goals to reduce energy poverty and support vulnerable groups and regions, relate to the degrowth imperative of reducing inequalities. The degrowth imperative of re-localization relates to some extent to the policy objectives on increasing energy security by lowering dependence on energy imports. However, the EU is also attempting to find new international partners for the import of liquified natural gas or hydrogen (European Commission, 2022a). The largest contrast relates to the degrowth imperative of economic re-orientation. Where degrowth calls for an abandoning of the economic growth paradigm, EU policy documents commonly state that a sustainable energy transition will lead to increased competitiveness and economic growth (e.g. Babiker & Ciucci, 2025a, 2025b). For example, the EU envisages the European Green Deal to be ‘a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use’ (European Commission, 2019b, p. 2). Consequently, EU energy policy is seen as closely aligned with a green growth pathway (Koch, 2018; Mauger, 2023; Ossewaarde & Ossewaarde-Lowtoo, 2020). The above quote from the European Green Deal shows that economic growth is seen as a means to address social issues such as unjust wealth and resource distribution. In contrast, degrowth sees the economic growth paradigm as a crucial contributor to such social issues (see Section 3.1).

4. SUMMARY OF RESEARCH QUESTIONS, METHODS AND RESULTS OF INCLUDED PAPERS

The following sections summarize the research questions, methodological approaches and results of each of the seven papers and one book chapter that are part of this thesis (see also Section 2.3 for a summary of how the publications link to the research questions of this thesis). Papers I and II investigate the aggregate CEI landscape in the EU as well as Norway, Switzerland, and the UK. Papers III – VIII focus on more specific topics or selected countries.

The present author contributed to the co-author papers (Papers I-VI) by coordinating and participating in the data collection. The initial conceptualization of these papers was conducted by the main authors with the doctoral student contributing to the formal analysis and writing of the papers. Papers VII and VIII were fully conceptualized by the present author who conducted all data analysis, as well as the writing of the papers. In the case of Paper VIII, the other co-authors contributed during the data collection and the reviewing of the paper, while the co-authors mainly contributed to reviewing Paper VII.

4.1. PAPERS I AND II: SUMMARY OF THE AGGREGATE EUROPEAN CEI LANDSCAPE

4.1.1. Paper I – Presentation of the process of compiling the ENBP inventory, a Europe-wide inventory of over 10,000 Community Energy Initiatives across 29 countries

Wierling, A., Schwanitz, V. J., **Zeiss, J. P.**, von Beck, C., Paudler, H. A., Koren, I. K., Kraudzun, T., Marcroft, T., Müller, L., Andreadakis, Z., Candelise, C., Dufner, S., Getabecha, M., Glaase, G., Hubert, W., Lupi, V., Majidi, S., Mohammadi, S., Nosar, N. S., … Zoubin, N. (2023). A Europe-wide inventory of citizen-led energy action with data from 29 countries and over 10000 initiatives. *Scientific Data, 10(1),* 9. https://doi.org/10.1038/s41597-022-01902-5

While not chronologically the first paper, this paper is presented first as it summarizes the effort to create a Europe-wide inventory of CEIs that provides the data for the other papers. This paper is not centred around a specific research question but rather describes the process of compiling an inventory of CEIs across Europe.

The open access 'Energy by the People (ENBP)' database (Wierling, Schwanitz, et al., 2022) described in this paper consists of over 10,000 entries of CEIs for all EU members states as well as Norway Switzerland, and the UK. Given the diversity of conceptualizations of CEIs (see also Section 3.2), the inventory aimed to be as inclusive as possible, while allowing potential users to filter for specific types of CEIs. However, the sample of CEIs included in the inventory is restricted to legally registered collective initiatives, thereby excluding individual citizens engaging in renewable energy as well as informal initiatives. Building on the process and outcome dimension framework proposed by Walker and Devine-Wright (2008), further guiding principles for the selection of CEIs for the inventory were:

1. the engagement in the energy transition,
2. the initiative being led by citizens,
3. the initiative striving for social or environmental benefits beyond pure economic interest.

Activities that were deemed relevant for the energy transition included (I) the production, distribution and trade of renewable energy (including energy carriers such as energy crops or fuel wood) and renewable energy technologies (e.g. solar panels), (II) the provision of energy services such as bike/car sharing, energy efficiency consulting or the operation of electric vehicle charging stations, and (III) conducting various energy-related awareness and information activities. In contrast to other studies that have investigated larger samples of CEIs (e.g. Hewitt et al., 2019; Holstenkamp & Müller, 2013), the ENBP inventory also includes initiatives that only engage in the above-listed activities as their secondary focus. This category includes, for instance, eco-villages, housing-, banking- and agricultural cooperatives also engaging in energy-related activities. As stated in Section 3.2, such actors are commonly referred to as 'prosumers'. The second and third criterion, however, were not evaluated on a case-by-case basis, as this would have required a screening of the statutes of all cases, which was not feasible given the large sample. Instead, these were evaluated on a general level for specific categories of CEIs (e.g. certain legal forms). The general selection criterion for the second guiding principle was the adherence to the one member-one vote principle (see Section 3.2). Certain legal forms, such as cooperatives are either legally obliged to adhere to this principle or commonly do so voluntarily, as outlined in this paper. A focus on providing benefits beyond purely financial profits was also assumed for certain legal forms, such as associations, cooperatives or foundations generally associated with concepts such as the non-profit-, social solidarity-, or third sector (ILO, 2022; ripess, 2015; Salamon & Sokolowski, 2016).

Additional groups of organizations were included if they had been defined as CEIs in previous studies, or by government authorities or relevant country level CEI umbrella organizations or networks. For example, in the case of Poland, 'energy clusters' have been included in the database, as they have been deemed relevant by local experts. Energy clusters are collaborations between 'natural persons, legal persons, scientific units, research institutes or local government units, concerning the production and balancing of demand, distribution or trade of energy' (Siudek & Klepacka, 2020, p. 194). Similarly, for Ireland, the 'sustainable energy communities' (SECs), as defined by the Sustainable Energy Authority of Ireland (SEAI, 2025b, 2025a), have been included even though an adherence to the one member-one vote principle cannot always be assumed. However, these represent an important alternative form to the transposed EU definitions of CECs and RECs, which is specific to Ireland (Energy Communities Repository, 2023a). A summary of the most common types of CEIs can be found in Paper II. The resulting potential over-inclusiveness of the ENBP inventory serves this thesis well, as it has the objective to provide an overview over the general European CEI landscape and investigate in more detail the extent to which different potential types of CEIs contribute to the energy transition and European energy policy objectives.

The inventory covers four main categories of CEI data. The first category includes administrative data on the CEI, such as name, registered address and year of foundation. The second category includes data on the types of activities that the CEI conducts. The third category tracks data on tangible assets of the CEI, such as renewable energy facilities (e.g. solar panels, wind turbines, hydropower stations, etc.) including their date of installation, location, installed capacity, etc. The fourth category covers time-tagged data, such as annual financial assets, number of members, etc.

The general data collection approach consisted of several steps. Initially, the scientific literature was reviewed for existing studies on CEIs in each country for contextual information and for identifying potentially relevant types of initiatives. Any existing data on CEIs available in these studies were added to the inventory. Next, various NGOs, umbrella organizations or CEI networks that keep track of CEI data were scanned. Following this, official registers such as national business registers were filtered for relevant legal forms conducting energy-related activities. Some countries also keep official registers of renewable energy facilities, such as the core energy market data register in Germany (Bundesnetzagentur, 2025), which can be filtered according to ownership of the facility. Finally, data were collected from individual CEI websites, financial reports and newspaper articles. The availability of data on CEIs varies greatly from country to country, which required adapting the specific data collection process for each country. The supplementary material for this paper provides detailed information on data sources and collection processes for the different countries.

The results of the data collection described in this paper serve as the data compilation for the subsequent papers. As part of the data collection, this also produced a detailed overview of the current procedures for tracking CEI-related data in the investigated countries. This information, which is summarized in the supplementary material, serves to answer RQ 2 of this thesis.

The final database was designed in accordance with the FAIR data principles, which advocate that data should be (I) Findable, (II) Accessible, (III) Interoperable, and (IV) Reusable (Wilkinson et al., 2016) (see also Section 2.2.3). The database adheres to these principles by being openly and freely available. Furthermore, the data are stored in a format that allows for easy navigation and querying with the help of SPARQL database management software. Wherever possible, data entries adhere to common classification systems, such as the European classification system for economic activities (Eurostat, 2008), or the Entity Legal Form Ontology that describes the different national legal business forms such as cooperatives or limited liability companies (GLEIF, n.d.).

4.1.2. Paper II – Key statistics on European Community Energy Initiatives derived from the ENBP inventory, estimating the people involved, renewable energy capacities installed, and finances invested

Schwanitz, V. J., Wierling, A., Arghandeh Paudler, H., von Beck, C., Dufner, S., Koren, I. K., Kraudzun, T., Marcroft, T., Mueller, L., & **Zeiss, J. P.** (2023). Statistical evidence for the contribution of citizen-led initiatives and projects to the energy transition in Europe. *Scientific Reports, 13(1)*, 1342. https://doi.org/10.1038/s41598-023-28504-4

Research Question:

What is the aggregate contribution of CEIs to the energy transition in Europe in terms of the people involved, renewable energy capacities installed and finances invested?

Paper II presents the aggregate results of the data collection on the CEIs described in Paper I, for all EU member states, as well as Norway, Switzerland, and the UK. The paper estimates the number of CEIs, people involved, renewable energy capacities installed, number of projects conducted and finances invested, on both the aggregate European level and for each country. As far as possible, the estimates are based on the data in the ENBP inventory, described in Paper I. However, the availability of data varies greatly from country to country (see also Sections 4.1.1 & 7.2). As such, estimations were made for those cases where data were missing. The exact estimation method varies from case to case and is described in detail in the supplementary material for the paper. For example, in countries in which only some data-points were missing, the final estimates are calculated by extrapolating the averages of existing data-points. In cases where this was not possible, other techniques were used. Total investments, for example, were commonly estimated using the installed renewable energy capacities of CEIs and general turnkey prices per kW for the associated renewable energy technologies. The exception is the value of the total number of initiatives, which represents the actual number of CEIs recorded in the database and therefore does not rely on any estimations. Note that, while the ENBP inventory contains a small number of CEIs also engaging in non-renewable energy technologies, these projects have not been considered in the estimates.

The paper finds that over 10,000 CEIs are or have been active in Europe, and that over two million people have been involved as members in these CEIs. The estimate is based on the most recent available data points for each CEI. These CEIs have initiated over 22,800 projects, which include the operation of renewable energy generation and distribution systems, as well as electric vehicle charging stations or conducting awareness raising, education and training programmes. Future planned projects are included in this figure. The renewable energy generation facilities that have been installed or were planned at the point of publication of the paper amounted to 7-10 GW of installed solar PV, solar thermal, wind power, hydropower, geothermal and bioenergy capacity. The difference between the lower and upper range mainly stems from two factors. First, the upper estimate includes projects that were still in the planning or construction phase at that time. The second factor relates to co-owned facilities where the share that is owned by the CEI is unknown. In such cases a lower estimate of 0% ownership and an upper estimate of 100% ownership was used. Combined, CEIs have invested an estimated EUR 6-11 billion into the construction or purchase of renewable energy facilities since 1990. This investment estimate, however, is the most inaccurate out of all previously mentioned estimates, as direct data on investments related to individual projects were rare. As such, this value is heavily based on estimates using, for instance, general turnkey prices for renewable energy technologies. It also does not use inflation-adjusted values.

The investigation shows that the earliest CEIs were already founded in the beginning of the 20th century, with low numbers of foundations in the first half of the century. CEI foundations have risen to a slightly higher stable rate for the second half of the century and have then grown exponentially since the 1990 and especially after 2000. Germany accounts for about half of all CEIs, followed by Netherlands and Denmark. Countries such as Austria, France, Italy, Sweden, Switzerland and the UK show numbers in the range of 200 to 400 CEIs. Most of the remaining countries have less than 100 CEIs, respectively.

4.2. PAPERS III – VIII: THEMATIC AND SPATIAL FOCUS PAPERS

4.2.1. Paper III – Investigation of the development of energy cooperatives in Austria, Germany, Denmark and the UK

Wierling, A., Schwanitz, V. J., **Zeiß, J. P.**, Bout, C., Candelise, C., Gilcrease, W., & Gregg, J. S. (2018). Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries. *Sustainability*, *10*(9), 3339. https://doi.org/10.3390/su10093339

Research Questions:

1. *Is there statistical evidence that energy cooperatives are important actors in the energy transition in Europe?*
2. *What are common reasons that support or hinder activities of energy cooperatives?*

Chronologically, paper III is the first paper relevant to this thesis. It builds on an early version of the ENBP inventory, specifically investigating the CEI subgroup of energy cooperatives in Austria, Germany, Denmark and the UK. In particular, it investigates the legal forms of 'Genossenschaft' for Germany and Austria, 'Interessentskap' for Denmark and 'BenComs' for the UK. The Danish sample is further restricted to only such initiatives that engage in wind power.

The results show that energy cooperatives have developed similarly in Germany and the UK, with low numbers up until the late 2000s followed by a significant increase. The growth then flattens out around 2015. Austria, on the other hand, shows a more continuous growth that started earlier, already in the late 1980s, and that stagnated in the late 2000s. Denmark shows a different pattern, with a stark increase as early as the 1980s and 1990s, followed by a drastic decline from 2000 onwards. By the time of publication of the paper, Denmark had the lowest number of initiatives compared to the three other countries.

The early increase of wind power cooperatives in Denmark was driven by anti-nuclear sentiments, as well as a shift in Danish policy-making towards supporting the use of the abundant national wind resources in an effort to decrease dependence on foreign fossil fuel imports. However, with the increasing size of wind turbines, and a rise of associated investment costs, as well as changes in the feed-in tariff scheme, wind power cooperatives increasingly had to compete with larger enterprises that benefited from economies of scale. This led to a closure of up to 90% of the smaller and medium-sized cooperatives, with only the largest showing higher survival rates.

The boom in energy cooperatives in Germany was mainly a result of feed-in tariffs introduced in 2000 and the later political emphasis on renewable energy after the Fukushima disaster in Japan in 2011. German cooperatives engage most commonly in solar PV, but are also active in wind power, bioenergy and hydropower. While a decline in new foundations was observed from the mid-2010s, member numbers for existing cooperatives have continued to grow since this time. However, the stagnation of new foundations coincides again with disadvantageous changes in renewable energy policies, such as the introduction of renewable energy deployment caps and declining feed-in tariffs.

The UK generally shows lower numbers of energy cooperatives compared to the other countries, as a result of complex planning procedures, among other factors. However, the trends in new foundations mainly coincide again with changes in feed-in tariffs. Yet, compared to Denmark, few initiatives have been dissolved, and no pattern could be identified in the dissolution rates. This suggests that policy changes, while having influenced foundation rates, have not resulted in existing initiatives being dissolved.

Energy cooperatives focusing on hydropower have played a significant role in the early electrification of Austria in the beginning of the 20th century. Newer cooperatives mainly engage in wind power and bioenergy. Farmers' cooperatives are key actors in developing bioenergy-based district heating facilities.

The main insight of this paper is that the activity of energy cooperatives correlates significantly with the introduction and cancellation of government support schemes for renewable energy technologies, first and foremost feed-in tariffs. This suggests that such initiatives are highly dependent on state subsidies. Note that, while this paper generally finds a decline in CEI activity with decreasing feed-in tariffs, more recent studies (e.g. Paper VI) conclude that the declining cost of PV facilities in recent years may lead to a reversal - or at least a slowdown - of the trend of declining CEI activity.

4.2.2. Paper IV – Historical development of energy cooperatives in Europe and investigation of their inclusivity in terms of the demography of members and steering committees

Wierling, A., **Zeiss, J.P.**, Candelise, C., Gregg, S., Hubert, W., Schwanitz, V.J. (2020). Who participates in and drives collective action initiatives for a low carbon energy transition? In Diemer, A., Nedelciu, E., Schellens, M., Morales, M., Ostdijk, M. (Eds.) *Paradigms, Models, Scenarios and Practices for Strong Sustainability.* Editions Oeconomia, Clermont-Ferrand (2020)

Research questions

1. *How have energy cooperatives evolved historically in Europe?*
2. *What forms of energy cooperatives exist today?*
3. *How democratic are energy cooperatives in terms of member participation and demographics?*

This book chapter investigates these questions using both exemplary cases and statistical analysis. It begins by shedding light on the historical development of energy cooperatives in Europe. The earliest energy cooperatives were established in the early 20th century. They focused on the electrification of rural areas in Europe that were de-prioritized by the early electrification efforts of governments and private enterprises. They often constructed small-scale hydropower plants and local electricity grids to power a few rural communities. In the second half of the 20th century, the creation of new energy cooperatives was mainly driven by fears of energy security, resource limitations and environmental pollution, amidst the turmoil of the oil-crisis and rising anti-nuclear sentiments during the Cold War. The early development of wind power cooperatives in Denmark in the 1970s and 80s is a prime example of this movement. Since around 2000, energy cooperatives have experienced exponential growth. More recent examples of CEIs show a wide portfolio or activities, ranging from virtual power sharing, light contracting, and energy consulting to mobility services.

Following the overview of the historical development of energy cooperatives, the book chapter scrutinizes the prevailing assumption that such initiatives promote just and inclusive participation. In the case of Swedish energy cooperatives, for example, the investigation shows that board members who are in charge of day-to-day decision-making were on average 63 years old at the time of writing the chapter. Furthermore, women were underrepresented on the board. In addition, only a few members participated in the annual general assembly. In the case of German solar PV cooperatives, the investigation also finds that these are mainly concentrated in areas characterized by higher-than-average household incomes. The Danish sample shows that energy cooperatives are mainly active in rural areas.

In summary, this book chapter provides evidence that the member demographics of energy cooperatives are not representative of society at large, but mainly comprise men above 60, with higher incomes and living in rural areas.

4.2.3. Paper V – Investigation of aggregate statistics, development barriers and geographical distribution of German and Italian Community Energy Initiatives active in solar photovoltaic energy

Wierling, A., **Zeiss, J. P.**, Lupi, V., Candelise, C., Sciullo, A., & Schwanitz, V. J. (2021). The Contribution of Energy Communities to the Upscaling of Photovoltaics in Germany and Italy. *Energies*, *14*(8), 2258. https://doi.org/10.3390/en14082258

Research Questions

1. *Relevance of citizen-led PV projects: What is the aggregate contribution of energy communities (ECs) in Germany and Italy to the upscaling of PV in terms of installed capacities?*
2. *Performance of ECs: Do energy communities pay more for realizing PV projects compared to established actors in the energy market?*
3. *Profiles of ECs: Where are these energy communities located and where are they active in installing PV production units?*

Paper V specifically investigates how CEIs in Germany and Italy contribute to the upscaling of solar PV. It also scrutinizes a previous investigation that suggested that CEIs developing solar PV and wind projects are burdened with higher construction, operation and maintenance costs compared to incumbent actors (IEA-RETD, 2016). Lastly, it investigates the geography of solar PV CEIs in the two countries. The choice to focus on solar PV CEIs in Italy and Germany was made because (I) solar PV is one of the most common technologies that CEIs generally engage in and (II) Germany and Italy, at that time[4], had similar conditions in terms of the regulatory framework and government subsidies and a similar CEI activity profile (majority of CEIs engaging in solar PV). However, there are far fewer Italian CEIs than German CEIs.

In both countries, CEIs have only marginally contributed to the deployment of solar PV capacities, with the amount of yearly installed capacities by CEIs having peaked in 2011. The paper shows

[4] More recently, a new form of CEI has emerged in Italy, under the transposed EU definition of REC, which focuses on energy sharing and self-consumption (see Section 5.1).

that CEIs have gradually moved towards installing larger PV facilities over time. This has been influenced by a gradual decline in turnkey prices for PV equipment and changes in feed-in tariffs, which affected the relative profitability of different size classes of PV facilities. A key difference between Germany and Italy is that Italian CEIs tended to purchase existing facilities, while German ones set up new facilities.

The investigation of the geography of CEIs shows that they are predominantly active on the local level, with PV facilities being located in the same NUTS-3[5] region as the CEI's headquarter. Furthermore, CEIs tend to be active in rural areas with lower-than-average population densities but higher-than-average available household incomes.

Lastly, the paper shows that CEIs, in general, do not face higher costs for the construction and maintenance of PV facilities, compared to the overall market. For Germany, the results clearly show no significant differences in costs. In Italy, the case is slightly more complicated as CEIs often purchase existing facilities. Due to limited data on the prices of PV facilities on the secondary market, the results of the investigation are less accurate but overall show a similar pattern as in Germany. In fact, as feed-in tariffs are connected to the individual facilities and fixed over a given timeframe, the purchase of pre-existing facilities is often even more favourable as the facilities inherit the higher feed-in tariffs that were applied at the time of installation.

4.2.4. Paper VI – Investigation of the evolution of business models that are deployed by German energy cooperatives active in the solar photovoltaics sector

Wierling, A., **Zeiss, J.P.**, von Beck, C., Schwanitz, V.J. (2022). Business models of energy cooperatives active in the PV sector—A statistical analysis for Germany. *PLOS Sustainability and Transformation 1(9)*, e0000029. https://doi.org/10.1371/journal.pstr.0000029

Research Questions

1. *What business models are deployed by energy cooperatives in Germany investing in the PV sector?*
2. *What is characteristic of their business models, and which one dominates?*
3. *What is the evolution of investments undertaken by energy cooperatives and how sustainable are the business models?*

Energy cooperatives are characterized by incorporating traits that are typical for traditional for-profit companies, as well as more socially-oriented organizations. For example, energy cooperatives often distribute dividends to their members, akin to private shareholding companies. At the same time, energy cooperatives may also aim to provide additional value beyond dividends to their members or the local community. Consequently, the business models of energy cooperatives differ from those of for-profit enterprises. Private for-profit companies tend to follow a business model where a value proposition is offered to a group of customers, which produces a revenue stream that generates profits for the shareholders. Energy cooperatives may use the revenue generated from the value proposition to external customers not only to pay dividends to their members, but to address various other economic or social needs of their members or the

[5] See Eurostat (2024c) for an explanation of the European NUTS classification system. NUTS-3 generally refers to the level of local regions/districts comprising one or more municipalities.

community. This paper aims to investigate the specific configurations of the business models of German PV cooperatives and their dynamics over time. It uses a version of the business model canvas by Osterwalder and Pigneur (2010), that was adapted by Dilger et al. (2017) and Mazzarol et al. (2018) to the case of energy cooperatives.

Building on a sample of solar PV cooperatives in Germany, the paper identified nine main business models in which these engage, ranging from a feed-in tariff model, where the CEI builds solar PV facilities, sells the electricity generated to the grid and uses the profits to pay dividends to the members, to tenant-contract models, where the CEI installs PV facilities for local consumption on apartment buildings, and E-mobility models where the CEI uses electricity from owned PV facilities to operate electric vehicle charging stations.

In order to successfully run the different business models, CEIs need a network of key partners, which usually comprise private citizens, local municipal authorities and financial institutions. Compared to for-profit companies, CEIs tend to fund their activities through member capital and to a lesser extent through loans.

The investigation of the evolution of CEI activities shows that the feed-in tariff model has been the most common model, as it represented a comparably simple, lucrative and risk-free business model that requires minimal technical and administrative expertise. However, with the more recent reduction of feed-in tariffs, this business model became less attractive, with more and more CEIs shifting to new business models to compensate for the reduced viability of the feed-in tariff model. However, while the business models have become more diverse in recent years, the main purpose tends to remain the financial support of its members. As such, the investigated CEIs are located on the more market-oriented side of the spectrum of cooperatives in general, when compared to other more community- and social mission-oriented cooperatives.

4.2.5. Paper VII – Development and application of a workflow for the evaluation of the quality of indicators used to assess CEI impact

Zeiss, J.P., Wierling, A., Schwanitz, V. J., Marcroft, T. P. (2025). Evaluating Quality of Impact Indicators for Community Energy Initiatives. *Accounting, Organizations and Society.* Submitted

Research Questions

1. *How have economic, environmental and social impact of CEIs been measured by the scientific community, government actors and by the CEIs themselves?*
2. *How can a more systematic and critical reflection of indicators used to measure CEI impact be facilitated in the future?*

The beneficial nature of CEIs is often proclaimed by researchers, government actors and CEI umbrella organizations. However, previous reviews of the CEI literature have found that the evidence base for the economic, environmental and social impact of CEIs is limited. While several efforts have been made to better understand the impact of CEIs, there has been little critical reflection on the quality of the indicators used to measure CEI impact. Thus, the paper aims to develop a workflow that can serve as reference frame to facilitate a more systematic discussion of the quality of future CEI impact indicators. For this purpose, the paper first synthesizes a conceptualization of impact, based on the insights from the impact assessment literature. Further, indicator quality criteria used by statistical offices, accounting institutions or in other literature streams (e.g. environmental/ sustainability indicators) have been mapped and transposed to the case of CEI impact assessment. The workflow is then applied to exemplary cases of CEI impact assessments conducted by the scientific community, government actors as well as CEIs and CEI umbrella organizations, to identify key challenges and best practices in CEI impact assessment and monitoring.

The workflow evaluates indicator quality using five steps: First, judging the quality of an indicator requires defining the impact it is expected to measure. An impact is defined by its three impact components. These are (I) a change in an observable, (II) an actor (=CEI) that causes the change in the observable, and (III) an impact recipient that is affected by the change in an observable. Second, the accuracy of an indicator is then dependent on its ability to reliably depict the change in the observable, establish causality between CEI activities and the change in the observable, and represent the impact recipient of interest (e.g. a group of people, a geographic area, an ecosystem/species). Third, the indicator's usability is dependent on the effort required to collect and process the necessary data to measure the indicator, its acceptance by relevant stakeholders and users, and its adherence to ethical standards and regulations. Fourth, the interpretability of an indicator is dependent on it being put into context with normative goals allowing for an objective judgement to be made of the desirability of the impact, as well as its comparability to other benchmarks, allowing for a further judgement to be made of the performance of the CEI in generating (avoiding) the desired (undesired) impact. Finally, the understandability of an indicator refers to the extent to which the indicator is accompanied by transparent documentation and metadata providing sufficient information to evaluate all previous criteria.

Among the scientific literature and governmental CEI impact assessments, the paper finds a large number of studies that simply identify impacts instead of quantifying them. Furthermore, both the scientific literature as well as governmental assessments are often characterized by insufficient documentation that precisely describes the impact to be measured, the associated indicators, as well as which affected entities have been considered in the assessment. The insufficient documentation is further compounded by tendencies to discuss CEI objectives and expectations instead of materialized impacts, as well as a high reliance on subjective opinions as indicators of materialized impacts. The investigated efforts by CEIs and CEI umbrella organizations, on the other hand, provide detailed and systematic documentation, with clear indicators that are linked to associated impacts. Furthermore, these efforts attempt to minimize, as far as possible, the reliance on subjective opinions. However, there is a tendency to use proxy indicators that measure CEI activities that may lead to an impact, instead of the impact itself.

The paper also briefly discusses the efforts to investigate the impact of RECs by the aforementioned engineering-focused literature stream (see Section 3.2). While this literature stream was not directly included in the investigation, given that it is not typically considered part of the more social science-oriented community energy literature, a recent review of key performance indicators (Giannuzzo et al., 2025) used therein may nonetheless provide inspiration for the traditional community energy literature. In contrast to the traditional literature on CEIs, this engineering-oriented literature stream employs mathematically defined and more complex indicators to mainly investigate the economic performance of CEIs as well as their impact on the technical energy infrastructure.

The paper concludes with recommendations regarding the role of different actors in future CEI impact assessment and monitoring. The role of the scientific community lies in developing a palette of high-quality indicators for CEI impact assessment. For this purpose, a closer collaboration between the engineering and social-science oriented CEI research domains may be fruitful, combining the expertise on developing quantitative indicators of the former with the expertise on the social dynamics of CEIs of the latter. The role of government actors lies in further specifying the most policy-relevant impact that CEIs are expected to generate. This will allow a more targeted approach to CEI impact assessment, avoiding an excessive reporting burden on CEIs as a result of attempting to assess too wide a spectrum of impacts. Finally, the role of CEI umbrella organizations lies in establishing appropriate processes of reporting the required data, as well as ensuring that the developed indicators are well documented and understandable by CEI members who are likely not experts in the field of impact assessment.

4.2.6. Paper VIII – Investigation of the alignment of Community Energy Initiatives with the core ideas of degrowth

Zeiss, J.P., Schwanitz, V.J., Wierling, A., Marcroft, T., von Beck, C., Diemer, A. (2025). Community energy initiatives as drivers for degrowth? An empirical investigation of their alignment with five imperatives of degrowth. *Journal of Cleaner Production 513,* 145612. https://doi.org/10.1016/j.jclepro.2025.145612

Research Question:

How do European Community Energy Initiatives align with the imperatives of Degrowth?

Across Europe, there are numerous forms of CEIs that engage in a variety of activities. There are CEIs that focus on local energy self-sufficiency, de-privatization of energy infrastructure, energy democracy and energy justice, and the provision of non-monetary (community) benefits. Such examples are intuitively aligned with the ideals of the of degrowth movement. However, it is unclear to what extent they are representative of the community energy sector as a whole. Thus, this paper presents a statistical investigation into the alignment of the concepts of community energy and degrowth on an aggregate level.

To test the alignment of CEIs with the degrowth idea, the paper initially reviews definitions of degrowth that are found in the scientific literature, as well as among influential national and international degrowth networks and umbrella organizations. Thereby, the following five degrowth imperatives could be identified:

- Imperative 1: Reduce environmental impact (reduce environmental impact to a level that can be sustained within the planetary boundaries)
- Imperative 2: Re-orient economic priorities (replacing the economic growth paradigm and transformation of the value system towards dematerialization of well-being)
- Imperative 3: Reduce inequality (reduction of injustice in wealth and resource distribution within and across countries)
- Imperative 4: Foster democratic decision-making (strengthening elements of direct democracy)
- Imperative 5: Re-localize production and consumption (increasing focus on local production and consumption)

The statistical investigations in this paper are based on the data in the ENBP inventory, with additional data collected for a more in-depth comparison of French and German CEIs. In addition, the paper uses findings from previous studies to investigate the alignment of CEIs with the five degrowth imperatives.

The results show that CEIs generally align with the imperatives of environmental impact reduction, fostering democratic decision-making and re-localizing production and consumption. The alignment with the imperatives of economic re-orientation and reducing inequality show stark differences across countries and types of CEIs. The comparison of German and French CEIs shows that the former tend to be more market-oriented, focusing on generating financial benefits for their members, while the latter are more social mission-oriented, focusing, for example, on supporting low-income households in energy efficiency upgrades, as well as requiring lower membership fees, resulting in lower financial entry barriers.

5. SYNTHESIS AND DISCUSSION

This thesis set out to investigate the three main research questions of how the CEI landscape has evolved across Europe over time (RQ 1), the challenges regarding the monitoring of CEI activities and impact (RQ 2), and how CEIs align with the different perspectives of the energy transition and the European energy policy objectives (RQ 3). This chapter will begin with a summary of the historical development of CEIs in Europe (Section 5.1), identifying five major phases. The historical development of CEIs demonstrates the increased attention of EU policymakers towards this concept, having led to the recent formalization of CEIs in EU law (Directive 2018/2001; Directive 2019/944). However, the formal recognition of CEIs brings an increased need for a precise and unified definition of CEIs, and systematic reporting and monitoring of their activity. Thus, Section 5.2 discusses the current state of CEI monitoring and the challenges that arise from the commonly used data compilation methods. Finally, Section 5.3 elaborates on the contributions of CEIs to the different aspects of the energy transition, as well as the European energy policy objectives.

5.1. THE HISTORICAL DEVELOPMENT AND CURRENT LANDSCAPE OF CEIS IN EUROPE

Paper II shows that the extent to which CEIs have been able to establish themselves in different European countries varies greatly. In 2023, Germany accounted for nearly 50% of the active CEIs listed in the ENBP inventory. In fact, out of the 30 countries included in the investigation, the top half account for approximately 96% of all active CEIs. This can be partially explained by the size of the country, showing a moderate correlation between the number of CEIs and population[6] ($r = 0.58$). However, some countries, such as Luxembourg and Estonia, while having a comparably low number of CEIs, show some of the highest densities of CEIs in relation to population numbers.

[6] Population data were taken from the World Bank: https://data.worldbank.org/indicator/SP.POP.TOTL

On the other hand, countries such as France, the UK and Spain show a very low density of CEIs per million inhabitants, even though the three countries all belong to the ten countries with the highest absolute numbers of CEIs.

CEIs in Europe vary in terms of organizational structure, technological focus and business model. The most common legal form that CEIs adopt is that of a cooperative, but CEI may also take on the form of associations, foundations or joint-stock companies. However, there are also less conventional forms, such as energy clusters in Poland, SECs in Ireland. Both are similar in that they represent collaborative networks of local citizens, private businesses and government authorities with the goal of managing and advancing the transition to a more sustainable energy system on the level of individual municipalities or administrative regions. Schwanitz et al. (2022), for instance, point to the negative perception of cooperatives in Poland as a likely reason for the preference of the energy cluster concept over energy cooperatives. This negative perception of cooperatives generally stems from the use of this legal structure during the Soviet Era. Another difference is the aspect of primary or secondary energy focus. Most previous CEI mapping efforts (Candelise & Ruggieri, 2020; e.g. Hewitt et al., 2019; Holstenkamp & Müller, 2013) have only investigated such initiatives whose primary activity relates to the energy sector. The category of CEIs that do not engage in the energy sector as their primary activity encompasses, for example, housing, banking and agricultural cooperatives or various other associations. Such associations may include sports clubs, environmental organizations or cultural associations, among others. Other examples are ecovillages, whose primary goal is more generally focused on sustainable communal living arrangements but often includes the production of their own renewable energy for self-consumption. Apartment associations are the dominant form of CEIs, for instance, in Estonia. These tend to install PV facilities on their rooftops, thereby contributing to the energy transition. Agricultural cooperatives engaging in bioenergy, on the other hand, make up the majority of Czech CEIs. Such CEIs with an engagement in the energy sector as a secondary activity make up roughly one half of the entries in the ENBP inventory.

The technological focus of CEIs also varies from country to country. While solar PV dominates in most southern and central European countries, wind power is more common in countries such as the Netherlands, Sweden and Denmark. Denmark, however, is a special case, where CEIs initially engaged heavily in wind power but have now moved on to focus on solar thermal- and biomass-based district heating (c.f. Paper II, Supplementary material).

The variety of CEIs across Europe is also evident in the differences in purpose. On the one hand, German energy cooperatives tend to have a strong focus on providing financial benefits to their members, while French CEIs often use the profits resulting from the generation and sale of electricity as a means to provide wider benefits to the community, while others, such as community benefit societies, which represent the most common form of CEIs in the UK, are even legally obliged to provide community benefits to persons other than their members (Coalfields Regeneration Trust, 2020) (cf. Papers II suppl. material, VI & VIII).

However, even though the above provides a glimpse of the diversity of CEIs across Europe, certain phases of development can be identified, at least among the countries with higher CEI activity (Fig. 3). While an indication for the start and end of each phase is given in the figure, it is important to note that these may vary to some degree from country to country.

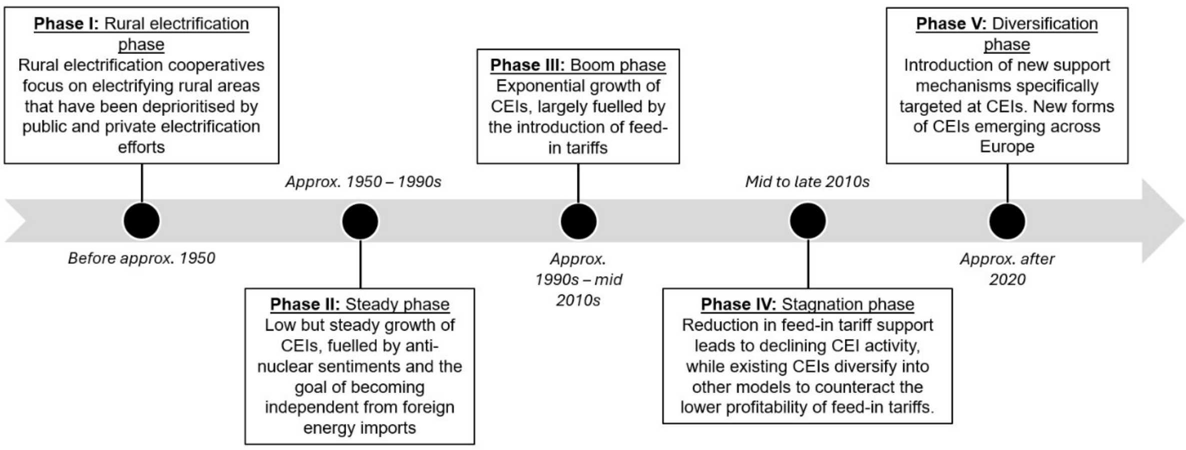

Figure 2: Key Phases of CEI development in Europe

The first phase of CEI development began in the late 19th century and lasted until around the end of the 1940s (cf. Paper II & IV). During this period, major private and state actors focused on the electrification of larger towns and cities, while rural areas were deprioritized. As a result, rural communities came together to build and maintain local electricity distribution grids, either connected to the national grid, or often powered by their own hydropower stations, to supply their own needs. These were common in various countries in Europe, such as Spain, Austria and Germany. Other studies suggest, for instance, that there were up to 6000 such rural electrification cooperatives in Germany alone (Faust, 1977; Holstenkamp, 2015; Yildiz et al., 2015). However, only a few of these have survived until the present day (Klagge et al., 2016; Yildiz et al., 2015), hence the numbers presented in the ENBP inventory are far lower, as they only include those rural electrification cooperatives that are still active today. Those that did survive now tend to belong to the larger CEIs, continuing to operate local electricity distribution grids. CEIs that maintain extensive energy infrastructure are also among the few to employ personnel, with sometimes more than 100 employees (cf. Paper VIII).

The second phase lasted for most of the second half of the 20th century, ending in the 1990s or early 2000s, and was characterized by slow growth in the community energy sector, mainly fuelled by anti-nuclear sentiments and the goal of becoming independent from foreign energy imports (c.f. Papers II & IV). Note that Paper II indicates considerable growth in CEIs during phase II. However, this mainly represents the establishment of various housing-, banking-, and agricultural cooperatives or cultural associations and sports clubs, which only began to engage in the (renewable) energy sector much later, mostly through installing solar PV panels. As such, the number of initiatives actually engaging in energy activities is much lower. The CEI 'EWS Schönau' (EWS Schnönau, n.d.) in Germany is an example of this movement, being established after the Chernobyl disaster. The largest activity during this phase was in Denmark, where numerous wind power and district heating cooperatives have been established as a result of anti-nuclear sentiments and aims to reduce the dependence on international fossil fuel imports (Eikeland & Inderberg, 2016; c.f Johansen, 2021; Mey & Diesendorf, 2018). Danish CEIs represent around one half of the CEIs in the ENBP inventory that were established between 1950 and 2000 and had a primary purpose related to the energy sector. Estimates on their total numbers vary, with Paper III finding close to 1000 wind power cooperatives alone, while Papers I and II identify roughly

400 CEIs including both wind power and district heating cooperatives. The difference in numbers is a result of two factors. Firstly, Paper III also includes dissolved wind power cooperatives, finding that only around 12% still exist today. The ENBP inventory, on the other hand, only includes CEIs that remain active today. Secondly, different definitions have been used in the initial mapping conducted in Paper III and the final ENBP inventory represented in Papers I and II. The differences in definitions will be discussed in detail in Section 7.1.2.

The period from the late 1990s to the mid-2010s marks the third phase characterized by a huge growth of CEIs in Europe. This exponential growth was mainly the result of a combination of technological innovation and favourable regulatory conditions (c.f. Papers II & III). Wilson et al. (2020) demonstrate that 'granular technologies', such as solar PV or wind power, are associated with lower investment risks, lower complexity and higher returns on investment. These new technological advances, particularly in the PV sector, benefited CEIs that tend to be more risk averse (c.f. Paper VI), have lower technical and administrative expertise and less available capital (Brummer, 2018), compared to incumbent actors. From a regulatory perspective, the exponential rise in newly established CEIs was mainly driven by the introduction of lucrative feed-in tariff schemes (c.f. Papers II, III, V, VI) (Busch et al., 2021; c.f. Candelise & Ruggieri, 2020; Klagge et al., 2016; Nolden, 2013; Yildiz et al., 2015). Feed-in tariffs allowed for a comparably simple and risk-free business model, where CEIs were guaranteed a specific price per kWh of electricity generated over a given timeframe (c.f. Paper VI).

Phase IV is characterized by the decline of feed-in tariffs in most European countries in the latter half of the 2010s. The decreasing profitability of the traditional feed-in tariff business model led to an overall decline in newly established CEIs (c.f. Paper II), while existing CEIs had to diversify their portfolio to new business models (c.f. Paper VI). New business models were often centred around local self-consumption (see also Paper VIII) or offering sustainable mobility services. More recently, a change in the German emission trading system in 2022 sparked a new business model for CEIs. The European emission trading system (European Commission, n.d.-g) allocates European companies a certain quota of annual GHG emissions. Companies that emit less than their quota can sell their surplus to companies that emit more than their quota, thereby incentivizing reductions in GHG emissions. Private citizens are normally excluded from this system. However, in 2022, the German government introduced the possibility for owners of electric vehicles to sell their emission quota, which they save as a result of using an electric vehicle with lower emissions compared to combustion engine vehicles. However, private owners of electric vehicles cannot directly sell their quota, but have to go through an intermediary (BMUV, n.d.). By now, various entities provide this service of bundling the quotas of private citizens and reselling them to large companies in need of additional emission quotas. Several existing CEIs[7] have therefore started offering this service to their members and customers, keeping a percentage of the profits from selling the quotas. Paper III indicates that, at least initially, existing CEIs may have adapted well to the declining feed-In tariffs by switching to such alternative business models. For instance, in Germany, even though growth in new CEIs has slowed down, member numbers in existing CEIs continued to grow. This suggests that existing CEIs adapted to the changing circumstances by offering new attractive services to their members. Similarly, while foundation rates declined in the UK as a result of declining support mechanisms, the data do not show a

[7] Some examples of German CEIs that provide this service are AlbWerk (n.d.), BürgerEnergiegenossenschaft Biederbach eG & Elztal (n.d.), Weißachtal Kraftwerke eG (2025), and Teuteburger Energie Netzwerk eG (2025).

significant increase in the closure rate of existing CEIs. On the other hand, CEIs in Italy have undergone a concentration phase, with larger CEIs managing to grow to the national scale, while smaller CEIs struggled to survive (c.f. Paper II, supplementary material). A similar trend can be observed in Denmark, even though occurring already in the late 1990s/early 2000s. Declining support mechanisms and larger investments required to build increasingly larger wind turbines resulted in only the largest CEIs being able to compete with private wind power developers (c.f. Paper III). Yet, more recent data for Germany also suggest a decline in activity within the German community energy sector. The aforementioned findings from Paper III, suggesting that existing CEIs continued to grow in size, are based on data that only cover the years up to 2016. A more recent snapshot from early 2023 of a sample of 539 German energy cooperatives, shows that a significant number of CEIs did not publish any annual reports in recent years, with nearly one quarter having published their last report in 2015 (Fig. 3). According to German law (HGB 2025, §336), cooperatives are legally obligated to publish their annual reports for a given year within the first few months of the following year, at the latest. The high number of CEIs that fail to do so may indicate that these CEIs are functionally inactive, even though they are still officially registered as an active entity. In such cases, a further wave of CEI dissolutions can be expected.

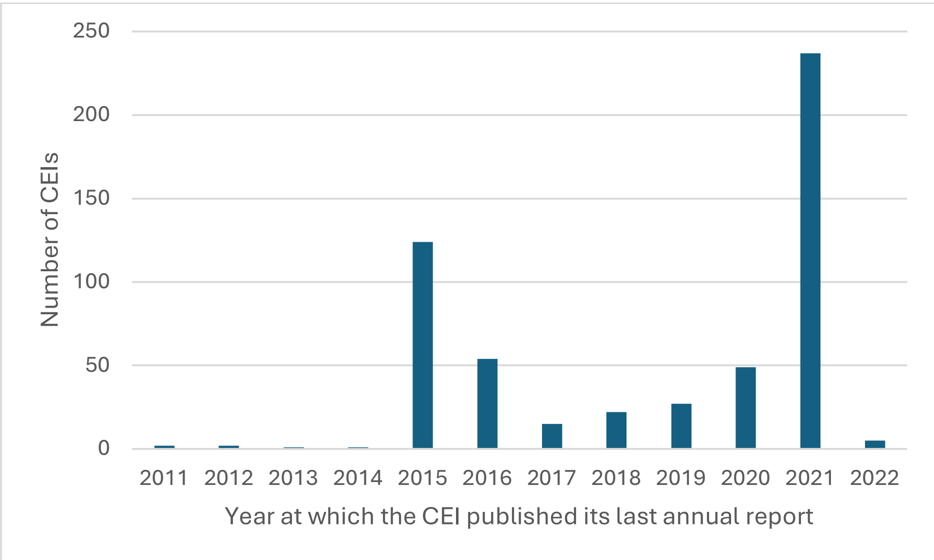

Figure 3: Year of publication of latest annual report for a sample of 539 German energy cooperatives. Snapshot taken in early 2023

Finally, the fifth phase is characterized by a renewed policy focus on CEIs and a potential shift to renewed CEI activity. However, phase V exhibits a key difference when compared to the previous phase characterized by favourable policy-settings for CEIs (phase III). During phase III, CEIs benefitted from lucrative feed-in tariffs, which were targeted at renewable energy producers in general. In phase V, on the other hand, supportive policies that specifically target CEIs are put into place in the EU and its members states. While individual EU members states may have put into place specific policies to support CEIs at an earlier point, the start of this phase on the European level can be marked by the official recognition of CEIs by the EU through the directives

2018/2001 and 2019/944. The European Energy Communities Facility (2025a) exemplifies this trend. This EU-funded initiative aims to provide financial support to CEIs, using the EU definitions as an eligibility test for potential candidates. Similarly, the German government has enacted a subsidy programme for wind power projects initiated by CEIs that conform to the German transposition of the definitions provided by the EU directives (BMWE, 2024). Given the recency of this development, the ENBP inventory only covers the initial years of this phase. As such, only limited conclusions regarding the effect of these policy developments on the community energy sector can be drawn from the available data. However, several exemplary cases may suggest that an increase in CEI activity can be expected as a result of such targeted policy-making. In countries with little historical CEI activity in particular, new forms of CEIs have been on the rise in recent years. These include, for example, the aforementioned energy clusters in Poland or SECs in Ireland. Croatia has also seen a rise in activity lately, with CEIs often taking a more holistic approach beyond the energy sector, such as eco-villages. Another example is Estonia, where apartment associations have recently started to invest in renewable energy. In Italy, new self-consumption CEIs are emerging under the transposed EU definition of RECs. These are collaborations between private households, public actors and SMEs that jointly produce, share and consume renewable energy (c.f. Paper II, supplementary material; Paper VIII) (European Commission, 2024b).

5.2. CURRENT APPROACHES TO MONITORING THE COMMUNITY ENERGY SECTOR IN EUROPE

Comparing the trend of yearly established CEIs (Paper II) with publication patterns of CEI literature (Bauwens et al., 2022; van der Schoor, 2019) shows that coinciding with the growth in CEI foundations, there was also an increasing interest in the topic within the scientific community. The increasing scientific evidence of the various economic, social and environmental benefits that CEIs can provide has also sparked the interest of European policymakers, as evident, for instance, by the significant number of EU-funded research projects, such as COMETS (European Commission, 2024a), COME RES (European Commission, 2023b), COMPILE (European Commission, 2022b), or ECCO (ECCO, 2021). Finally, this has led to the official acknowledgement of CEIs in EU law in the form of RECs (Directive 2018/2001) and CECs (Directive 2019/944). However, more recently, researchers have also begun to criticise the highly positive acclaim of CEIs, arguing that the evidence base, largely based on individual or few case studies, is hardly representative of the community energy sector as a whole (Berka & Creamer, 2018; e.g. Bielig et al., 2022; Schwanitz, Wierling, et al., 2023) (see Section 1.3). As the EU roadmap for future CEI-related policy-making aims to strengthen targeted support for such initiatives, the EU has acknowledged the risk of potential misuse of these support mechanisms and therefore calls for a more systematic monitoring of CEI contributions to the European energy transition goals (Energy Communities Repository, 2024).

In order to develop a better monitoring system for CEI impact, it is necessary to first understand to what extent CEI impact is currently monitored. Two aspects are important in this regard. First, a data availability and quality aspect focusing on what systems for tracking CEI-related data are currently in place; and second, a methodological aspect focusing on how the available data are transformed into indicators that are able to accurately represent the community energy sector and its economic, environmental and social impact. Paper I provides detailed information on the former aspect, while Paper VII discusses the latter. The data collection for CEIs, which is described in Paper I, also aimed to provide the data in a format that adheres to the FAIR data principles (Wilkinson et al., 2016) (See also Sections 2.2.3 & 4.1.1). Thus, the following discussion on the current approaches to compiling CEI-related data will also be guided by the FAIR data principles. Paper VII uses insights from the impact assessment and indicator development literature (Bodem-Schrötgens & Becker, 2019; Ebrahim & Rangan, 2014; European Commission, 2023a; Eurostat, 2014; Gebara et al., 2024; Joumard & Gudmundsson, 2010; e.g. Niemeijer & De Groot, 2008; Vanclay, 2002) to specifically investigate the quality of the indicators used in existing investigations of CEI impact, both in academic studies, as well as by government actors and CEIs and CEI umbrella networks.

5.2.1. Current processes of compiling CEI-related data in Europe

Currently, there is no regular, unified and systematic monitoring of CEIs in Europe. The ENBP inventory presented in Paper I is currently the most extensive database of CEIs. However, it represents a one-time snapshot that will not be updated in the future. The same applies to other previous academic efforts to map the community energy sector in Europe or in specific countries (Candelise & Ruggieri, 2020; e.g. Hewitt et al., 2019). On the European level, the EU established the Energy Communities Repository in 2022 (European Commission, 2024b), intending for it to be a central hub for CEI-related information. The repository provides a map of existing CEIs including information on their economic, environmental and social impact, based on voluntary self-reporting of data by CEIs. However, the repository only managed to collect data on 107 CEIs, which is far below the 10,000 CEIs that the ENBP inventory contains. While the definitions of CEIs used in these two mapping efforts do not align completely (the repository, for example, only includes initiatives with an energy-related primary purpose), the drastic difference in numbers still indicates that the sample contained in the EU database is not representative. Beyond such government-run repositories, several national NGOs and umbrella organizations maintain more or less regularly updated databases on CEIs. These contain various levels of information. Some of the larger umbrella organizations that track CEI data are, for instance, the Dutch organization HIER Opgewekt, which maintains the 'Lokale Energie Monitor' (e.g. HIER opgewekt, 2024), tracking name, type, location and foundation year of Dutch CEIs as well as data on CEI-owned renewable energy production units. Another example is the French organization Énergie Partagée which maintains an interactive map of CEIs that are part of the Énergie Partagée network (Énergie Partagée, n.d.-a), providing data on their name, location and history, as well as the technology and capacity of energy generation facilities owned by these CEIs. On the European level, the European Federation of Citizen Energy Cooperatives (REScoop, 2025a) keeps a register of CEIs that are members of the federation.

While these data sources tend to be accessible and allow the data to be reused, the fragmented nature of the numerous independent actors reduces their level of findability. In addition, the data are published in various formats, ranging from interactive maps to excel spreadsheets and pdf files. This reduces interoperability in terms of the opportunity to automatically retrieve and process the data without lengthy manual screening. Furthermore, the data from such organizations often lack a quality control mechanism. During the data collection process for the ENBP inventory, cross-referencing such data with other sources highlighted various incorrect or outdated datapoints. Furthermore, such efforts tend to focus on CEIs that have an energy-related primary purpose. Other CEIs, such as agricultural, housing or banking cooperatives operating renewable energy facilities as a secondary activity, are often overlooked.

Beyond such efforts to directly monitor CEIs, there are other sources that are not exclusively focused on CEIs but which still contain relevant data. Most important among this category are national business registers. CEIs are commonly registered as legal entities (such as a cooperative)[8] and are therefore listed in such business registers. Typically, these are operated by government authorities, but some are also run by private for-profit organizations. Due to their centralized nature, the national business registers themselves tend to be easily findable. For example, the EU provides a list of national business registers for its member states (European Union, 2022). However, the extent to which specific data are findable within these registers varies greatly from country to country. Some registers simply allow for a search of the registered entities by name. Others provide detailed search masks that allow filtering by, for example, legal form or activities, adhering to internationally standardized classification schemes for economic activities such as the NACE codes (Eurostat, 2008). The amount of available data, and degree of interoperability also vary from register to register. In some cases, only basic administrative data are available, while other registers provide, for example, extensive annual financial data. However, such detailed data may be locked behind a paywall or may only be available in the form of scanned document uploads, allowing no automated retrieval and processing of the data. OpenCorporates maintains a ranking of the business registers of numerous countries (OpenCorporates, n.d.-a). The ranking is based on the amount of information provided (e.g. annual financial accounts, directors, shareholders), the extent to which this information is provided free of charge, the flexibility of the company search tool, and the extent to which the information is machine readable, either allowing bulk data downloads or offering an API[9]. As the ranking shows, countries such as the UK and France have some of the best scores, while the business registers of Austria and Spain score very poorly in the ranking.

Apart from administrative data that are valuable for the investigation of the development of CEIs (e.g. foundation dates, membership numbers, investments) and general information on their activities, business registers provide little data on the actual contribution of CEIs to the energy transition, most importantly any data on the renewable energy facilities installed by CEIs. Centralized data are sparse, apart from a few exceptions. One of the most extensive, detailed and best maintained sources of data on renewable energy facilities is the German core energy market data register (Bundesnetzagentur, 2025). Since 2019, all owners of renewable energy production facilities are obligated to register them with the Federal Network Agency, which publishes the data in a freely accessible database. This database contains detailed data on type of technology, location, technical specification, installed capacities, ownership and more, all accessible through an inbuilt API. There are similar databases in a few other countries, even though they are less detailed, such as the Swedish wind turbine register (Energimyndigheten, n.d.) or the Czech energy

[8] Note that unofficial CEIs also exist. However, as mentioned in Section 3.2, these are not included in this investigation.

[9] An API (Application Programming Interface) is an access point that allows other applications to communicate with the API provider. In the case of business registers, this allows, for example, the programming of a customized search and data extraction tool.

atlas (Calla, n.d.). For most other countries, such data are, if at all, exclusively available directly on CEI websites, which naturally represents the least findable and interoperable data source.

In summary, while large amounts of data on CEIs are available, these data often lack quality controls and tend to be fragmented, not standardized, and poorly machine readable, lowering the possibility for automated retrieval and monitoring. The creation of the ENBP inventory (c.f. Paper I), which was a multi-year process by a large research team, shows that continuous monitoring on a European level is hardly feasible at this point. There are only a few countries in which umbrella organizations dedicate significant effort into monitoring the national community energy sector.

5.2.2. Current approaches to assessing CEI impact

Various attempts to assess the economic, social and environmental impact of CEIs have been made by the scientific community, government actors as well as CEIs and CEI umbrella organizations thus far. Brummer (2018), Berka & Creamer (2018), and Bielig et al. (2022) provide a summary of the impacts investigated by the scientific community. Economic impacts include local economic value and job creation, investing in local infrastructure, business innovation, combatting fuel poverty, and increasing the material well-being of households. Environmental impacts include CEI contributions to GHG emission reductions through the deployment of renewable energy technologies, public acceptance of renewable energy technologies, energy efficiency improvements and changes in energy consumption behaviours. Social impacts include building community spirit, -trust, and -cohesion, education and awareness raising, fostering inclusivity and strengthening political representation.

Efforts on behalf of European government actors to investigate CEI impact include, for example, a report compiled by the European Joint Research Centre (Caramizaru & Uihlein, 2020), as well as the European Energy Communities Repository (European Commission, 2024b). The report by the European Joint Research Centre discusses the potential benefits of CEIs based on a review of the literature, as well as an investigation of 24 cases across Europe. It initially mentions similar benefits to those identified in the scientific literature. The report then goes into more detail on the contributions of CEIs to the deployment of renewable energy technologies, and their effect on the physical energy infrastructure and the costs of maintaining the energy system. The European Energy Communities Repository, on the other hand, is a curious case. The project ran from 2022 to 2024 and, as can be seen on its current website (European Commission, 2024b), it collected data from 107 CEIs across Europe. As of today, it only presents three impact indicators, i.e. the total renewable energy capacity installed, finances invested, and GHG emissions saved by these CEIs. However, the project originally set out to conduct a far more comprehensive assessment of CEI impact, including social and economic aspects. In fact, up until summer 2024, the project hosted a database of CEI impact indicators, accompanied by documentation on the measurement methodology for the indicators. However, after completion of the project, the European Directorate General for Energy decided to remove nearly all evidence of this larger impact assessment. Previous versions of the projects website, that where saved by the Internet Archive, nevertheless hint at this initial assessment (Internet Archive, 2023, 2024a, 2024b). Several inquiries to the European Directorate General for Energy regarding the reason for the removal of the documentation of and most data produced by this effort have been unsuccessful, as all contact information leads to email addresses that are now defunct.

Furthermore, CEIs and CEI umbrella organizations themselves have also initiated efforts to map and assess their impact. In 2021, a stakeholder workshop initiated, among others, by the European Federation of Energy Cooperatives (RESCoop) and the Electra Energy Cooperative in Greece, mapped the potential impacts of CEIs (Proka et al., 2021). This process identified nine impact categories, ranging from technological and energy market impacts to sociocultural and policy impacts. As early as 2012, the Ashton Hayes Energy Community set out to develop a framework to monitor its impact (Ashton Hayes Going Carbon Neutral, 2010; NEF, 2012). The initiative, which is run in part by local volunteers, aims to transform the village of Ashton Hayes into a carbon neutral community. The framework covers short-, medium- and long-term social, environmental and economic impact of the initiative on the community and households. Lastly, the French CEI umbrella organization Énergie Partagée (Énergie Partagée, 2024) initiated several projects to investigate the impact of its members. In 2019, Énergie Partagée published an assessment of the economic impact of French citizen wind and PV projects (Énergie Partagée, 2019). The investigation covered taxes paid, jobs created, rents paid and the returns on investments of such projects. Since 2023, Énergie Partagée also provides a social impact self-assessment tool for its members. In addition to the aforementioned economic impact, the tool also covers impacts related to networking and collaboration among actors in the energy sector, ownership of renewable energy technologies, civic involvement and participation in decision-making processes, and increasing local resilience and energy independence. Finally, the recently established European Energy Communities Facility, which is coordinated by the European Federation of Energy Cooperatives (RESCoop), aims to provide financial support to selected CEIs. In turn, it obligates chosen CEIs to complete a regular impact assessment survey (European Energy Communities Facility, 2025b). However, due to the early stages of the project, no information on this impact assessment survey is available, beyond the statement of intent.

Paper VII investigates the above-mentioned efforts in terms of the indicators and measurement methodologies used to assess CEI impact. For this purpose, Paper VII first develops a workflow for the selection and evaluation of high quality CEI impact indicators (see also Section 4.2.5). In doing so, several key issues and best practices could be identified. In line with the developed workflow, these can be grouped into aspects relating to the definition of the impact, as well as the accuracy, usability, interpretability and understandability of the employed indicators. First and foremost, as may already become evident from the impacts discussed above, there is a tendency to only investigate positive impact (benefits), while negative impact is overlooked (c.f. Van Der Waal, 2020). Furthermore, given the fragmented and often limited availability of CEI data (see Section 5.2.1), most investigations into economic, environmental and social impact of CEIs are based on individual cases, a single point in time and a focus on only a few selected impacts (Berka & Creamer, 2018; c.f. Bielig et al., 2022). Some exceptions are Hanke et al. (2021), Fraune (2015), Radtke (2014) or the Energy Communities Repository, which investigate larger samples of CEIs, the Energy Communities Facility which aims to conduct repeated assessments, and Callaghan & Williams (2014), Wüste & Schmuck (2012), or the effort by the Ashton Hayes Energy Community and Énergie Partagée, which measure a wide spectrum of impacts.

Among the scientific literature, Paper VII also finds that impacts are commonly only identified, instead of quantified. This is commonly the case when interview or survey respondents mention that a certain impact has occurred. Often, such studies do not intend to investigate CEI impact as their primary research objective, instead identifying impacts in the process of investigating their true research question. As such, indicators are often not explicitly stated and linked to the associated impact but need to be inferred from the text. Only very few cases systematically define the employed indicators, such as Hanke et al. (2021) and Mundaca et al. (2018). Furthermore, various studies investigate the expectations or objectives of CEIs, instead of the materialized impacts. The fact that such studies have been cited by various literature reviews (e.g. Berka & Creamer, 2018; Bielig et al., 2022; Brummer, 2018) as evidence of the impact of CEIs points to a risk of misinterpretation. Further potential for misinterpretation stems from the inherent ambiguity of the concept of community energy. As such, it proves difficult in some cases to discern whether studies investigate the impact of CEIs or municipal-led projects (see e.g. Hoppe et al., 2015; Schweizer-Ries, 2008). A similar ambiguity can also be observed when defining who is affected by an impact. Often, reference is simply made to ‘citizens’ or ‘local community’. However, there are cases that precisely define those affected, for instance, in terms of geographic scope (e.g. Okkonen & Lehtonen, 2016; Phimister & Roberts, 2012) or by referring to specific stakeholders such as farmers (Hicks & Ison, 2011; Mundaca et al., 2018) or women (Fraune, 2015). Studies of CEI impact also tend to rely on subjective data. While this is unavoidable when investigating aspects such as the acceptance of renewable energy or community confidence and trust, it is possible to limit the potential variability resulting from such subjective data. Bauwens & Defourny (2017), for example, measure generalized interpersonal trust among members of a CEI using standardized questions that have been field-tested and refined by the World Values Survey. However, such cases are rare, with studies often using non-standardized responses of survey or interview candidates as indicators. This issue is even more pronounced when subjective opinions are used to assess impacts that are objectively measurable, such as GHG emission reductions or the increased income of stakeholders (e.g. Ruggiero et al., 2014; Wüste & Schmuck, 2012). Lastly, it occasionally proves difficult to establish that a certain impact is actually the result of CEI activities and not caused by other factors (see also Proka et al., 2021). An approach that is taken in a few exemplary studies (e.g. Devine-Wright, 2005; Musall & Kuik, 2011; Schweizer-Ries, 2008; Warren & McFadyen, 2010) is to compare the results with a spatially or temporally removed control group with otherwise similar conditions. Lastly, CEI impacts are rarely put into context with similar impacts generated by other entities, or general averages that would allow an interpretation of the performance of a CEI in generating or avoiding a desirable or undesirable impact. For example, information on taxes paid by CEIs has limited informative value without comparisons being made to taxes paid by other renewable energy developers.

Evaluating the quality of the indicators and measurement methodology of the governmental efforts proves more challenging due to even poorer documentation, especially in the case of the European Energy Communities Repository, where nearly all documentation was removed after completion of the project. However, some of the issues discussed above can also be found among such efforts. This includes the reliance on subjective opinions, discussion of objectives and expectations instead of materialized impact, vague definition of those affected by the impact, and limited comparability to general benchmarks. The report by the Joint Research Centre serves as an example of the latter issue. Here, CEI contributions to renewable energy deployment are given in terms of the number of solar panels installed, or rooftops covered by solar panels. Such non-standardized units (in contract to kW of installed capacity) offer limited comparability to other cases. Furthermore, in the case of the Energy Communities Repository in particular, the question of the representativeness of the data arises. Here, exclusively members of CEIs have been surveyed, yet, in the end, statements were made regarding the impact of CEIs on the wider community. For example, it is questionable to what extent members of a CEI can judge the CEI's impact on the acceptance of renewable energy technologies among the general public. A positive aspect, however, is the use of the EU definitions of CECs and RECs to clearly delineate which entities are seen as CEIs in the context of the assessment.

In contrast to the efforts by government actors and the scientific community, investigated efforts by the Ashton Hayes Energy Community and Énergie Partagée represent the most systematic and well documented approaches. However, while Énergie Partagée provides detailed methodological documentation for the social impact self-assessment tool, this documentation is not fully publicly available. Both frameworks provide a clear list of impacts and associated indicators. Furthermore, both examples indicate an awareness of the issue of relying on subjective opinions, attempting to provide both subjective and objective indicators wherever possible. These efforts also focus on using data that are representative of those affected by the impact. In the case of the Ashton Hayes Energy Community, a survey of the inhabitants of the village was planned to provide most of the required data. Énergie Partagée, on the other hand, provides instructions on how to measure impact on the correct geographic scale, for instance, in terms of taxes paid at the local, regional and national level. The main issues identified in the case of the Ashton Hayes Energy Community relate to a vague definition of the CEI. It is not fully explained whether the Ashton Hayes Energy Community refers to the village or a separate legal entity representing the CEI. Furthermore, it is unclear whether the developed framework has ever been fully applied. This may indicate that the framework required too much effort in terms of data collection and processing to be useful. In the case of Énergie Partagée, the main issue is in the use of several proxy indicators measuring certain activities conducted by a CEI that may lead to the associated impact, instead of actually measuring the impact. An example is the use of the number of training or awareness raising workshops conducted by a CEI as indicator for increased knowledge and awareness relating to the energy system. On the one hand, this approach reduces the effort required to collect the necessary data, as most indicators can be measured with the internal data of the respective CEI using the self-assessment tool. Furthermore, such indicators do not require additional steps to establish causality between indicator measurement and CEI activity. On the other hand, this approach limits the explanatory value of the indicators in terms of measuring the real impact.

It is important to note that the engineering-oriented literature stream (see also Section 3.2) also includes a considerable number of studies investigating the performance and impact of energy communities (see Giannuzzo et al., 2025). Bauwens et al. (2022) see this literature stream as being separate from the traditional community energy literature, due to its strong technological focus. In fact, comparing the corpus of literature reviewed by Giannuzzo et al. (2025) with the literature on the impact of CEIs reviewed by Brummer (2018), Berka & Creamer (2018), or Bielig et al. (2022) shows almost no overlap. However, this literature stream has recently also started to adopt the EU definition of RECs, and as such we may see a convergence of the two literature streams in the future. A crosscheck of the key papers referenced in Giannuzzo et al. (2025) indicates that this trend is led by authors from Italy (Cielo et al., 2021; e.g. Cutore et al., 2023; Mutani et al., 2021). This observation is supported by the fact that the Italian transposition of the

EU directive defines RECs as a group of energy producers and consumers connected through a common energy grid under the same medium voltage station (Energy Communities Repository, 2023b). This definition of RECs strongly aligns with the technological conceptualization of energy communities that has already dominated this literature stream. While a small number of studies addresses the social aspects of the investigated projects, such as energy poverty reduction, inclusiveness or local representation (Ceglia et al., 2022; e.g. Couraud et al., 2023), the results of Giannuzzo et al. (2025) indicate that investigations of economic performance and impact on the technical energy system dominate this literature stream.

Nonetheless, this literature stream shows a far more systematic approach to the assessment of REC impact and performance when compared to the traditional community energy literature. The performance indicators identified by Giannuzzo et al. (2025) all come with a precise description, including mathematical formulas for their calculation. Furthermore, the indicators tend to focus on the impact that materializes within the REC. In Italy, where most of the studies on RECs, that were reviewed by Giannuzzo et al. (2025), are located, RECs are clearly delineated in terms of the physical infrastructure that connects all REC members. This resolves many of the issues related to the ambiguous definition of a CEI and those affected by the CEI, which can be found in the traditional community energy literature. However, Giannuzzo et al. (2025) point out that the proposed indicators require significant data collection that may reduce their usability for individual REC members. As such, the complexity of the proposed indicators may limit their transferability to other CEIs, especially small, volunteer-run CEIs with limited resources.

5.3. CEI CONTRIBUTIONS TO THE ENERGY TRANSITION AND EU ENERGY POLICY OBJECTIVES

Section 3.4 has outlined how CEI definitional criteria and EU energy policy objectives align with the imperatives of a more radical sustainability transition as envisaged by the degrowth movement. These have a common focus on reducing the environmental impact of the energy system (e.g. GHG emission reduction, renewable energy deployment, energy efficiency improvements), fostering democratic decision-making and the participation of citizens in the energy system, as well as ensuring a fair and inclusive energy transition and reducing inequalities. In addition, both the degrowth imperatives and the CEI definitional criteria emphasize the aspect of localness and economic reorientation. The European energy policy, on the other hand, defines energy security, economic growth and competitiveness as additional objectives. Using this framing, it is possible to discuss how different types of CEIs in the ENBP inventory align with the various CEI definitional criteria, EU energy policy objectives as well as a narrower technological transition or wider societal sustainability transition perspective on the energy transition.

5.3.1. CEI contributions to a renewable and efficient energy system

As shown in Paper II, the CEIs in the ENBP inventory have installed up to 10 GW of renewable energy capacities in Europe. Nearly half of the entries in the ENBP inventory represent CEIs that primarily engage in non-energy activities, such as banking, housing and agricultural cooperatives, or cultural associations and sports clubs. Such initiatives are not considered CEIs within the EU definitions of RECs or CECs, and likely neither by Walker and Devine-Wright (2008). These types of CEIs dominate in Estonia and the Czech Republic, but are also common in, for instance, Germany and Sweden. Thus, the value of 10 GW of renewable energy capacity represents a maximum value that includes the above-mentioned borderline cases. However, even then the contribution of CEIs to the total deployment of renewable energy capacities is in the lower single digit percent range. The exceptions are Belgium, where CEIs currently contribute around 5% of the total renewable energy capacity, and Finland, where one cooperative (Metsä, 2024) contributes around 15% of the total annual renewable energy production. However, this cooperative can be considered a controversial case, as it is a nationally active forestry cooperative with over 100,000 members. The cooperative operates several biomass power plants to power its sawmills and other production facilities. Thus, its primary non-energy focus disqualifies it from most CEI definitions. Furthermore, its national focus also does not align with the 'local focus' criterion. As will be discussed further below, the degree of democratic decision-making also tends to be inversely correlated to the size of a CEI and as such, the extent of active involvement of all members in the decision-making is likely far lower than in other more typical CEIs.

There are two more noteworthy examples where CEIs played a significant role in the technological energy transition. First, electricity cooperatives during the first phase of CEI activity in the early 20th century (see Section 5.1) substantially contributed to the electrification of rural areas, for instance, in Germany (Faust, 1977; c.f Yildiz et al., 2015). Second, as shown in Paper III, wind power cooperatives were an important driver of the upscaling of the Danish wind power sector in the 1980s and 1990s, with up to 40% of all Danish wind turbines being owned by CEIs during the peak phase (c.f Paper II, supplementary material). However, in both cases, only a few of these CEIs remain active today.

Beyond the few cases mentioned above, CEIs only play a marginal role in terms of direct renewable energy deployment. This begs the question of whether CEIs contribute to a renewable and efficient energy system indirectly through other means. Chief among the indirect contributions to the energy transition are the claims that CEIs increase public acceptance of renewable energy technologies, as well as contribute to energy saving, for instance, by offering energy efficiency consulting or triggering changes in consumption behaviour, or by raising awareness of energy issues in general. This is echoed by the EU definitions of CEIs as well as various academic papers, as summarized, for example, by Brummer (2018) or Berka and Creamer (2018). A number of studies have investigated these aspects, mostly on a case study basis, focusing on the effect on the CEI members themselves (e.g. Burchell et al., 2014; Musall & Kuik, 2011; Schweizer-Ries, 2008; Warren & McFadyen, 2010). While an aggregate level investigation of the impact of CEIs on these aspects was not possible in this thesis due to a lack of reliable data, some interesting observations could still be made. For example, Paper II estimates that more than two million citizens are members of the CEIs listed in the ENBP inventory. As a result of their membership, they have likely gained new knowledge and awareness of energy-related issues and potentially changed their behaviour accordingly. It can also be assumed that each member, in turn, has an effect on the awareness and behaviour of other people in their immediate surroundings. On the other hand, among German solar PV cooperatives in the ENBP inventory, less than 15% mention energy efficiency-related objectives in their purpose statements (Paper VI). Similarly, Schwanitz et al. (2023) find that only around 7% of CEIs in the ENBP inventory report that they have initiated energy efficiency and energy savings projects or information campaigns. Furthermore, it is interesting to consider these aspects from a definitional perspective. Walker and Devine-Wright (2008), who provide one of the earliest conceptualizations of community energy (see also Section

3.2), discuss at great length how the term ‘community’ can be interpreted. However, they do not actually discuss which activities CEI may engage in. The case studies chosen by the authors suggest a limitation to initiatives that engage in renewable energy generation. Out of the two EU definitions, the one of CECs specifies activities such as electricity generation, distribution and trade, but also energy efficiency and operating electric vehicle charging stations, while the definition of RECs only specifically mentions that RECs are entitled to produce, consume, store, share and sell renewable energy (CEER, 2019; Directive 2018/2001; Directive 2019/944). This leaves open the question as to whether initiatives that focus primarily on activities such as awareness raising, education and consulting instead of the operation of (renewable) energy infrastructure qualify as CEI under these various definitions. For example, the generation of renewable energy plays only a subordinate role in the Irish definition of SECs, and coincidentally, this type of CEI is not considered a direct transposition of the RECs and CECs as defined by the EU (Energy Communities Repository, 2023a; SEAI, 2025b).

Beyond their direct and indirect contributions to the technological energy transition, CEIs are also expected to provide various additional benefits that contribute to a wider transition to a more democratic and equitable society focused on human well-being instead of economic growth (see Section 1.2). These aspects will be discussed in more detail in the next sections.

5.3.2. CEI contributions to an economic re-orientation

The EU definitions of CECs and RECs in particular emphasize that CEIs should not (exclusively) focus on generating financial profits. Among CEIs, the orientation towards generating profits or addressing societal or environmental needs varies greatly, both from country to country, as well as over time. Starting with the rural electrification cooperatives in the early 20th century, these CEIs had a clear mission to fulfil the needs of rural communities to gain access to electricity (c.f. Paper IV). Following the ideal of cooperatives as local self-help organizations that was envisioned by early cooperative pioneers (c.f. Peal, 1988), these CEIs commonly built hydropower stations and local electricity grids in areas that were deprioritized by private and public electrification efforts. During the boom phase of CEIs in the early 2000s, this picture changed significantly. The feed-in tariff-based business model, which was common, for instance, in Germany, mainly focused on generating renewable electricity, which was fed into the national grid, receiving lucrative remunerations, that were paid out as dividends to members (Papers II, V, VI). Here the focus was on capitalizing on an opportunity to profit from state subsidies. Based on a smaller sample of CEIs across Europe, Paper VIII also finds a common focus on paying member dividends. Paper VIII also shows that a majority of the investigated sample of German PV CEIs exclusively mention the economic support of their members in their purpose statements. However, similar concepts such as the rural electrification cooperatives can also be found more recently in the form of local district heating cooperatives, for instance, in Austria, Finland and Denmark (Paper II, supplementary material), that focus on fulfilling the local need for heating solutions. In fact, Danish regulations specifically forbid profit-generation for district heating companies, which has been stated as being an important factor for the dominance of cooperative forms in this sector (Gorroño-Albizu et al., 2019). Similarly, housing cooperatives/apartment associations that install renewable energy facilities do so to fulfil the need of their members (= tenants/apartment owners) for affordable and clean energy. French CEIs also tend to take on a more needs-based approach, focusing on combatting energy poverty, building community spirit, or raising public awareness (Paper VIII). As mentioned in Section 5.1, the feed-in tariff business model has been in decline in most countries due to decreasing subsidies. As a result, previous CEIs relying heavily on this business model are either diversifying their portfolio or being discontinued, while new forms of CEIs are emerging across Europe. CEIs are consequently akin to social enterprises which are hybrids between market-oriented businesses and social mission-oriented organizations (Dilger et al., 2017; Ebrahim et al., 2014; Huybrechts & Mertens, 2014). The extent to which CEIs are oriented more towards the market-oriented goal of providing financial profits for their members or the social goal of fulfilling specific needs for their members of the wider community may vary from case to case (Bauwens & Defourny, 2017; Berka & Creamer, 2018; c.f. Candelise & Ruggieri, 2017; Dilger et al., 2017).

5.3.3. CEI contributions to a democratization of the energy system

First and foremost, Paper II estimates that over two million people are involved in CEIs as members, thereby directly participating in the energy system and driving the energy transition. As summarized in Paper I, CEIs often choose legal forms that require adherence to the one member-one vote principle, where each member has one vote, regardless of the shares owned. This is the typical decision-making structure of cooperatives, as defined in the cooperative principles of the International Cooperative Alliance (ICA, n.d.-a). The analysis of French CEIs in Paper VIII indicates furthermore that even those CEIs with legal forms that do not strictly require adherence to the one member-one vote principle often tend to do so voluntarily, in any case. However, the statutes of CEIs show that they are typically run by a steering committee or board, which are responsible for the day-to-day operations, hence reflecting a representative democratic system instead of a direct democratic one. Paper IV suggests that women and younger people may be underrepresented in such steering committees or boards. Only major decisions are voted on by all members in the annual general assemblies. Paper IV investigates the participation rate of members in such general assemblies for a small sample of Swedish CEIs, finding that, on average, only 15% of the members join these meetings. The low rate of participation of members in CEI decision-making is also discussed by Van Veelen (2018). Other authors have also pointed out that the level of participation of members in decision-making decreases with the increasing size of a CEI (Rommel et al., 2018). Paper VIII confirms this finding, based on a small sample of 85 European CEIs taken from the European Energy Communities Repository (European Commission, 2024b).

Beyond internal decision-making dynamics of CEIs, it is also worth investigating the inclusivity of CEIs in terms of who participates in them, consequently having the opportunity to influence CEI decision-making. Paper IV finds that CEI members tend to be ‘well-off, rural, male sexagenarians’. Similarly, Fraune (2015) found a underrepresentation of women in German CEIs. Paper VIII also finds a low share of women and younger members (<35 years) among the sample of CEIs listed in the European Energy Communities Repository (European Commission, 2024b). In addition, Paper VIII shows that the membership fees vary greatly from country to country, with French CEIs having comparably low fees, while Swiss and Czech CEIs have very high fees. In general, membership fees of EUR 500 or more are not uncommon for European CEIs, representing a significant share of the total savings of low-income households. However, the high fees of Czech CEIs are an exceptional case, possibly because these are predominantly larger agricultural cooperatives that only engage in bioenergy as a side-activity. Furthermore, Paper VI finds that about one third of the investigated sample of German solar PV cooperatives set geographical restrictions for membership. While this is in line with the definitional criterion of having a local focus, it arguably infringes on the idea of open and inclusive membership. In addition, Paper VI also finds rare cases in which CEIs restrict membership to certain demographic groups. In summary, CEIs are often owned and run by a small group of people who do not represent the demographic composition of society (Sebi & Vernay, 2020; Van Veelen, 2018). However, examples such as the SECs in Ireland show that some CEIs specifically emphasize inclusiveness. The Sustainable Energy Authority of Ireland (SEAI), which oversees all SECs, states that members of the steering committee of an SEC should reflect the demographics of the neighbourhood/town/region in which it operates (SEAI, 2025a). On the other hand, the SEAI does not set any requirements in terms of governance structures, such as adherence to the one member-one vote principle.

These challenges regarding inclusiveness also provide further insight into the claim that CEIs contribute to the acceptance of renewable energy technologies (see also Section 5.3.1). It is often stated, that the option for local inhabitants to participate in the planning process for renewable energy facilities, as well as benefit from their operation, for instance, in terms of returns on investment, increases acceptance, particularly in the case of wind turbines (Ellis et al., 2009; Langer et al., 2017; e.g. McLaren Loring, 2007; Warren & McFadyen, 2010). However, the evidence presented above regarding the inclusivity of CEIs suggests that both decision-making power and potential benefits remain concentrated on a small group of people not necessarily representative of the local community. This challenges the claim that the participatory and inclusive nature of CEIs lead an increase in the acceptance of renewable energy projects. Other studies have shown that these issues may lead to significant local resistance to planned renewable energy facilities (Simcock, 2013, 2016; Walker et al., 2010).

5.3.4. CEI contributions to reducing inequalities

The degrowth idea, which represents a more fundamental societal transition, as outlined in Section 3.1, commonly emphasizes the need for a more just distribution of wealth and other resources. CEIs have two means of contributing to this, either by providing benefits to members or the external community, thereby potentially taking a greater public or mutual benefit orientation, as outlined by Bauwens and Defourny (2017). As indicated in Paper VI, German CEIs, for instance, tend to mainly focus on the needs of their members. An analysis of the purposes statement of 374 German CEIs shows that only 46 CEIs state a purpose other than fulfilling their members' economic, social and cultural needs. Apartment associations, which are the predominant type of CEI in Estonia (c.f. Paper II), are similarly oriented towards mutual benefit. Their focus is on providing renewable energy to their members, who, according to the Estonian Apartment Association Act, need to be owners of apartments in the same building complex (Apartment Associations Act 1995). The rural electrification cooperatives that were active in parts of Europe in the early 20th century (c.f. Sestion 5.1), represents another example of mutual benefit oriented CEIs. Such cooperatives were established to provide electricity to their members, although in some cases they were subsequently required by law to also provide electricity to non-members on the same terms as for members (Holstenkamp, 2018). While the above examples align with the ideal of cooperatives as self-help organizations (c.f. Peal, 1988), the extent to which such mutual benefit oriented CEIs contribute to a redistribution of wealth and resources depends on the demographics of the member-base. The discussion of CEI contributions to a democratization of the energy system (Section 5.3.3) has presented several points that indicate that members of modern CEIs tend to be predominantly older men from medium to high-income households, a demographic group that is typically already privileged. Similarly, rising real-estate prices have led to increased difficulties, for example, for younger and low-income demographics to purchase real-estate in Estonia (Kährik & Pastak, 2023). As such, members of apartment associations in Estonia likely do not represent disadvantaged groups. Members of rural electrification cooperatives, on the other hand, represented a part of society that lived in deprioritized rural areas with no access to electricity. By focusing on providing electricity to their members, such cooperatives contributed to a reduction in wealth and resource disparities.

However, other CEIs specifically focus on providing public/collective benefits to stakeholders beyond members. French CEIs, for example, often focus on supporting low-income households with energy efficiency refurbishments of their homes, collaborate with schools to offer training courses to raise awareness of energy issues, or support local social and cultural institutions or events (c.f. Paper VIII). In the UK, CEIs are often active in remote rural areas, focusing on community development, for instance, by refurbishing community buildings and combatting energy poverty (Seyfang et al., 2012, 2013; Walker et al., 2010). Similarly, Irish SECs focus on supporting the development of the community (neighbourhood, town, region) that they represent. Their overarching goal is to develop and implement an energy master plan for the community. This includes measures such as supporting homeowners in energy efficiency upgrades, facilitating sustainable modes of transport, retrofitting public buildings, or offering training workshops and information campaigns (SEAI, 2025b). The database on SECs hosted by SEAI shows, for instance, that about one third of all SECs specifically mention the reduction of energy poverty as one of their goals (SEAI, n.d.).

While other CEIs may not directly conduct activities aimed at supporting vulnerable groups or communities, they may still generate collective benefits. An important factor potentially contributing to a redistribution of wealth and resources are the local economic benefits of CEIs. A study conducted by the French CEI umbrella organization Énergie Partagée, for example, suggests that citizen-led renewable energy projects generate up to three times the local economic value compared to private developments (Énergie Partagée, 2019). This occurs mainly through the use of local actors during the planning, construction and operation of the renewable energy facilities, as well as the return on investments to shareholders, who are predominantly located in proximity to the facility (see also Section 5.3.5). As such, even though profits are not directly re-invested into the local community, but paid as dividends, they remain in local circulation. An earlier study conducted on behalf of the British Department of Energy and Climate Change (Capener, 2014) finds that community wind turbines could generate up to 12 times the local economic benefits compared to privately owned wind turbines. This is based on an assumption that 40% of the revenues are paid into a community benefit fund and the remaining 60% are distributed to members as dividends. However, the investigations in Paper IV and Paper V suggest that at least in Germany, CEIs are predominantly located in richer regions. In such cases, it is questionable to what extent local economic benefits will contribute to a redistribution of wealth and resources.

5.3.5. CEI contributions to a re-localization of the production and consumption of energy

The local focus has been emphasized by both the original conceptualization of CEIs by Walker and Devine-Wright (2008) and the EU definitions of CECs and RECs. However, a local focus can be defined in various ways, most importantly whether (I) the members are located in proximity to the CEI, (II) the CEI conducts activities such as the installation of renewable energy facilities, on a local level, and (III) the benefits are distributed locally.

While Walker and Devine-Wright (2008) and the definition of CECs and RECs emphasize local benefits, the definition of RECs also emphasizes that CEI members should be located in proximity to the CEI. As already pointed out in Section 3.2, some national transpositions of the EU definition of RECs have provided more precise requirements on the aspect of proximity of members to the CEI. Membership is either restricted in terms of administrative regions (e.g. same municipality/ department/ region as the CEI) or distance (e.g. within a certain radius of the CEI). Paper IV shows that the majority of members of CEIs in Denmark tend to be located within a 50km radius of the respective CEI. Similarly, a significant number of German CEIs have already put in place geographical restrictions for members prior to the establishment of the EU definitions (c.f. Paper VI).

In terms of activities, both Paper V and Paper VIII show that CEIs tend to predominantly install renewable energy production units within the same NUTS-3 region. In fact, Paper VIII shows that around two thirds of the renewable energy facilities in the ENBP inventory are within only 10km of the CEI's headquarters. However, a small number of CEIs operate renewable energy production units that are located further away, occasionally even in foreign countries. CEIs also tend to cooperate with other local actors, such as municipal authorities, local cooperative banks or municipal energy utilities (Paper VI). However, a more varied picture presents itself in regard to the use of local resources. Paper VIII finds that German CEIs mostly use solar PV panels from Asian (particularly Chinese) manufacturers, while French CEIs predominantly use solar PV panels from European manufacturers. This indicates that French CEIs consciously aim to break with the global trend of using PV panels from Chinese manufacturers, which dominate today's market (IEA, 2022b).

The aspect of local benefits can be investigated in terms of the use of energy produced and the distribution of the financial profits generated. CEIs have commonly focused on feeding renewable electricity into the national grid. Only recently, a shift towards more self-consumption projects has been observed (c.f. Paper VIII). The exceptions here are the rural electrification cooperatives established during the early 20th century that focused on providing electricity to local communities, as well as modern CEIs focused on maintaining district heating facilities, or housing cooperatives that operate renewable energy facilities to fulfil the energy demand in their own buildings. The aspect of localized financial benefits has already been discussed in the previous section in more detail. CEIs either use profits to fund further local activities or distribute profits as dividends to members, who are generally located in proximity of the CEI. Therefore, financial benefits tend to remain in local circulation.

5.3.6. CEI contributions to EU energy policy objectives

CEI contributions to the EU objectives of moving to a participatory, fair and efficient energy system based on renewable energy technologies have already been covered as part of the previously discussed contributions to the energy transition (Sections 5.3.1-5.3.5). The two remaining EU energy policy objectives are increasing energy security and fostering economic growth. The EU aims to increase energy security by fostering the local production of renewable energy, as well as increasing energy efficiency, thereby lowering dependence on international energy imports (Babiker & Ciucci, 2025a; European Commission, 2022a). While CEIs contribute to this policy objective through the installation of renewable energy facilities and, to a lesser extent, by providing energy efficiency services, CEIs only rarely refer to energy independence in their purpose statements. For example, among the purpose statements investigated in Paper VI, only two explicitly mention energy independence. The exception are Danish wind power cooperatives, which were often motivated by the goal to reduce dependence on international oil imports as a result of the major oil crises in the 1970s and 1980s (Paper II). However, beyond the dependence on energy imports, the EU also faces challenges regarding the dependence on imports of raw materials and equipment for renewable energy technologies, such as solar panels (e.g. van Wieringen & Hüntermann, 2022). In this regard, Paper VIII finds that some CEIs are more aware of this issue than others, predominantly relying on European solar panel manufacturers. This is evident from a comparison of German and French CEIs.

Finally, European energy policy takes an opposing stance to the degrowth movement in terms of economic preferences, emphasizing economic growth instead. Section 5.3.2 has discussed the extent to which CEIs are aligned with the economic growth narrative, pointing out that CEIs are often a hybrid between market-oriented businesses and non-profit, social mission-oriented organizations that are typically seen as compatible with the degrowth ideals (Demaria et al., 2013, 2013; Dilger et al., 2017; Petridis et al., 2015). Paper II estimates that CEIs in Europe have collectively invested EUR 6-11 billion in the energy transition. The French CEI umbrella organization estimates that for every euro invested in community renewable energy projects, an equivalent of 2.5 euros in local economic benefits are generated, consisting of returns in investments to shareholders, taxes and rents paid, as well as reimbursements for work related to the planning, construction and maintenance of the facilities (Énergie Partagée, 2019). This would suggest that CEIs across Europe may contribute between 15 and 27 billion euros to the local economy. However, specifically in terms of jobs created, it is worth noting that CEIs mainly rely on volunteers. Paper VIII finds that among a sample of 540 German CEIs, less than 16% report having formal employees. Furthermore, only 3% have more than 10 full-time equivalent employees. However, there are also rare cases of more than 100 employees. CEIs with formal employees are mainly those that operate a local energy distribution system, requiring specialized skills. A significant number of them represent some of the remaining old rural electrification cooperatives.

6. SUMMARY AND POLICY IMPLICATIONS

Table 5: Summary of key phases of CEI development in Europe, and characteristics of archetypical CEI, policy setting, monitoring needs, and degree of formalization of CEI associated with each phase

CEI development phase	**Phase I** (Before 1950)	**Phase II** (1950s – 1990s)	**Phase III** (1990s – mid 2010s)	**Phase IV** (mid - late 2010s)	**Phase V** (after 2020)
Policy setting	Focus on electrification of urban areas. Deprioritisation of rural communities.	Nuclear energy developments, global oil crises	Lucrative FiTs in most European countries	Gradual decline FiTs	Implementation of targeted policies and support mechanisms for CEIs on the EU and member state level.
Level CEI activity	Medium-High	Low	High	Low-medium	Medium
Examples of archetypical CEIs	Rural electrification cooperatives	Danish wind power & district heating cooperatives	CEIs using FiT business model	Previous CEIs using FiT business model with with diversified portfolio	Various: e.g. sustainable energy communities (Ireland), apartment associations (Estonia), renewable energy communities (Italy), collective self-consumption, eco-villages
Technological focus	Mainly hydropower + electrical grid	Wind, biomass and solar thermal based district heating	Granular renewable energy technologies (mainly wind and PV)	Granular renewable energy technologies (mainly wind and PV)	Wind, PV, e-mobility, smart grids, local electricity and heating grids, energy efficiency
Diversity of activities	Low; operation of local energy infrastructure, selling of energy to customers/members	Low; mainly electricity and heat production and supply	Low-Medium; renewable energy generation, feed-in to public grid, renumeration through FiTs. Different uses of profits	Medium; existing CEIs begin to diversify to new activities to counteract declining FiTs.	High; Self-consumption, Energy sharing, Mobility services, Energy efficiency services, district heating
CEI alignment with CEI definitional criteria	(☒) Primary & sust. energy focus ☒ Public benefit focus ☑ Participatory governance (☑) Inclusive membership ☑ Local focus ☑ Non-monetary benefits focus	☑ Primary & sust. energy focus ☒ Public benefit focus (☑) Participatory governance (☑) Inclusive membership (☑) Local focus (☑) Non-monetary benefits focus	(☒) Primary & sust. energy focus (☒) Public benefit focus ☑ Participatory governance (☒) Inclusive membership (☑) Local focus (☒) Non-monetary benefits focus	(☒) Primary & sust. energy focus (☒) Public benefit focus ☑ Participatory governance (☒) Inclusive membership ☑ Local focus (☑) Non-monetary benefits focus	☑ Primary & sust. energy focus (☒) Public benefit focus (☑) Participatory governance (☒) Inclusive membership ☑ Local focus ☑ Non-monetary benefits focus
Relationship between CEI and state	CEI acting as self-help initiatives to address failures in policymaking	Activism against energy policy-making (e.g nuclear energy)	CEIs acting to capitalize on opportunities provided by state (FiT)	Existing CEIs trying to find alternatives to the FiT business model	'State supported self-help'
Degree of legal formalisation	Low, no specific CEI legislation	Low, no specific CEI legislation	Low, no specific CEI legislation	Low, no specific CEI legislation	High, EU Directives on RECs, CECs and transposition thereof by member states, various eligibility criteria for CEIs
Monitoring needs	Low	Low	Low	Low	High

Table 5 summarizes and links the previous discussions on the historical development of the European community energy sector, CEI monitoring and the contributions of CEIs to the different aspects of the energy transition, as well as European energy policy. As stated in Section 5.1, the historical development of CEIs can be separated into five overarching phases. Note, however, that the table represents a generalization on the whole European community energy sector and may therefore not apply in its entirety to individual EU member states. As such, not all phases may have occurred in every EU member state and the indicative time periods may vary to some extent from country to country.

On the aggregate level, CEI activity has varied greatly across the different phases. While the data presented in Paper II do not show a significant activity in phase I, other studies have estimated that several thousand rural electrification cooperatives may have been active at the beginning of the 20th century (Faust, 1977; Holstenkamp, 2015; Yildiz et al., 2015). As few rural electrification cooperatives remain active today, they have not been captured in the ENBP inventory. Rural electrification cooperatives were characterized by a local focus on non-monetary mutual benefits, by providing electricity to their members who were connected to the same distribution network. While no data could be collected regarding the inclusivity of their membership in terms of demographics, beyond an adherence to the cooperative ideals of open and voluntary membership (c.f. ICA, n.d.-a), their focus on rural areas that were deprioritized by public and private electrification efforts suggests that they contributed to reducing inequalities in resource distribution. In terms of the use of sustainable energy technologies, these cooperatives generally used hydropower plants for electricity production but also distributed fossil-fuel-based electricity from the public grid.

Phase II has seen only little CEI activity, with CEIs mainly forming out of anti-nuclear activism and aims to reduce dependence on international fossil fuel imports (c.f. Paper II). Cases such as the EWS Schönau show that some CEIs established in this period engaged in a variety of activities such as political lobbying and activism, energy saving consulting, or supporting individual citizens who wanted to invest in renewable energy technologies (EWS Schnönau, n.d.). However, the most dominant form of CEIs during this period were Danish wind power and district heating consumer cooperatives, focusing mainly on generating electricity from wind power or heat from biomass and later from solar thermal facilities to supply their members (c.f. Gorroño-Albizu et al., 2019) (Paper I & II, supplementary material). Danish wind power and district heating cooperatives were initially characterized by open and inclusive membership, and a non-monetary mutual benefit focus on providing renewable electricity or heat to their local customers (c.f. Gorroño-Albizu et al., 2019). Furthermore, the long-existing non-profit rule in the Danish energy sector forbade the distribution of profits to members and shareholders. However, while this still remains true for district heating cooperatives, the wind power cooperatives later moved to a less participatory, market-oriented model characterized by a focus on generating profits, exclusive membership, and voting rights based on shares held, instead of the one member-one vote principle. These were also characterized more often by both fewer and more spatially distributed members (Gorroño-Albizu et al., 2019). This was largely due to the abolishment of the non-profit rule in the electricity sector and the introduction of feed-in tariffs (Eikeland & Inderberg, 2016; Gorroño-Albizu et al., 2019)(Paper III). In fact, Gorroño-Albizu et al. (2019) criticize that studies of the history of Danish community energy often confuse wind power cooperatives and wind power guilds, with the latter representing the more profit-oriented, exclusive cases mentioned above. This is mainly due to both wind power cooperatives and wind power guilds being registered under the same legal form (see also Section 7.1.2).

Fuelled by lucrative feed-in tariffs (c.f. Herbes et al., 2017) and advancements in granular energy technologies such as wind power and solar PV (c.f. Wilson et al., 2020), phase III has undeniably seen the largest level of growth in the sector. During this period, CEIs mainly focused on producing and feeding electricity into the national grid, generating financial profits from the remuneration through feed-in tariffs. Solar PV was the dominant technology during this phase. However, how these profits are used varies from country to country. German CEIs, representing a large part of the CEIs in the ENBP inventory, tend to be more mutually oriented towards providing financial benefits to their members, while French CEIs have a stronger public benefit orientation, using (parts of) the profits to provide services to (disadvantaged) external stakeholders (e.g. energy efficiency consulting for low-income households). While most CEIs adhere to the participatory one member-one vote governance principle, differences can also be found in terms of the inclusivity of the member base and steering committees. While these are often male, of older age and belonging to above average income classes, cases such as French CEIs are characterized by significantly lower membership fees, making it more attractive for low-income households to participate. Finally, while most CEIs in this phase are characterized by members and renewable energy production units being located in close proximity to the CEI headquarters, the energy produced is fed into the public grid instead of being consumed locally.

In Phase IV, existing CEIs adapted to the declining feed-in tariffs by developing new business models, or were discontinued, while few new CEIs were established. The characteristics of CEIs only change slightly from phase III to IV, as the latter is mainly characterized by the CEIs already active in phase III. The main difference is a diversification of business models, for instance, towards a focus on self-consumption. This indicates a strengthening of the local focus, as well as some degree of re-orientation towards the fulfilment of (local) energy needs instead of generating financial profits.

Phase V sees a variety of new forms of CEIs emerging as a result of new support mechanisms targeted directly at CEIs. However, given the recency of this phase, the ENBP data do not currently show whether this renewed support will lead to similar CEI activity levels that could be observed during phase III. Common among most of these new types of CEIs is a focus on the local provision of energy and energy services, fulfilling the needs of members or stakeholders, instead of generating profits. In several countries, these new types of CEIs, such as apartment associations in Estonia or SECs in Ireland, are not allowed to distribute their profits to members. However, there are differences in terms of public benefit orientation, participatory governance and inclusiveness of membership. Steering committees of Irish SECs, for instance, are supposed to reflect the demographic composition of the community (neighbourhood, town, region) in which they are active. Furthermore, they have a clear public benefit orientation, aiming to support the whole community in the energy transition. However, democratic decision-making, for instance, by way of the one member-one vote principle, are not emphasized. Collective self-consumption concepts such as the RECs in Italy or apartment associations in Estonia adhere to the one member-one vote principle but tend to be more oriented towards providing services to their members, who are restricted to a specific apartment building or neighbourhood.

The developments summarized above have significant implications for European energy policy-making in general and community energy policy-making in particular, as they resonate with the debate on universal and targeted policy-making, which has a long tradition especially among social policy-making. In essence, universal social support schemes distribute benefits to the whole population, while targeted schemes only provide support to those social groups that need it. Universal schemes have been mainly criticized for their costliness and lack of consideration of the diversity of the respective needs of various demographic groups within a population. Targeted schemes, on the other hand, have been criticized for being overly bureaucratic, requiring extensive procedures to test the eligibility of each individual for a given support scheme, as well as the risk of errors in such testing procedures (Besley & Kanbur, 1990; e.g. Carey & Crammond, 2017; Fisher et al., 2021; Mkandawire, 2005).

In the context of CEIs, feed-in tariffs can be seen as a universal support scheme, applicable to any entity operating renewable energy production units, regardless of whether these are CEIs, NGOs, private citizens or commercial businesses. Eligibility was exclusively based on their engagement in the renewable energy sector and monitoring required little more than tracking the amount of renewable energy fed into the public energy grid. This offered CEIs considerable freedom in designing their specific purpose, organizational structure, and use of profits. Furthermore, this has also allowed many other initiatives, such as housing-, or farming cooperatives to engage in the energy sector. On the other hand, previous evidence has shown that this model has often resulted in more market-oriented CEIs.

In the most recent phase of CEI development, a more targeted approach to supporting CEIs has been adopted in the EU and its member states. As can be expected, this has led to a variety of eligibility criteria for CEIs, such as restrictions in terms of geographical scale, membership, organizational forms or profit orientation (cf. Energy Communities Repository, 2024; Directive 2018/2001; Directive 2019/944). Cases such as the European Energy Communities Facility (European Energy Communities Facility, 2025a) or the German subsidy scheme for wind power facilities installed by CEIs adhering to the transposed definitions of the EU directives (BMWE, 2024) exemplify this new approach of tying (financial) support to specific eligibility criteria. Furthermore, the testing of the adherence of potential CEIs to these criteria requires significant monitoring efforts, which, as shown in Section 5.2, are often lacklustre. Consequently, a further specification of the eligibility criteria and more systematic monitoring of CEI have already been called for. The European CEI roadmap (Energy Communities Repository, 2024), for instance, points out that terms such as ‘proximity’, ‘effective control’, or ‘social, economic and environmental benefits’, all of which are used in the definitions of RECs and CECs, are highly subjective. The extent to which the transposed national regulations provide precise inclusion and exclusion criteria varies significantly (see Section 3.2). The following example illustrates how a conceptually ambiguous definition, in combination with poorly chosen indicators and reporting methodologies, can increase the risk of misuse of such targeted CEI support. Both definitions by the EU state that the primary purpose of a CEI is ‘to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits’ (Directive 2018/2001, Article 2(16); Directive 2019/944, Article 2(11)). Only a few

EU member states have specified this further (Energy Communities Repository, 2024). As mentioned in Section 5.2.2, assessments of the benefits generated by CEIs often rely on subjective opinions gathered from surveying CEI members. In consequence, any initiative could theoretically fulfil this definitional aspect, as long as its members report that the initiative generates some sort of community benefit.

On the other hand, studies also show that CEIs have already struggled with fulfilling previous reporting requirements due to a lack of resources or expertise, for example, in relation to the planning process for renewable energy facilities (e.g. Nolden, 2013; Park, 2012). As Section 5.1 shows for a sample of German CEIs, even today they often do not fulfil the requirements of submitting their annual financial reports within the given timeframe. A recent brief by the European Federation of Citizen Energy Cooperatives and other CEI actors reiterates these issues, pointing out that more stringent reporting requirements would further increase the administrative burden for CEIs (Proka et al., 2021). The code of practice of Eurostat specifically emphasizes that statistical accounting should avoid placing an excessive burden on respondents (Eurostat, 2017). Similarly, the aforementioned German subsidy scheme for community wind turbines has already been criticized by the German Cooperative and Raiffeisen Confederation (DGRV), which represents many the traditional energy cooperatives established during the feed-in tariff phase. The DGRV has lobbied for less strict eligibility criteria for this subsidy scheme that would allow CEIs more freedom in choosing their business model, organizational form and purpose (DGRV, 2025).

The increased degree of formalization of CEIs in phase V through the implementation and monitoring of eligibility criteria may initially seem contradictory to the trend of increasing business model diversity in the same phase. However, it is important to note that formalization is not to be conflated with unification. While unification may be the long-term goal of European policy-making for the community energy sector, this is not yet the case. As discussed in Section 3.2, the different EU member states take a variety of approaches in transposing the EU directives to the national level. As such, while certain types of CEIs may dominate in individual countries (e.g. local collective self-consumption initiatives in Italy), this is not the case on the European level. In addition, various countries have established (additional) alternative definitions for CEIs beyond the transposed EU definitions. This is the case, for example, in Ireland, Poland and Estonia, as shown by the policy briefs produced by the European Energy Communities Repository (European Commission, 2024b). Furthermore, a distinction needs to be made between requirements in terms of organizational form and activities conducted. While the recently enacted CEI regulations propose a variety of eligibility criteria, for instance, regarding geographic scale, membership requirements or profit orientation, the definition of CECs in particular remains comparably open in terms of the allowed activities. In contrast, eligibility to receive feed-in tariffs was restricted to the single activity of producing and feeding renewable energy into the public grid, while aspects regarding organizational form were largely irrelevant.

Thus, the two recent forms of support mechanisms that benefited CEIs (universal feed-in tariffs for all renewable energy installers vs. targeted support for CEIs) differ significantly in their approaches and outcomes. From a technological perspective focusing on the deployment of renewable energy capacities, the historical data show that universal feed-in tariffs have been the most effective support mechanism for CEIs. At the same time, this allowed CEIs to adopt more market-oriented business models mainly focused on generating profits for members. The recent definitions of CECs and RECs by the EU, as well as their transpositions to national law, emphasize CEI contributions to the wider sustainability transition beyond a purely technological transition. Similar aspects are also reflected in European energy policy-making, for instance, in regard to ensuring a fair and participatory energy transition process. While such stricter requirements reinforce the social nature of CEIs, recent evidence indicates a decline in the overall activity of CEIs, as a result of the loss of the less strict feed-in tariff support mechanism. Whether the new targeted support schemes will result in similar activity in the community energy sector as during phase III is yet to be seen.

The different phases also represent a different relationship between CEIs and the state, in terms of the dependence of the former on the latter. Phase III was characterized by CEIs with a strong focus on profiting from feed-in tariffs enacted by the state. As evident in the decreasing CEI activity in phase IV, correlating with the declining feed-in tariffs, the high activity of the community energy sector in phase III was largely dependent on these state subsidies (c.f. Sebi & Vernay, 2020). In contrast, the rural electrification cooperatives in phase I are akin to social movements and third sector organizations, developing out of the need to address a (perceived) failure of the private or public sector (Alexander, 2010; Diamond, 2010; Tilly, 1978), instead of capitalizing on opportunities provided by state support mechanisms. In fact, excessive reliance on external funding from private or state actors is often seen as a risk to the ideal of cooperatives as autonomous entities, as it may allow such external actors an increased degree of influence over the cooperatives' decision-making (ICA, 2017; Peal, 1988). Finally, the most recent development indicates a hybridization of the two types of relationships between CEIs and the state, which can be summarized as 'state supported self-help', in which targeted public support aims at fostering CEIs that focus on fulfilling local energy needs, for example, through self-consumption models. However, Da Silva et al. (2018) question whether the increased political interest in and support for CEIs is not simply the result of a general shift in the political mindset from the welfare state providing crucial public services, towards citizens being expected to increasingly take care of such matters by themselves. The societal challenges of such a development can be illustrated by the following example. In most European member states, consumers are charged transmission tariffs as part of electricity and/or gas prices. This is used for the operation and maintenance of the public energy infrastructure. Commonly, the size of this fee is dependent on the amount of energy consumed (Dedecca et al., 2020). Consequently, if more consumers move to partial or full self-consumption, thereby paying lower transmission fees, then the financial burden of operating and maintaining the public grid will increasingly lie with those consumers who are not engaging in self-consumption (c.f. Gregg et al., 2020). In combination with the previous results that indicate that members of CEIs are often from medium to high-income households (Sections 5.3.3 & 5.3.4), this may exacerbate issues of energy poverty as this burden of paying for the maintenance of the public energy grid may fall disproportionately on low-income households. As such, these self-consumption trends may lead to a further privatization and commodification of energy services.

7. VALIDITY AND LIMITATIONS

The validity and limitations of the results presented in this thesis can be separated into two categories: First, the conceptual validity relates to the framing of the energy transition along the green growth versus the degrowth discourse as well as how CEIs have been defined during the data collection process and which types of CEIs have been included in the ENBP inventory as a result of the chosen definition. The second category relates to the chosen methodology of data collection and analysis, and potential resulting inaccuracies.

7.1. CONCEPTUAL VALIDITY

7.1.1. Degrowth as a reference frame for the investigation of the transformative potential of CEIs

This thesis set out to investigate the contributions of CEIs to the energy transition, which first and foremost required an understanding of the concept of 'energy transition'. While this inherently entails a technological shift, in this case to a renewable and efficient energy system, Section 3.1 has highlighted that technological transitions tend to go hand in hand with social, cultural, political or economic changes. As it has been claimed that CEIs generate various social, economic and environmental benefits, purely focusing on their contributions to the technological aspects of the energy transition would have insufficiently captured their potential societal value. In order to provide structure to the discussion of the various socio-technical contributions of CEIs, this thesis has conceptualized the energy transition on a spectrum ranging from a narrow technological perspective represented by the green growth concept to a more radical societal transformation represented by the degrowth concept. Thus, five imperatives of a degrowth transformation have been identified, guiding the discussion on the transformative potential of CEIs.

However, degrowth remains a 'concept in the making' (Petridis et al., 2015, p. 176) and does not come without internal controversies (c.f. Demaria et al., 2013; Eversberg & Schmelzer, 2018; Sekulova et al., 2013). Van den Bergh (2011), for instance, points out that there is no actual consensus among the degrowth community on what exactly is expected to 'degrow'. Some scholars argue for a reduction of the economy in terms of GDP, while other scholars envision a reduction in the physical throughput of resources, while in turn, others focus on aspects of worktime reduction. Each perspective of degrowth comes with its own challenges. For example, Hickel (2020) emphasizes that degrowth is not simply a reduction in GDP, as this would be akin to a recession, which tends to come with a variety of additional social issues, such as rising unemployment, decline in public services and a general rise in inequality. The perspective of physical degrowth in terms of resource consumption is present, for instance, in the Degrowth Declaration, a joint document produced at the 'first international conference on socially sustainable economic degrowth for ecological sustainability and social equity', which sees degrowth as a temporary process towards a '"steady state economy" with a relatively stable, mildly fluctuating level of consumption' (Research & Degrowth, 2010, p. 524). Yet, as Georgescu-Roegens (1977) argues, even a steady state economy would require a continuous input of new resources, merely to maintain the current level and counteract the degradation of equipment and infrastructure over time. Hence, a truly sustainable society that does not require additional resource input would have to be in a state of constant, indefinite decline. This argument, of course, opens itself up to the same criticism of the growth paradigm that led to the development of the degrowth concept in the first place: Continued degrowth of resource use can be no more sustainable than continued growth. Meanwhile, with regards to the perspective of work-time reductions, some scholar argue for a shift to an informal economy driven by voluntarism and neighbourhood help (Cosme et al., 2017; Demaria et al., 2013; Trainer, 2012), while others scholar argue for concepts such as job guarantees (Hickel, 2020). Finally, Van Den Bergh (2011, p. 884) finds that a majority of degrowth proponents tends to have a more idealistic – and potentially unrealistic – radical view, where degrowth involves changes to 'values, ethics, preferences, financial systems, markets (versus informal exchange), work and labour, the role of money, or even profit-making and ownership'. Trainer (2012), for example, envisages a degrowth society based on local, self-sufficient and frugal neighbourhoods. Similarly, Bauhardt (2014) also envisages a shift to more self-reliance regarding public services currently provided by the state, such as retirement, health and education services. Yet, this somewhat idyllic depiction of local communities is not grounded in robust scientific findings (Mocca, 2019). For example, authors such as Kallis (2018) acknowledge that it is unlikely that small communities will be able to provide highly specialized services such as advanced health services or higher level education.

Acknowledging these debates around the characteristics of a degrowth transformation, some authors have argued that degrowth is best understood not as a scientific theory but as an alternative narrative or 'slogan' to the dominant growth narrative, aiming to inspire various new ideas and rally citizen-driven, bottom-up social movements that envisage more sustainable ways of living, such as eco-villages, cooperatives, and promoters of solar energy, local currencies and organic agriculture (Augustyn, 2024; Demaria et al., 2013; Kallis, 2018; Petridis et al., 2015). The ideal CEI, as envisioned, for instance, by Walker & Devine-Wright (2008), or the EU definitions of RECs and CECs are a prime example of such initiatives consistent with this perspective of the degrowth idea. Consequently, even though degrowth represents a radical idea characterized by a number of ongoing debates on how exactly a degrowth society should look like and how it can be achieved, it is exactly this aim of creating a radically different narrative that makes it useful as a reference frame to investigate the full transformative potential of CEIs.

7.1.2. Selection process for CEIs to be included in the ENBP inventory

As has become evident from the discussion of the definitional aspects of CEIs (see Section 3.2), there are several different concepts of CEIs (c.f. Bauwens et al., 2022), making it challenging to find a single unifying definition. This variety of concepts also posed an initial challenge in terms of setting distinct criteria along which to decide whether certain initiatives are to be included in the ENBP inventory, on which this thesis is based. As stated in Paper I (see Section 4.1.1), three guiding aspects were chosen as the selection criteria, which are (I) an engagement in the energy transition, (II) being citizen-led and (III) that the initiative strives for social or environmental benefits beyond pure economic interest. Out of these three criteria, the first was the easiest to operationalize and test on a case-by-case basis. Paper I describes a clear set of activities that were seen as indicating 'an engagement in the energy transition'. Nevertheless, some CEIs operating traditional fossil fuel-based energy generation facilities, in addition to sustainable energy technologies, were also added to the database. This included, for instance, apartment associations or district heating cooperatives operating oil boilers in Estonia and Finland. However, these generation units were not included in the aggregate estimates in Paper II, such as total renewable capacities installed by CEIs. For the second and third criteria, however, a testing on the level of individual CEIs was not feasible. Instead, CEIs belonging to certain types of entities (e.g. specific legal forms) were generally included if the evidence suggested that such entity types complied with the criteria. For example, it was assumed that cooperatives generally adhered to the one member-one vote principle, even though not all EU member states legally enforce this principle for this legal form (c.f. Karakas, 2019). However, the International Cooperative Alliance specifically states the one member-one vote rule as one of the seven cooperative principles (ICA, n.d.-a), suggesting that cooperatives voluntarily adhere to this rule. Similarly, the criteria of striving for social or environmental benefits beyond pure economic interest was seen as being fulfilled by organizational forms generally considered to be part of the social solidarity- , non-profit - or third sector (ILO, 2022; ripess, 2015; Salamon & Sokolowski, 2016). The adjustment of the inclusion criteria for Danish wind power cooperatives from the initial mapping effort described in Paper III to the final ENBP inventory (Paper I) exemplifies these conceptual challenges (see also Section 5.1). Gorroño-Albizu et al. (2019) have criticised the findings in Paper III for also including so-called wind power guilds. According to the authors, these are often commercial partnerships with a proportional voting system based on shares, and as such do not qualify as CEI. To address this criticism, the final ENBP inventory only includes such entities that have more than 10 founding members and where no majority shareholder can be identified, thereby differentiating them from the wind power guilds typically run by fewer members (c.f. Paper I, supplementary material). Furthermore, initiatives that were listed in databases by European and national CEI umbrella organizations, such as RESCoop (REScoop, 2025a), Énergie Partagée (Énergie Partagée, n.d.-a) or HierOpgewekt (HIER opgewekt, 2025), were included without checking in detail the adherence of each listed CEI to the aforementioned criteria. Nevertheless, this likely only led to the over-inclusion of cases, which ultimately served the purpose of this thesis in getting as broad an overview as possible of the landscape of CEIs across Europe.

Yet, certain forms of CEIs have still not been considered in this thesis. Chief among them are informal initiatives, as these are not registered in any centralized registers, which makes their identification far more difficult. In terms of centralized data sources that can assist in identifying such initiatives, there are only a few examples that build on crowdsourced data, such as Repowermap (n.d.) or the ‘Map of tomorrow’ (Ideen^3 e.V., n.d.). The former maps all kinds of initiatives and actors related to the energy transition in Europe, while the latter tracks a loosely defined set of initiatives that support a ‘transition of the society towards a solidary ecological sustainable community’ (Hoffmann, n.d.). For reference, Seyfang et al. (2013) found that around 35% of the initiatives in their sample were informal CEIs. While such numbers suggest that informal initiatives may account for a significant share of CEIs, the EU definitions of CECs and RECs indicate a trend towards increased formalization of the sector (c.f. Horstink et al., 2021). Increased formalization tends to grant greater access to resources (Seyfang et al., 2013; Wittmayer et al., 2021), which is reflected in the trend to tie support for CEIs to the adherence to the definitions of CECs and RECs (Energy Communities Repository, 2024; European Energy Communities Facility, 2025a). While few aggregate level studies have been conducted on informal CEIs, likely also due to the above-mentioned difficulty in identifying them, it is reasonable to assume that such informal initiatives do not commonly engage in energy generation, trade or distribution activities, due to the required resources and administrative procedures involved therein (c.f. Seyfang et al., 2013). As the EU definitions of CECs and RECs put strong emphasis on CEIs engaging in such activities, it is likely that the ENBP inventory covers the majority of CEIs that are of potential relevance to the EU definitions.

Furthermore, it is worth noting that opposition movements, such as anti-wind power initiatives, also potentially fulfil several of the CEI definitional criteria. Based on the idea that social movements and organizations form to address (perceived) failures of the state or private sector (Alexander, 2010; Diamond, 2010; Tilly, 1978), such initiatives are established to address the (perceived) negative impact of renewable energy facilities, for example, related to landscape aesthetics, health or biodiversity. While they tend to also be citizen-driven and have a local focus, their opposition to (certain aspects of) the energy transition sets them apart from other CEIs, which is why they have not been further considered here. The German umbrella organization of anti-wind power initiatives, for example, provides a map of such initiatives, indicating that there is a significant number of such initiatives (Windwahn, n.d.).

7.2. METHODOLOGICAL VALIDITY

From a methodological perspective, the main limitations of this thesis relate to the availability and reliability of the data. As has been discussed in Section 5.2.1, the availability of the data varies greatly from country to country. The goal of this thesis, and the connected COMETS project, was specifically to go beyond previous studies that limited their scope to individual cases or small samples in selected countries. With over 10,000 CEIs identified, the ENBP inventory provides one of the most extensive databases of CEIs across European countries, containing, at a minimum, basic administrative data for the respective CEI. Nevertheless, the key statistics presented in Paper II (people involved, finances invested, renewable energy capacities installed) are often based on extrapolations of the existing data to the total sample for each country. The detailed methods of estimation are described for each country in the supplementary material of Paper II. Furthermore, the availability of more advanced data varied greatly from country to country. This includes, for instance, data on member demographics, brands and types of equipment installed, member participation in annual meetings, detailed financial data or full purpose statements. Thus, Papers III – VIII, which investigate specific aspects of CEIs (business models, inclusivity, link to degrowth,…), are often focused on selected countries or specific subsets of CEIs. To increase data availability as far as possible, numerous different data sources were used, ranging from official registers and previous studies to individual CEI websites and news articles. Connected to the issue of data availability is the fact that discontinued initiatives are often not listed in business registers anymore, making these hard to identify. This issue is clearly visible when comparing the number of early rural electrification cooperatives in the ENBP inventory with estimates of their true number during the period of their peak activity in the early 20th century. Where the ENBP inventory contains less than 50 German CEIs that were founded before 1950, other studies estimate that more than 6000 may have existed during their peak (Faust, 1977; Yildiz et al., 2015). As a result, the estimates on the aggregate contributions of CEIs to the energy transition first and foremost reflect the contributions of those CEIs that are currently active, and not the cumulative historical contribution.

From a data reliability perspective, it is important to note that ultimately all data are self-reported by the CEIs. This is true even for official business registers or renewable energy facility registers such as the German core energy market data register (Bundesnetzagentur, 2025). However, the self-reporting of data by CEIs to such official registers is often subject to certain validation procedures to increase the accuracy and trustworthiness of the data. For example, in Germany, the cooperative law (§53 GenG) requires CEIs registered as a cooperative to have all annual reports, protocols of general assemblies and statutes validated by a state-approved auditing organization. Similarly, renewable energy production units that have been reported to the German core energy market data register are regularly cross-referenced with the associated data of the network operator for the grid to which the unit is connected. Less reliable are individual CEI websites or news reports. However, where possible, multiple data sources have been cross-referenced during the data collection process to identify inconsistencies (see Paper I, supplementary material).

8. OUTLOOK

8.1. FUTURE RESEARCH AND MONITORING NEEDS

This thesis has shown that CEI development in Europe has gone through several phases. In contrast to previous phases, the most recent phase is characterized by policy initiatives and support mechanisms directly targeted at CEIs. The findings summarized in this thesis indicate that this new policy-setting is leading to the emergence of new types of CEIs in Europe in this last phase, potentially leading to a resurgence of CEI activity after the decline caused by the reduction in feed-in tariffs. However, given its recency, many questions remain in regard to the future development of the community energy sector. Firstly, efforts such as the REScoop policy tracker (REScoop, 2024) show that the EU directives setting the policy-framing for CEIs have not yet been sufficiently transposed into national law in all countries. While individual dominant forms of CEIs are emerging in some countries, as a result of the new regulatory frameworks (e.g. Italy, Ireland), a concentration to specific organizational structures, business models and energy-related activities cannot be seen yet on the European level. Thus, future research will be required to observe how the community energy sector adapts to the new regulatory setting and whether specific types of CEIs will emerge as dominant forms, similar to the prevalence of feed-in tariff-based CEIs during phase III. Furthermore, a better understanding of the effects of the policy changes on existing CEIs will be needed. Examples such as Germany suggest that existing CEIs established during phase III, may not always comply with the new regulations, thereby not being eligible for the new support schemes (DGRV, 2025). Here, special attention should be paid to those types of CEIs that do not engage in energy-related activities as their main purpose. Feed-in tariffs allowed such sports and cultural associations or banking-, housing- or agricultural cooperatives to engage in the energy transition besides their main activity. With nearly half of the entries included in the ENBP inventory representing such initiatives, their contributions, for instance, in terms of renewable energy deployment, should not be ignored.

From a practical perspective, significant improvements in terms of data availability and usability are needed to further investigate the questions above as well as evaluate the eligibility of CEIs to the new support mechanisms and the economic, environmental and social impact of CEIs as a result of their inclusion in such support mechanisms. The FAIR data principles proposed by

Wilkinson et al. (2016) state that data, or at least the related metadata, should be findable, accessible, interoperable and reusable (see also Section 2.2.3 & 4.1.1). While it may not be possible for all data to comply with these principles, for instance, due to data protection regulations, all data should be accompanied by sufficient and transparent documentation and metadata (Wierling, Schwanitz, et al., 2021). Such documentation should allow third parties to judge the quality of the data, as well as provide information regarding terms of use and methods of accessing and processing the data. Schwanitz et al. (2022) have tested the degree to which a variety of databases related to the low carbon energy transition adhere to the FAIR principles, finding that there are significant shortcomings. While these databases do not specifically apply to the field of CEIs, several of them are of relevance nonetheless (e.g. business registers and national databases on energy facilities). Section 5.2.1 has shown that a considerable amount of data on CEIs are already being collected in some countries. However, these data also lack standardization, accessibility and interoperability. In terms of official registers, initiatives such as OpenCorporates (OpenCorporates, n.d.-b) or the European business register (European Union, n.d.) show that efforts are being made to merge and standardize the data. However, there are still significant shortcomings, especially in terms of data availability and accessibility, with large amounts of data remaining restricted behind paywalls (OpenCorporates, n.d.-a). In contrast, databases on CEIs maintained by CEI umbrella organizations, such as Énergie Partagée (Énergie Partagée, n.d.-a) or HIERopgewekt (HIER opgewekt, 2024), tend to be freely accessible, but are even more limited in terms of standardization of typologies, units, or data formats across different sources.

Beyond the aspects related to data availability and usability, there is a need to develop more robust methods of assessing CEI impact, especially given the higher monitoring requirements associated with the targeted support mechanisms that have recently been put in place (c.f. Paper VII). Currently, impacts are often simply identified based on the subjective opinions of respondents, instead of being quantified. Furthermore, assessments are often poorly documented, making it difficult to judge whether the data used are representative of the impact recipient (e.g. demographic group, geographic area) that is affected by the impact. The exception being a number of CEIs and CEI umbrella organizations that are already developing and using frameworks and tools to assess CEI impact. The Ashton Hayes Energy Community, for instance, developed a holistic framework to assess its economic, environmental and social impact (NEF, 2012). The French CEI umbrella organization Énergie Partagée, on the other hand, offers its member organizations a toolkit for self-assessment of their social impact (Énergie Partagée, 2023). As Paper VII shows, these are already among the most systematic, well-documented and easily understandable efforts of assessing CEI impact. The workflow presented in Paper VII aims to facilitate a more systematic discussion of the indicators employed in CEI assessment, as well as serve as a guide for the future selection of high-quality indicators and transparent documentation. In the scientific community there is a need to move beyond the simple identification of impacts towards the development of methodologically robust, quantifiable indicators to measure CEI impact. Closer attention should specifically be paid to developments in the two parallel research streams discussed in Section 5.2.2 There is currently a more social science-oriented and a more engineering-oriented community energy research domain (c.f. Bauwens et al., 2022), with very little overlap. However, the adoption of the EU definitions of CEI in both literature streams may indicate their convergence. Where the social science-oriented literature relies heavily on interview and survey-based studies of CEI impact, the engineering-oriented literature often makes use of modelling and simulation tools to investigate CEI impact. As such, a closer collaboration between the two research domains may prove beneficial for both, combining the knowledge of the social dynamics of CEIs of the former with the expertise on indicator quantification of the latter. Meanwhile, there is a need to ensure that additional reporting requirements for CEIs are kept at a level that is appropriate to the expertise and resources available to CEI members, especially, given that administrative requirements related to the operation of a CEI are already commonly named as a key barrier to their success (Allen et al., 2012; Brummer, 2018; Seyfang et al., 2013). Thus, from a policy-perspective, there is a need for further specification of the contributions to the energy transition that are expected from CEIs, beyond the vaguely defined 'environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates' (Directive 2019/944, Article 2(11)). This way an assessment and monitoring of the most policy-relevant CEI impacts can be prioritized. Finally, cases such as the self-assessment tool developed by Énergie Partagée, show that CEI umbrella organizations can play a key role in ensuring that future CEI impact assessments are accompanied by sufficient documentation that is understandable by non-experts and conducted in a way that is appropriate to the level of expertise and the available resources of the individual CEI.

8.2. POLICY OUTLOOK

With right-leaning parties gaining strength during the 2024 European Parliament elections, policy priorities are shifting (Hix et al., 2024). The second Commission under Ursula von der Leyen has reiterated the energy policy objectives set out in the European Green Deal in the previous legislative period. However, the focus has moved more towards fostering a competitive industry, while aspects of environmental protection have been deprioritized (Bocquillon, 2024; European Commission, 2024c). The priority of building a competitive European industry is to be achieved, for example, by reducing the administrative and regulatory burden for all actors in the European economy (European Commission, 2024c). A recent study also finds differences in terms of the discourse on the European Green Deal among the different parties in the European Parliament (Pollex, 2025). Whereas left-leaning parties emphasize aspects of global distributional justice as well as environmental protection, right-leaning parties focus more on the distribution of the costs and benefits of the Green Deal within Europe. In line with the recent rise of right-learning parties, this further indicates a de-prioritization of environmental policy goals and a potential increasing focus on the intra-European distribution of costs and benefits of the energy transition. In terms of the progress towards achieving the goals of the European Green Deal, the previous commission has enacted a variety of policies relating to some of the targets, while other goals have been insufficiently addressed (Marelli et al., 2025). Although a dismantling of already-existing policies is seen as unlikely during this legislative period, slower progress towards achieving the remaining targets is expected (Bocquillon, 2024; Hix et al., 2024). Data from an annual survey of sustainability experts conducted by the Institute for European Environmental Policy show a decline in confidence that the goals of the European Green Deal will be achieved (IEEP, 2023, 2024, 2025).

These trends may have implications for the future development of the community energy sector. While it is unlikely that existing legislation regarding CEIs (e.g. the European CEI definitions) will be dismantled, we may see a slowdown in the transposition process to national law. As outlined in Section X, the transposition of the EU directives related to CEIs (Directive 2018/2001; Directive 2019/944) remains lacklustre in several European countries. Furthermore, we may see a shift in the characteristics of the CEIs that have been emphasized. During the feed-in tariff phase, the crucial characteristic of CEIs was the generation of renewable energy. However, the EU definition of CECs specifically allows an engagement in non-renewable energy technologies. With the de-prioritization of environmental objectives outlined above, we may see a rise in CEIs not engaging in renewable energy technologies. At the same time, the stronger focus in the European policy-discourse on the distribution of the costs and benefits of the energy transition resonates to some extent with the ideas of inclusiveness and collective benefit orientation emphasized in the EU definitions. On the other hand, the narrative around economic growth and competitiveness contrasts with the emphasis on CEIs generating non-monetary benefits that can be found in the EU definitions. The increased regulatory complexity and need for monitoring associated with the targeted CEI support schemes tied to the EU definitions contradict the abovementioned goals of reducing bureaucracy. As such, it is questionable whether existing support schemes for CEIs (BMWE, 2024; e.g. European Energy Communities Facility, 2025a) will remain in place, as well as whether new mechanisms will be implemented in other countries, and what characteristics of CEIs will be emphasized in such potential new mechanisms. As shown in Section 3.2, the EU definitions of CEIs leave significant room for interpretation during the process of transposition into national law. While initial data from the ENBP inventory suggest that the targeted CEI support mechanisms in phase V may lead to an increase in CEI activity in the future, after the stagnation in phase IV, it remains uncertain to what extent the new political orientation within the EU will affect the development of the community energy sector.

The Danish example offers an interesting alternative to the two policy approaches of feed-in tariffs or targeted CEI support. As discussed in Section 5.1 the growth of both wind power and district heating cooperatives in Denmark was strongly influenced by the non-profit rule for the energy sector. This rule obligated energy providers to convert all profits from one year into lower energy prices for customers during the next year (Chittum & Østergaard, 2014; Eikeland & Inderberg, 2016). While this rule was abolished in the electricity sector in the 1990s, it remains in place for district heating suppliers. This rule is seen as a major factor in the dominance of CEIs in the current district heating sector, as this rule results in the sector being less attractive for commercial actors (Gorroño-Albizu et al., 2019). In contrast to the past and present policies of feed-in tariffs or targeted support for CEIs, which reinforce the dependence of CEIs on financial state support, this approach sets a regulatory framework that allows CEIs to compete with private actors in the energy sector without additional subsidies. This also results in lower monitoring requirements, as there is no need to verify whether CEIs qualify for various support mechanisms. Finally, in contrast to the feed-in tariff approach, it also ensures the social character of CEIs emphasized in the EU directives, by forbidding the generation and distribution of profits in the energy sector as a whole. The Mankala companies in Finland (Korteniemi, 2018), while not classified as CEIs due to a lack of democratic decision-making, follow similar non-profit rules, where energy is provided at production cost to the shareholders. These examples present an alternative where comparably simple regulatory frameworks can support CEIs while avoiding the challenges of dictating specific organizational forms, business models and activities for CEIs and requiring advanced monitoring systems to control their respective adherence.

9. Conclusion

This thesis set out to map the European community energy sector and its historical development, as well as how CEIs, on an aggregate level, contribute to the energy transition and European energy policy objectives. In view of the increased interest in and support for CEIs by European policymakers, accompanied by calls for more systematic monitoring of CEI impact, the thesis further set out to map current processes and associated challenges related to the reporting and compiling of CEI-related data and assessment of CEI impact in Europe. The thesis builds on extensive data collection that resulted in an inventory of over 10,000 CEIs in the EU, plus Norway, Switzerland and the UK, which was carried out as part of the EU-funded COMETS project, in which the doctoral student was involved. In order to investigate the contributions of CEIs to the energy transition, the thesis adopted a framework that views the energy transition as a spectrum ranging from a purely technological transition to sustainable energy technologies on the one hand, to a deeper sustainability transition where the technological change is interlinked with other social, economic, cultural and political changes, on the other. The two sides of the spectrum have been represented by the concepts of green growth and degrowth. European energy policy objectives and definitional criteria for CEIs were then also situated on this spectrum.

The thesis first presents an overview of the historical development and current state of the community energy sector in Europe, showing that there are drastic differences from country to country in terms of CEI activity. Today, CEIs are strongly concentrated in a few European countries such as Germany, Netherland, Denmark or France. However new initiatives are also emerging in other countries. While the community energy sector shows a high degree of diversity in terms of activity, historical development and organizational forms adopted by CEIs, a few common patterns could still be identified. On a general level, CEI development can be separated into five phases, driven by different political and socio-economic contexts. The first phase during the early 20th century was driven by motives of self-help, largely independent from state support, focused on electrifying rural areas that had been de-prioritized by private and public electrification efforts. The second phase, which lasted for most of the second half of the 20th century, saw only little CEI activity beyond Denmark, mostly driven by anti-nuclear sentiments or the goal of being less dependent on international fossil fuel supply chains. Phase III, which began in the later 1990s, saw a drastic increase in CEI activity, driven by lucrative state support for renewables in the form of feed-in tariffs. However, this phase also produced a significant share of more market oriented CEIs often focusing on capitalizing on the support schemes to generate profits for their members. With the decline of the feed-in tariffs in the second half of the 2010s, the growth of the community energy sector slowed down in phase IV. Existing CEIs often adopted new business models or were discontinued. Phase V, which began with the official recognition of CEIs by the EU (Directive 2018/2001; Directive 2019/944), marks a shift towards support mechanisms and policy-making directly targeted at CEIs. Initial data from the ENBP inventory indicate a potential revival of the community energy sector, with various new forms of CEIs being tested. However, it remains unclear whether CEI activity with return to similar levels as during the peak in phase III.

This is followed by a discussion of the current processes of monitoring the community energy sector. Two main challenges were identified. The first challenge relates to the general lack of data and fragmented nature of the available data. While a number of national umbrella organizations maintain databases on CEIs, similar efforts on the European level, such as the European Energy Communities Repository, which aimed to create a centralized hub for CEI data, are still in their early stages. Thus, monitoring of CEI still requires significant manual data collection. The second challenge identified relates to the methodological robustness of the indicators used to assess CEI impact. Common issues in this regard are the discussion of objectives and expectations instead of materialized impact, and the use of subjective opinions of survey and interview respondents. Furthermore, CEI impact assessments generally come with poor documentation, for instance, with indicators not being explicitly described and linked to the associated impact, making a quality evaluation difficult. However, the investigation also revealed that CEIs and CEI umbrella organizations themselves are already conducting efforts to map and assess CEI impact. These efforts often represent some of the more systematic and well-documented approaches to CEI impact assessment.

Finally, the thesis discussed how CEIs contribute to the energy transition and European energy policy objectives. As outlined in Section 3.2, CEI definitions vary in the extent to which they emphasize certain characteristics of CEIs. The EU has proposed two definitions of RECs and CECs, with the former being especially demanding in terms of the requirements that CEIs need to fulfil. While the CEI definitions and the European energy policy objectives emphasize the technological shift to a sustainable and efficient energy system, both of them also describe additional aspects representative of a broader societal transformation. This includes a focus on the democratisation of the energy system, increasing citizen participation, as well as on aspects on fairness and inclusivity. However, while European energy policy emphasizes competitiveness and economic growth, CEI definitions and degrowth imperatives (representing a wider societal transition) emphasize aspects of fulfilling (basic) needs and collective benefits beyond profit maximization. CEIs in Europe are estimated to have installed around 10 GW of renewable energy capacity. Yet, in most countries their contribution to the total renewable capacities installed remains in the lower 1-digit percent range. Most of the renewable energy deployment by CEIs has occurred in phase III as a result of lucrative feed-in tariffs. Beyond the contributions to renewable energy deployment, an estimated two million people across Europe are members of CEIs, thereby contributing to an increase in citizen participation in the energy transition. However, the findings presented in this thesis indicate that the member-base of CEIs may lack inclusivity in terms of their demographic representation of the population. The lack of inclusivity among members, combined with some types of CEIs primarily focusing on providing financial benefits for their members, questions the extent to which CEIs contribute to reducing inequalities in terms of resource and wealth distribution. This issue is characteristic for the feed-in tariff-based CEIs in phase III in particular. However, examples such as French CEIs show that some CEIs established during this phase also have a strong focus on providing non-monetary collective benefits, often specifically targeting disadvantaged demographics such as low-income households. Furthermore, the new forms of CEIs that are emerging in phase V indicate a re-orientation towards the provision of non-monetary (collective) benefits, in line with the requirements set out by the recently enacted European definitions of CEIs. Common among most types of CEIs, however, is a local focus in terms of the proximity of both the members and conducted activities to the CEI headquarters. Recently, an increased focus on self-consumption of the energy produced has also been observed.

From a policy perspective, the shift from universal feed-in tariffs in phase III to support mechanisms targeted directly at CEIs in phase V has led to considerable changes in the dynamics within the community energy sector. The feed-in tariff model supported CEIs indirectly through subsidies to renewable energy technologies. On the one hand, this option provided considerable freedom to CEIs in terms of their organizational form and purpose. Historical evidence suggests that this model has led to the largest increase in CEI activity to date. On the other hand, it is also prone to produce more market-oriented CEIs, that mainly contribute to the technological energy transition through deploying renewable energy technologies, with less focus on the social aspects of the energy transition. The current strategy by the EU establishes support mechanisms targeted directly at CEIs that are tied to far stricter requirements in terms of their impact beyond the deployment of renewables. While recent evidence shows that CEIs have diversified their activity portfolio, moving away from the market-oriented feed-in tariff model, there has also been a decline in overall CEI activity. Furthermore, such targeted CEI support mechanisms are characterized by higher monitoring needs, in order to test the adherence of CEIs to the stricter demands regarding organizational form, purpose and activities and consequently their eligibility for such support mechanisms. As this thesis has shown, the reporting of CEI data is currently highly fragmented and lacks standardization. While this policy approach may foster more transformative types of CEIs, it also risks a generally lower activity in the community energy sector, as a result of the increased reporting requirements for CEI that are often already struggling to fulfil current administrative obligations. Furthermore, the feed-in tariff model has led to a high dependence of CEIs on this support mechanism, as is evident in the considerable decline of CEI activity coinciding with the gradual reduction of feed-in tariffs. While not visible in the data yet, it is reasonable to assume that the current targeted (financial) support mechanisms may create a similar dependence. The case of Denmark illustrates a potential alternative approach to those mentioned above. Denmark saw significant growth in both wind power and district heating cooperatives in the 1980s. An important factor was the existence of a non-profit rule in the Danish energy sector, obligating energy suppliers to convert profits from one year into lower energy prices for their customers the next year. The majority of wind power cooperatives were subsequently discontinued or moved to more market-oriented business models as a result of the discontinuation of the non-profit rule and the introduction of feed-in tariffs in the electricity sector. However, due to the continued existence of the non-profit rule in the district heating sector, cooperatives remain the dominant form therein. This policy approach fosters a more social type of CEI, focusing on the fulfilment of the energy needs of its members and external stakeholders, while simultaneously avoiding drastically increased monitoring requirements to control the CEI's adherence to the various aspects of the EU definitions and resulting eligibility for state support schemes. It also reduces CEI dependence on state subsidies.

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PAPER I: A EUROPE-WIDE INVENTORY OF CITIZEN-LED ENERGY ACTION WITH DATA FROM 29 COUNTRIES AND OVER 10000 INITIATIVES.

scientific data

OPEN

DATA DESCRIPTOR

A Europe-wide inventory of citizen-led energy action with data from 29 countries and over 10000 initiatives

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Numerous case studies show that citizens engage in various ways in renewable and low carbon energy projects, thereby contributing to the sustainable energy transition. To date, however, a systematic and cross-country database on citizen-led initiatives and projects is lacking. By performing a major compilation and reviewing copious data sources from websites to official registries, we provide a Europe-wide inventory with over 10,000 initiatives and 16,000 production units in 29 countries, focusing on the past 20 years. Our data allow cross-country statistical analysis, supporting the elicitation of empirical insights capable of extending beyond the perspective of single case studies. Our data also align with ongoing efforts to implement two EU Directives that aim at strengthening the active role of citizens in the energy transition. While the focus of our data collection is on Europe, the data and methodology can contribute to the global analysis of citizen-led energy action.

Background & Summary

The Paris Agreement signed in 2015 states that greenhouse gas emissions resulting from human activities must be reduced as soon as possible in order to limit global warming well below 2°C compared to pre-industrial levels by 2100[1]. This will require a rapid low carbon transition in almost all sectors of human activity, and in particular reaching net zero emissions for the production, distribution, and consumption of energy services[2].

In many countries, ordinary citizens are coming together through collective initiatives to play an active role in this transition. Particularly in Europe, citizen-led energy projects have grown to produce, distribute, and consume energy from renewable sources while being governed democratically, with benefits accruing locally[3]. While many of these initiatives are small in scope, they are of sufficient importance to policymakers as they actively involve people in the transformation[4–6]. Under the name of energy communities, citizen-led energy action has been specifically addressed in two separate EU directives (Directives EU-2018/2001[7] and EU-2019/944[8]). Despite this, data collection on the topic has not been undertaken systematically until now. Notable exceptions include Harnmeijer *et. al.*[9], Harnmeijer *et. al.*[10], Haggett *et al.*[11], Hewitt *et al.*[12], Kahla *et al.*[13], Hoicka and MacArthur 2018[14], Wierling *et al.*[15], Gorrono-Albizu *et al.*[16], and Berka *et al.*[17]. Haggett *et al.*[11] is an early inventory on citizen-led action in Scotland. While Kahla *et al.*[13] collects long-term data on German citizen-led energy cooperatives and associations ('Bürgerenergiegesellschaften und Energiegenossenschaften'), Hewitt *et al.*[12] carry out a mapping exercise, compiling over 400 community energy initiatives in 8 European

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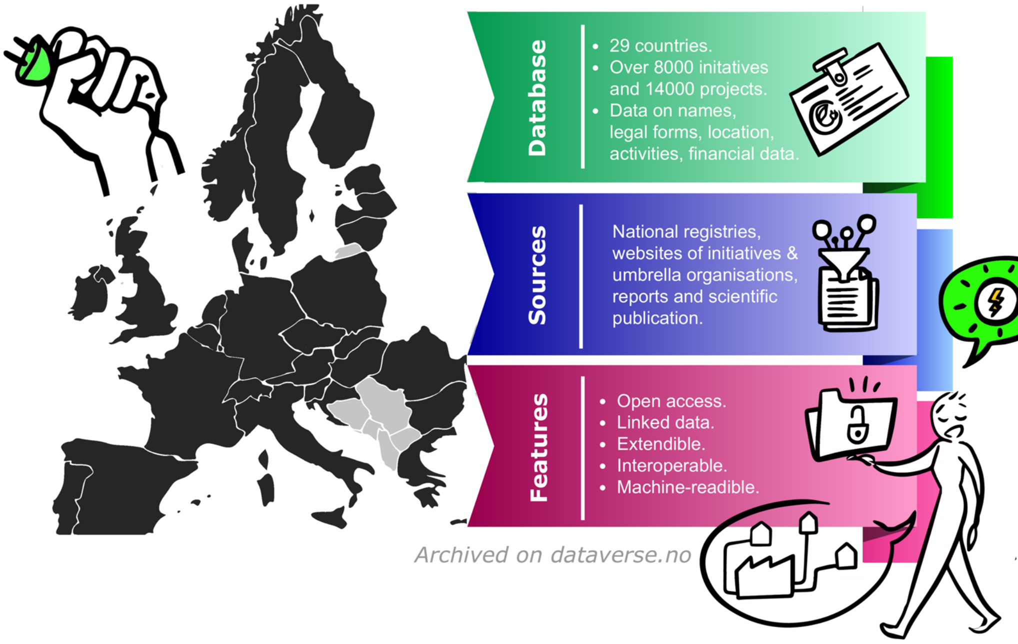

Fig. 1 Overview on the EU-wide inventory of citizens collectively engaging in the energy transition.

countries. Wierling *et al.*[15] is the precursor to the inventory presented here. The majority of the research done on the phenomenon of citizen-led energy action, however, takes the form of case studies, surveys, or compendia (c.f. Holstenkamp 2018[18]). Such studies provide meaningful insights drawn from smaller sets of examples, but fail to give an understanding of the aggregate contributions of these initiatives. Additionally, Non-Governmental Organizations (NGOs) in some European countries that support, structure, and track national citizen energy movement have provided analyses of the impact of these actions (c.f. RESCOOP.eu - the European Federation of Citizen Energy Cooperatives). To this point, the analyses do not provide a comprehensive review of citizen-led climate action in Europe based on a dataset driven approach. While the data produced in this manner has been invaluable to the present effort, it is neither exhaustive nor sufficiently detailed to support in-depth analysis of the sector. Therefore, the research community has been calling for dataset driven approaches (Harnmeijer *et. al.*[9], Wierling *et al.*[15], Hewitt *et al.*[12]).

The data presented here is the first to capture the nature and scope of collective citizen-led action in the energy transition for each country in Europe (Fig. 1). The data consists of a broad range of variables to a high degree of granularity, covering both organizations and the individual projects that they manage, e.g., units under own operation to produce renewable electricity or the operation of charging stations for electric mobility. This dataset draws on official registries, umbrella organization databases, news reports, websites of initiatives, and both individual organization legal documents (bylaws, meeting minutes, etc.), social media, and websites. Collection was performed over a period of four years by an international team of trained researchers and assistants and validated both manually and through automated processes. Figure 2 provides a schematic overview of the design of the inventory, which we detail in the remainder of this paper. An additional publication will complement the documentation of the database by detailing the steps undertaken to implement the FAIR guiding principles[19] for machine-actionable reuse of the data. These 15 principles suggest organizational steps to increase the findability (F), accessibility (A), interoperability (I), and reusability (R) of data.

Being the first of its kind, the Europe-wide inventory of citizen-led energy initiatives can be valuable to all key actors concerned with citizen engagement in the energy transition, from policymakers to academics to advocacy organizations to the citizen-practitioners themselves. The dataset allows generalizable conclusions to be drawn both within and between countries, permitting comparisons across both time and borders. Of particular value to public authorities and legislators, these analyses give insights into the impacts of citizen initiatives on the energy transition and of policy decisions on those same initiatives. This data will be particularly relevant over the next few years within public policy, as the member states of the EU implement the directives involving Energy Communities into local law and track the impacts of these policy changes on the emergence and success of citizen-led initiatives in their jurisdictions.

A systematic analysis of the enabling and disabling factors for these initiatives is now achievable with this dataset for the first time by comparing between countries and within a given country across time. This data can be used to support the construction of likely trajectories that citizen engagement will take and to make recommendations for how to alter or improve those trajectories. Citizen-led projects themselves and their network organizations can also benefit from this dataset, strengthening their ability to advocate for their position in the energy transition and helping them to learn from the experiences of initiatives in other countries. The aggregated contribution of energy communities to the energy transition at the national and European level can be

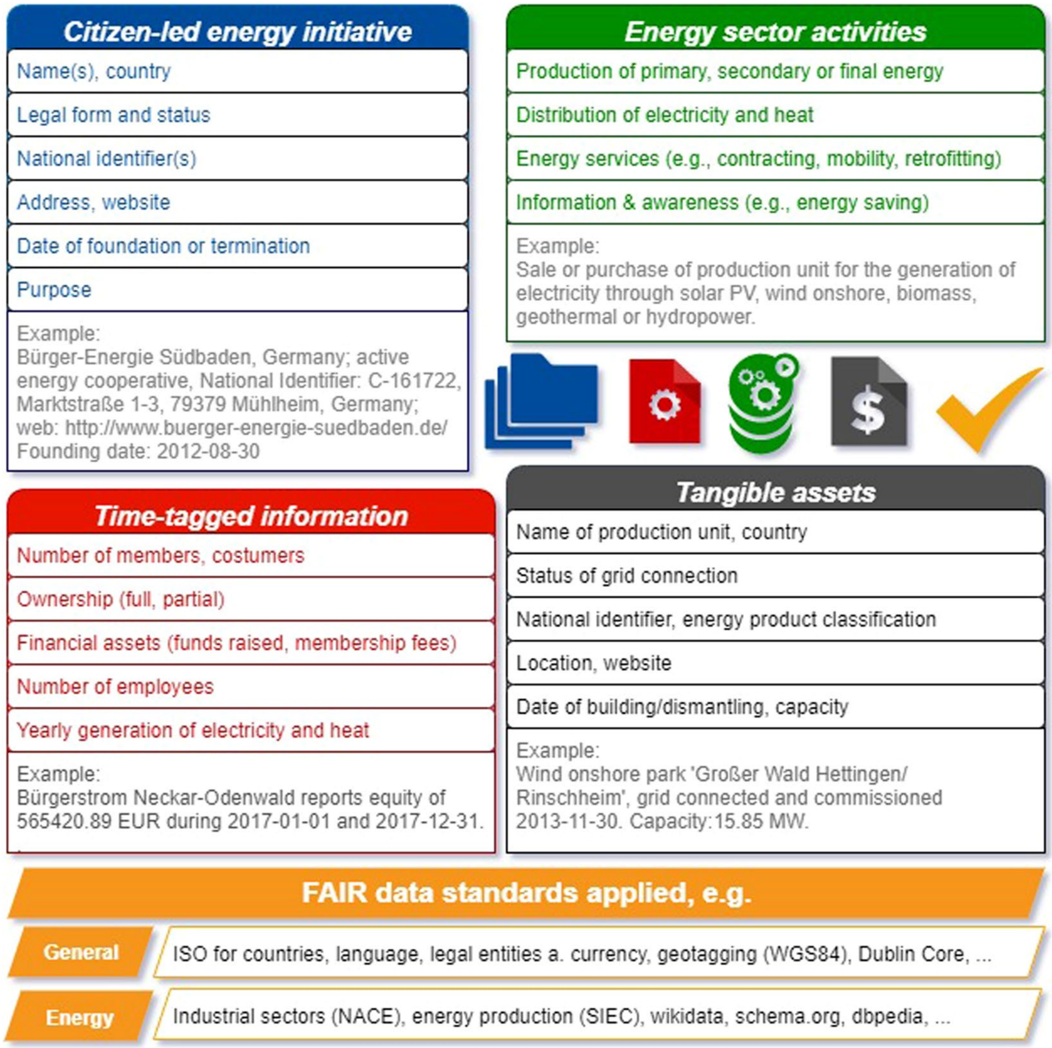

Fig. 2 Schema of the inventory on citizen-led energy initiatives in 29 European countries. The figure gives examples about the type of information gathered. For the taxonomy and definitions of terms refer to the Supplementary Material.

documented with the help of the data. According to these estimates, at least 2 million people invested their time, creativity, and money into the installation of about 10 GW of renewable capacity. While the focus of our data collection is on Europe, the data can also support empirical analysis of citizen-led energy action around the globe.

Methods

Defining criteria for citizen-led renewable energy initiatives. The literature provides a wide array of terms and definitions for citizen-led renewable energy initiatives, ranging from 'community renewable energy projects (CREs)[20]', 'local low-carbon energy initiatives (LLCEIs)[21], to 'grassroots energy initiatives (GIs)'[22]. Recently, the European Commission has published two related definitions, being Citizen Energy Communities (CEC)[7] and Renewable Energy Communities (REC)[8]. As a result of the various definitions, this paper adopted a broad conceptualization, aiming to be over-inclusive rather than under-inclusive. The inventory allows filtering based on, for example, the legal form of the initiative, to provide future users with the possibility to select sub-samples of the dataset that fit their own criteria. Relevance of initiatives for the inventory is decided based on three aspects,

1. the initiative being led by citizens,
2. the initiative striving for social or environmental benefit beyond pure economic interest, and
3. the initiative engaging in activities related to the energy transition.

Activities considered are not only production and distribution of energy, but also include actions such as information and awareness raising. Note that the inventory reports collective citizen initiatives and not initiatives of individual citizens.

For the purpose of defining the aspects of 'citizen-led' and additional social or environmental benefits, we adopted the concept of process and outcome dimensions by Walker and Devine-Wright (2008)[20], where the process dimension refers to the degree of participation of the initiative's members in its decision-making and the outcome dimension refers to the degree to which the initiative focuses on providing community benefits. Thereby, *community* is understood as communities of place and/or interest[23]. The highest degree of participation in the initiative's decision making process is given for cases following the 'one member - one vote' principle' (OMOV principle). Here, in comparison to companies such as shareholdings, every member has one vote, independent of the share owned by the respective member. For the majority of countries in Europe, the 'one member - one vote' principle applies to the legal form of cooperatives[24,25]. Consequently, typical actors included in the inventory are cooperatives under the individual national law. Other legal forms were included for specific countries if evidence suggested a high degree of participation in decision-making processes. Legal forms were identified and categorized using the Entity Legal Form Codes provided by the Global Legal Entity Identifier Foundation (GLEIF)[26]. Table 1 summarizes the included legal forms for each country.

The following areas of activity have been classified as relevant for engagement in the energy transition (see also Table 2):

- Production and distribution of energy: Comprising the operation, installation, and/or financing of any kind of renewable energy generation facility (solar-PV, wind, hydro-power, geothermal, bio-energy), distribution of electricity or heat, energy trade, collective purchasing of energy and energy-related products, and the production and trade of energy-related products (such as energy crops);
- Provision of energy services: Including low carbon self-consumption, contracting of light, car sharing and operation of EV charging stations, bike sharing, retrofitting of buildings, and energy efficiency and energy saving measures (including the operation/installation/financing of co-generation units using fossil fuels); and
- Information & awareness: Such as energy-related education and awareness raising and energy consulting services.

Additional taxonomic details are provided in the Supplementary Material. We follow ISO-25964 (The international standard for thesauri and interoperability with other vocabularies).

Data search and extraction process. Data collection extended over a period of four years, from 2018 to 2021, sourcing from four overarching categories of data sources. These include 1) pre-existing registries and databases, 2) individual websites of the initiatives, 3) regular (financial) accounts and reports of the initiatives, and 4) direct interviews with members of the initiatives or experts in the field of citizen-led renewable energy initiatives. Curated data sources include official registries operated by state agencies such as official business registers and energy market data registers (e.g., the German Marktstammdatenregister[27], Swedish Vindbrukskollen[28], Danish Datavirk[29]), commercial/non-profit/scientific databases such as commercial business registers and pre-existing databases on community energy operated by NGOs and other non-governmental actors (e.g Dutch Lokale Energie Monitor[30], database of the European federation of citizen energy cooperatives (REScoop)[31]), and lastly data from previous studies related to citizen-led renewable energy initiatives. Detailed information on these sources per country are provided in the Supplementary Material. Official registries, as well as commercial/non-profit/scientific databases, tend to be dynamically updated, while previous studies tend to provide static data collected within a given time period. In summary, priority was given to official registries operated by state agencies, followed by other curated databases and static data from previous studies. Thereafter, individual initiatives' websites, yearly accounts, peer-reviewed publications, and interviews with experts were used to fill in missing data and to validate the data already collected.

An initial meta-study was conducted for each of the investigated countries to identify relevant legal frameworks (e.g., legal forms for initiatives), previous literature on the topic of citizen-led, collective energy action, and potential data sources. If available, any existing data specifically on citizen-led renewable energy initiatives was thereafter added to the inventory. In such cases, all data obtained through this process was cross-referenced with official registries and/or individual initiatives' websites and yearly accounts and potentially updated. Following this step, a systematic search in business registries was conducted, expanding the previous data. Business registries where generally searched by filtering all entries for the relevant legal forms as well as keywords related to the energy transition. Ideally, business registries offer an integrated option to filter for both legal forms and area of activity (by following the NACE[32] or similar classification systems). For countries where business registers do not provide this option, a web search by keywords was conducted instead. Details for each country are provided in the Supplementary Material. Some countries maintain additional registries on actors engaging in the energy sector, such as the German Marktstammdatenregister that contains information on all installed energy generation facilities. If such registries were available, these were searched for all entries fitting the relevant legal forms of the actors. Following the process of identifying relevant initiatives, data was collected from the aforementioned sources.

Data Records

The data have initially been compiled in spreadsheets/csv-files, but subsequently transferred into records, applying the research description framework (RDF). The turtle format[33] was used as RDF serialization. Four top-level classes (or digital units) were used to organize the data (see Fig. 2), where each of them includes attribution information following the Dubling Core Standard. Top-level data classes are the following:

Country	Legal Forms – with ✓ (✓) or (✓) or x in-front indicating adherence to the OMOV-principle	GLEIFIdentifier
AUT	✓ Registrierte Genossenschaft (m.b.H.) (registered cooperative), ✓Verein (association)	8XDW, DX6Z
BEL	✓ Société coopérative (cooperative), ✓ Société coopérative à responsabilité limitée (limited liability cooperative), [✓] Société coopérative à responsabilité limitée à finalité sociale (social benefit limited liability cooperative), ✓ Société coopérative européenne (European cooperative), (✓) Association sans but lucratif (non-profit association), (✓) Association internationale sans but lucratif (international non-profit association)	28FE, 8E2A, 2QSA, YBHM, W3WH, V03J
BGR	[✓] Drushestwo s ogranitschena otgowornost (limited liability company). Other potentially relevant forms: Kooperazija (cooperative), Sdrushenie w obschtschestwena polsa (social benefit association)	VJ3G, CTCH, 3SHX
HRV	✓ Zadruge/Zadruga (cooperative)	G5RH
CYP	No legal forms for citizen-led energy actions. Cooperative law also established in Cyprus	N/A
CZE	✓ Družstvo (cooperative). Another possible relevant legal form: Zemědělské družstvo (collective farm)	9RVC, Z3BF
DNK	Interessentskab (partnership), Andelsselskab med begrænset ansvar (limited liability organisation)	7WRN, PZ6Y
EST	(✓) Korteriühistu (apartment association), ✓ Mittetulundusühing (non-profit association), ✓Tulundusühistu (commercial association)	8ZQE, PRTB, VSEV
FIN	✓ /[✓] Osuuskunta (cooperative)	EE90
FRA	(✓) SAS société par actions simplifiée (Simplified joint-stock company), [✓] SARL nationale (limited liability corporation), ✓ SCOP SARL coopérative ouvrià¨re de production (worker cooperative), Association foncière urbaine (urban real-estate association), Association déclarée (association), ✓ Association déclarée reconnue d'utilité publique (registered public benefit association), ✓ Association non déclarée (undeclared association), [✓] SICA SARL d'intérêt collectif agricole (collective interest limited liability agricultural company), Société coopérative agricole (agricultural cooperative), [✓] Indivision entre personnes physiques (partnership between physical persons), Autre SA coopérative à conseil d'administration (other joint-stock cooperative), Autre SARL coopérative (other limited liability cooperative)	6CHY, JR7T, V1Z5, 9O0S, BEWI, XH8C, 491H, H3ZD, 211B, Q634, 8II5, 4DZU
DEU	✓ Eingetragene Genossenschaft (registered cooperative company), [✓] Eingetragener Verein (registered association)	US8E, QZ3L
GRC	✓ but limited citizen leadership Ενεργειακή Κοινότητα (Energy Community - specific sub-form of a cooperative)	J3VJ
HUN	Yet limited activities in citizen energy, but current relevant legal form: Egyéb szövetkezet (Other cooperatives)	DPY1
IRE	(✓) Friendly Society, no legal form: Sustainable Energy Communities	54SK, n/a
ITA	Associazione (association), Società Cooperativa (cooperative), Società Semplice (simplified company), Società Consortile A Responsabilità Limitata (limited liability consortium), Società Cooperativa a Responsabilità Limitata (Limited liability cooperative), Consorzio (consortium), Società A Responsabilità Limitata (limited liability company), Società Per Azioni (joint-stock company), Cooperativa Sociale (social cooperative)	1TON, QRZJ, 2XXH, BL52, CTNS, HN75, OV32, P418, PHMS
LVA	No GLEIF registered legal forms, but citizens engage in: ✓ Biedriba (society), ✓ Kooperatīvā sabiedrība (Cooperative society)	8888 8888
LTU	Only one registered GLEIF code: ✓ Kooperatinės bendrovės (Cooperatives). People also engage in Housing associations	LUGM 8888
LUX	[✓] Société civile (civil company), ✓ Société coopérative (cooperative society), (✓) Association sans but lucratif (non-profit association), (✓) Société coopérative organisée comme une société anonyme	SQ1A, V5OS, 2JEI, STBC
MLT	✓ Cooperative society	F5X7
NLD	✓ Coöperatie (cooperative), (✓) Vereniging (association, society), [✓] Stichting (foundation, trust)	NFFH, 33MN, V44D
NOR	✓ Samvirkeforetak (cooperative), ✓ Europeisk samvirkeforetak (european cooperative)	K5P8, O7LB
POL	(✓) but limited citizen leadership SpóÅ‚dzielnie (cooperative), informal concept of "Energy Clusters"	8TOF, n/a
PRT	✓ Cooperativa (cooperative), associação	1HGD, ALPT
ROU	✓ Societate Cooperativă Europeană (European cooperative society)	UWEE
SVK	✓ Družstvo (cooperative)	I7AS
SVN	✓ Zadruga z omejeno odgovornostjo (cooperative limited liability)	RAX7
ESP	✓ Sociedad cooperativa (cooperative)	1QU8
SWE	✓ Ekonomisk förening (economic association), [✓] Samfällighetsförening (joint-ownership association), ✓ Bostadsförening (housing association before 1930), ✓ Bostadsrättsförening (tenant owner's association after 1930), [✓] Ideell förening (non-profit organization), [✓] Enkla bolag (regulated partnership between two partners)	C61P, n/a, WZDB, SSOM, 1TN0, n/a
CHE	✓ Genossenschaft, Société coopérative, Società cooperativa (cooperative)	QSI2
GBR	✓ Community benefit society, company, community interest company, LLP	IYXU, H0PO, 17R0, Z0EY

Table 1. Relevant legal forms, GLEIF legal entity codes, and information on prevailing of the One-Member-One-Vote (OMOV) Principle in a country. Information on OMOV sourced from EPRS[25]. Abbreviations: (✓) - optional, but common choice, [✓] - or alternatively also proportional, multiple, plural votes, ((✓)) for cooperatives of natural persons. Note: 8888 means pending status.

1. Administrative data on citizen-led energy initiatives: Name (legal, alternatives), status (active/inactive), isLegalOrganization (yes/no), National Identifier(s), country code, postal address, contact, website, year of foundation, year of termination, legal form (as text and as code), industrial sector classification (national and international sector classification, e.g., for the production of electricity), One-member-one-vote (connected to legal forms, refer to Table 1), purpose statement (text, English and/or national language), makesOffer (specification of areas of activity in the energy sector);
2. Tangible assets: Name of production unit, status (active/inactive), IsGridConnected (yes/no), geotagged location, street address, country, national production unit identifier(s), technology and energy product identifier (e.g., photovoltaic), year of commissioning, year of decommissioning, nameplate capacity, estimated yearly generation, equipment specification;

Standard	Name and use
SIEC[35]	Standard International Energy Product Classification
GLEIF[26]	Global Legal Entity Identifier Foundation
ISO 3166[36]	Alpha-2 and alpha-3 country codes
ISO 639-1[37]	Codes for the representation of names of languages — Part 1: Alpha-2 code
ISO 4217[38]	International currency codes
NACE[32]	Statistical classification of economic activities of the European Union
schema.org[39]	Shared vocabularies for structured data on the internet.
dbpedia[40]	Structured information used to encode city names or tangible assets
wikidata[41]	Structured information used to encode semantic information, e.g., wikidata Q194356 of a "wind farm"
OEO[42]	Open Energy Ontology

Table 2. List of applied classification standards and controlled vocabularies.

3. Singular activities undertaken by an initiative: For example, the purchase and sale of tangible assets (dates, values/prices), organisation of events; and
4. Time-tagged information, with yearly resolution: Number of members, number of customers, number of employees, financial assets (total assets, fixed assets, tangible assets, current assets, total equity and liabilities, equity), percentage ownership of assets, yearly generation of electricity or heat per production unit.

The inventory is publicly accessible at dataverse.no and adheres to the FAIR data guiding principles[19]. Technical details about the FAIRification process will be described in a complimentary publication. This implies that the inventory, as well as the instances of the four classes, are described through rich metadata and linked with persistent identifiers. Controlled vocabularies and ontologies have been used to define the metadata and assign classification standards. Table 2 lists these standards. Further information about additional uses of country standards and classification is available in the Supplementary Material.

The inventory on citizen-led energy initiatives is publicly open from the general purpose repository dataverse.no[34]

Technical Validation

As a general validation measure, the four-eyes principle was strictly implemented. This implies that the person in charge of collecting the data was not the same for validating the data. Where possible, data have been cross-checked with other publications and aggregated information. Also, statistical tests were performed, such as verification of the possible range of data. Detailed information about validation undertaken country-by-country is available in the Supplementary Material.

Due to different legislation and reporting requirements in each of the countries, the coverage of data varies considerably. We can report the tendency that more detailed information is available for larger initiatives. Furthermore, legal forms are not yet available or under implementation in some countries (see also Table 1), which is why we are only able to report very basic information. In the Supplementary Material we provide assessments on the data coverage within each of the countries, using available literature or other information as benchmarks. Overall, above 70 percent of the initiatives were officially registered and over 70 percent have a website established. Information about members and production units is available for 40 percent and 50 percent respectively. Countries with the best coverage include Belgium, Denmark, Germany, and the Netherlands, whereas much less information is available from the Czech Republic, Finland, Croatia, and Switzerland.

Our dataset falls short in covering a number of initiatives and their activities for the following reasons. First, it is likely that we were not able to identify all initiatives that predate 1980 but still exist today (e.g., historic electrical cooperatives). Second, we are not able to cover all dissolved initiatives that lack a trackable web presence or have been deleted from official registers. In general, the coverage of initiatives and their activities in a given country is best if it requires official registration. For example, registration is typically required for initiatives engaging in the production of electricity, whereas neither initiatives nor activities of housing associations need formal or standardized recording. Therefore, our data likely underestimate the role of housing associations, which play an important role in Eastern European countries. Third, we exclusively rely on voluntary information available from websites or other media for collecting data on soft activities such as information and awareness raising, education, and consultancy services. Therefore, we are likely underestimating the contribution of collective action in this regard, overemphasizing initiatives engaging in the production of energy services.

Usage Notes

The inventory on citizen-led energy initiatives in European countries is available for reuse under the Creative Common licence CC-BY 4.0. Licensees may copy, distribute, display, perform, and make derivative works and remixes based on it only if they give credit (attribution) to the authors by citing this manuscript.

Although we put utmost attention to ensure high quality data (see the Section above), the inventory should be reused with caution. The concept of energy communities or citizen-led action in the energy transition is constantly evolving and cross-country monitoring standards do not yet exist. Moreover, obligations for registering and/or updating existing initiatives and projects differs across countries, which is why the data are incomplete. Thus, the numbers may serve as conservative estimates, able to provide country- and European-level snapshots.

Code availability

No custom code was used to generate or process the data described in the manuscript. Rather, a combination of open software tools was applied. However, the supplementary material published at the repository[34] contains customized SPARQL commands to query the inventory.

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Author contributions
V.J.S. and A.W. supervised the design of the research project and coordinated all tasks. V.J.S., A.W. and J.P.Z. supervised the design of the inventory and the collection of data. The following authors contributed to data collection for Austria (C.B., T.K., A.W., S.D.,J.P.Z.), Belgium (T.M., A.W., C.B.), Bulgaria (V.J.S., I.K.K.), Croatia (J.P.Z., I.K.K., V.J.S.), Cyprus (I.K.K., V.J.S.), Czech Republic (J.P.Z., V.J.S., I.K.K.), Denmark (A.W., J.P.Z., L.M., I.K.K., H.A.P., V.J.S.), Estonia, (G.G., V.J.S., J.P.Z., L.M.), Finland (J.P.Z., C.v.B., I.K.K.), France (T.M., A.W.), Germany (A.W., C.B., T.K., L.M., J.P.Z., S.D., H.A.P.), Great Britain (A.W., M.G., P.R., M.Z.), Greece (I.K.K., Z.A., V.J.S.), Hungary (C.B., I.K.K.), Ireland (J.P.Z., P.R., V.J.S., H.A.P., C.B., S.M., T.M., L.M., A.W.), Italy (A.W., I.K.K., T.M., H.A.P., T.K., C.B., C.C., V.L., A.S., J.P.Z., S.M., N.Z., G.S., V.J.S.), Latvia (V.J.S., A.W., S.M., I.K.K.), Lithuania (V.J.S., I.K.K., C.B.), Luxembourg (V.J.S., T.M., P.R.,C.v.B.), Malta (C.B., I.K.K.), Netherlands (A.W., J.P.Z., C.B., H.A.P., N.S.N.), Norway (I.K.K., J.P.Z., A.W.), Poland (T.R., V.J.S., W.H., A.W.), Portugal (T.K., V.J.S.), Romania (S.D., I.K.K., C.B.), Slovakia (L.M., V.J.S., Y.R.P.), Slovenia (I.K.K., V.J.S., Y.R.P.), Spain (T.K., A.W., J.P.Z., S.D., H.A.P., C.B., I.K.K., V.J.S., T.M.), Sweden (I.K.K., J.P.Z., A.W.), Switzerland (L.M., A.W.). The manuscript was prepared by A.W., V.J.S., J.P.Z., C.B., H.A.P., I.K.K., T.K., T.M. and L.M. All authors reviewed the manuscript and participated in data validation.

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None of the authors declares competing interests.

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PAPER II: STATISTICAL EVIDENCE FOR THE CONTRIBUTION OF CITIZEN-LED INITIATIVES AND PROJECTS TO THE ENERGY TRANSITION IN EUROPE.

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Statistical evidence for the contribution of citizen-led initiatives and projects to the energy transition in Europe

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Statistical accounting of the impacts of citizen-led energy initiatives is absent, despite their impact on increased energy self-sufficiency and ramping up of renewable energies, local sustainable development, greater citizen engagement, diversification of activities, social innovation, and acceptance of transition measures. This paper quantifies the aggregate contributions of collective action in pursuit of the sustainable energy transition in Europe. We estimate the number of initiatives (10,540), projects (22,830), people involved (2,010,600), installed renewable capacities (7.2–9.9 GW), and investments made (6.2–11.3 billion EUR) for 30 European countries. Our aggregate estimates do not suggest that collective action will replace commercial enterprises and governmental action in the short or medium term without fundamental alterations to policy and market structures. However, we find strong evidence for the historical, emerging, and actual importance of citizen-led collective action to the European energy transition. Collective action in the energy transition is experimenting successfully with new business models in the energy sector. Continued decentralization of energy systems and more stringent decarbonization policies will increase the importance of these actors in the future.

Clean, secure, and affordable are key words in the ongoing energy transition toward a zero-carbon global energy sector[1]. Enabling and accelerating these goals requires massive mobilization of resources to lower greenhouse gas emissions and increase resource efficiency of energy and material systems[2]. Estimates predict global investment needs of $2063 billion annually between 2022 and 2025 and an average of $4189 billion per year thereafter to reach a net-zero emissions scenario by 2030[3]. While the importance of mobilizing both public and private investors across-the-board is emphasized[4], citizen-led initiatives and their manifold contributions have been systematically overlooked. This is despite their active involvement in, and pivotal contributions to, for example, the electrification of rural areas in the early twentieth century[5] or their leading role in enabling the shift towards wind energy in Denmark[6]. Focusing on the past twenty years, this paper quantifies the aggregate contributions of collective action and systematically identifies solutions in pursuit of the sustainable energy transition for European countries.

The secure, sustainable, and affordable provision of energy services for all is of prime public interest and is a goal in the international Sustainable Development Agenda[7]. Moreover, recent geopolitical turmoil and skyrocketing energy prices underline the importance of energy security and affordability. In Europe, the energy system is undergoing a stark transition driven by the liberalization of energy markets, the need to decarbonize energy and other sectors incentivized by climate policies (e.g., emission trading schemes, energy efficiency standards, carbon taxes, feed-in tariffs, and R&D grants)[2], and on-going data-driven digitalization of the energy sector[8]. As a result, energy markets are changing from traditionally centralized systems to decentralized modes of energy services provision. These markets are opening up to new technologies, schemes of operation and management, and new market actors (as the emergence of the term 'prosumer' demonstrates). The transition requires fundamental

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Citizen-led energy initiative	Criteria compliance level: y—yes, p-partly/limited, n–no	Example of an initiative	Example(s) of projects from that initiative
Energy cooperatives	(y) Citizen-leadership (y) Social and/or environmental benefit (y) Active in energy	Energiegenossenschaft Starkenburg eG is a 1000-member cooperative, founded by 13 citizens in the city of Heppenheim in 2010	Owning and operating 7 wind and 31 solar photovoltaic projects, also provides consulting and information services
Renewable energy communities	(p) Citizen-leadership, but often initiated by municipalities (y) Social and/or environmental benefit (y) Active in energy	Comunità energetica di Borutta is an Italian renewable energy community (CER) without a separate legal form, operating in the town of Borutta since 2020	Installation and operation of a 850 kW wind turbine and photovoltaic roof-top systems on town hall, sport centers, and schools. Striving for free-of-charge, self-produced electricity. Another motivation is halting rural depopulation
Energy communities	(p) Citizen-leadership, but often initiated by municipalities, local authorities and sometimes seen as an opportunity for companies (y) Social and/or environmental benefit (y) Active in energy	Minoan Energy in Crete was established in 2019 in Greece and is registered under the legal form of a cooperative. It has 313 members (incl. three Municipalities and the Region of Crete)	Operates a 405 kW solar photovoltaic system, members can purchase shares to meet their households' energy demand. Offers non-profit advice to citizens and public authorities for energy saving measures and energy efficiency upgrade of buildings. Decided recently to financially support families affected by the pandemic and the earthquakes
Sustainable energy communities	(p) Citizen-leadership encouraged through general principles (y) Social and/or environmental benefit (y) Active in energy	Camross Parish Development Association located in Laois, Ireland, is not a legal form itself, but registered in the SEAI network	Drafted a community-led plan to develop Camross as a "smart village" and to reduce GHG emissions. Promotes behavioral change, energy-independence, and climate action
Housing cooperatives and associations	(y) Citizen-leadership (y) Social and/or environmental benefit (p) Also active in energy (e.g., energy-efficiency measures, RE-based self-production of electricity) but housing is the primary focus	A multi-apartment residential building in Alytus, Lithuania, was registered in 2008 as a housing association	Installed a 14 kW geothermal heating system for the building. Other projects include renovation and improvement of energy efficiency
Sustainable mobility cooperatives	(y) Citizen-leadership (y) Social and/or environmental benefit (y) Active in energy through facilitating sustainable mobility (e.g., electric vehicle rental, carsharing, rail transport sector)	Ecotxe is a consumer cooperative on the island of Palma, Spain, that practices co-ownership and sharing of electric vehicles among local citizens	This cooperative counts 240 members and 275 users for its fleet of 5 electric cars. Works in partnership with the local government to provide a service that is complementary to public transport
Energy clusters	(p) Limited citizen-leadership, often initiated by municipalities, local authorities, and companies (y) Social and/or environmental benefit (y) Active in energy	Zgorzelecki Klaster Rozwoju Odnawialnych Źródeł Energii has 100 members and was selected in 2019 in a national call to become one of the Polish energy clusters (not a legal form)	Installed photovoltaic farms with a combined capacity of 46 MW. Has comprehensive energy plans for the region (incl. mobility sector). Strives for connecting renewable production and regional development
Historic rural electrification cooperatives	(y) Citizen-leadership (y) Social and/or environmental benefit (y) Active in energy	Société Coopérative d'Intérêt Collectif Agricole de la Région de Pithiviers was founded in 1919 as a rural electrification cooperative, counting over 1300 members today	Now also a local distribution company for both electricity and gas, serving over 26,000 customers. Began recently developing wind parks, opening the capital to local citizens and their initiatives
Eco-villages	(y) Citizen-leadership (y) Social and/or environmental benefit (p) Also active in energy but have a general sustainable development perspective	Tuggelite eco-village community is registered as a tenant owner's association (Bostadsrättsförening) in Sweden. Starting with 16 households in 1984, it now has 50 households participating	Combines energy and resource conservation measures for electricity, heating, and water needs. Operates a central district heating system for wood pellets and 120 m² of solar panels
Compared to companies and public sector			
Type	Criteria compliance level: y—yes, p-partly/limited, n–no	Type	Criteria compliance level: y—yes, p-partly/limited, n–no
For-profit companies	(n) Shareholder-leadership (n) Economic success is priority (y) Active in energy	Public sector power companies	(p) Elected official and public functionary leadership (p) Both—typically shared economic and social benefit (y) Active in energy

Table 1. Types and examples of citizen-led energy initiatives found across Europe, showcasing the variety of relevant (legal) forms and energy-related activities.

changes in the governance of energy systems[9,10]. While the European framework for a unified energy market has been set[11], countries differ widely in their formalizations and approaches to implementing EU legislation[12].

Our central object of study is citizen-led energy initiatives and their aggregate contribution to the low carbon energy transition in Europe (c.f.[13–15]), which complements the contribution by individual citizens[16]. Energy cooperatives are a prime example, but not the only one. Table 1 lists citizen-led initiatives found across Europe, showcasing the variety of relevant (legal) forms and energy-related activities. The supplementary material lists prevailing types in each country, along with details on data availability, which differs across countries[17]. We estimate the number of initiatives, projects, people involved, installed renewable capacities, and investments made for 30 European countries.

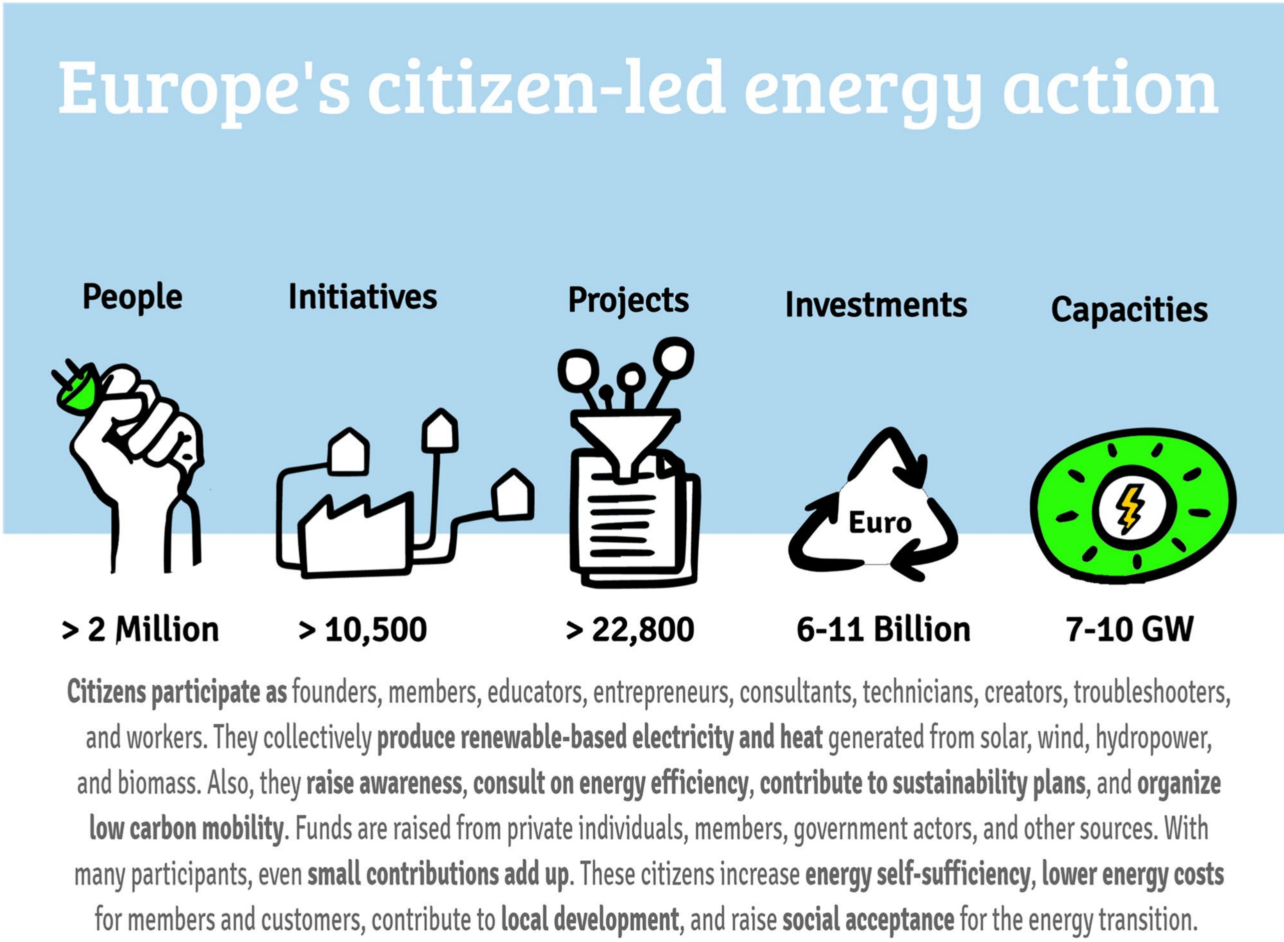

Figure 1. Europe-level aggregates. Contributions of citizens from 30 European countries to the energy transition. Most data collected are from 2000 to 2021.

Although we are aware that many conceptual and statistical issues exist and significant uncertainties remain, we support counting what has not yet been counted, thus bringing deserved attention. These issues would suggest that our estimates are conservative and could increase with: (1) more and broader effort (e.g., filling missing data and accounting for the contribution of individual prosumers), (2) statutory reporting requirements in all countries, and (3) timely reporting by initiatives (even obligatory reporting is often delayed by two or more years). Regarding our lack of accounting for the time-value of money, the direction of influence this would have on our estimate is not clear. While inflation suggests lower estimates, considering today's monetary values, technological learning acts in the opposite direction. Finally, the definition of the object of study has a substantial impact on the aggregate contributions that we arrive at; other research efforts with broader or more limiting definitions of collective citizen engagement in the energy transition will result in different figures, without however invalidating the overall picture of our results.

Results

Quantitative results at the European and country-levels. Figure 1 shows our estimates of citizen-led contributions to the energy transition in Europe. Focusing on data from 2000 to 2021, selected estimates for the number of initiatives (10,540), people collectively engaged (2,010,600), projects undertaken (22,830), finances invested (6.2–11.3 billion EUR), and renewable capacities installed (7.2–9.9 GW) were derived from country-level aggregates of 25–30 European countries (depending on the estimate). Table 2 shows the country-level aggregates for the number of initiatives, people involved, projects, renewable capacities, and finances. Note that among the projects included are those dedicated to the production and distribution of energy (e.g., the operation, installation, and/or financing of any kind of renewable energy generation facility, distribution of electricity or heat, energy trade, collective purchasing of energy and energy-related products), the provision of energy services (e.g., low carbon self-consumption, municipal lighting contractors, car sharing and operation of EV charging stations, bike sharing, retrofitting of buildings, and energy efficiency and energy saving measures), and information & awareness actions (e.g., energy-related education and campaigns, energy consulting services). While providing aggregates for renewable capacities, we do not separately report aggregate numbers

Country	Number of initiatives	Number of people involved	Renewable capacities installed	Number of projects	Total funds invested
Austria	389	21,750	352 MW	430	327.7 Million EUR
Belgium	112	162,905	156–566 MW	850	199.3–690.3 Million EUR
Bulgaria	14	93	N/A	14	N/A
Croatia	15	1300	10–60 MW	16	21.94–71.94 Million EUR
Czech Republic	38	266	31 MW	42	N/A
Cyprus	2	N/A	N/A	2	N/A
Denmark	665	306,650	2613 MW	600	411–2377 Million EUR
Estonia	132	5340	13 MW	142	9.5 Million EUR
Finland	94	105,700	87–172 MW	120	N/A
France	379	130,000	139–319 MW	2010	204–455 Million EUR
Germany	5015	391,500	2157–3279 MW	11,500	3152–4614 Million EUR
Greece	192	2120	0–86 MW	240	102.621 Million EUR
Hungary	8	65	0.03 MW	8	22,500 EUR
Ireland	565	25,000	9–14 MW	565	1.8–20.3 Million EUR
Italy	207	79,420	293–348 MW	558	110.8–184.8 Million EUR
Latvia	8	150	0.1–0.13 MW	9	0.825 Million EUR
Lithuania	21	650	0.3 MW	21	4.86 Million EUR
Luxembourg	68	1200	1–25 MW	86	4.028 Million EUR
Malta	2	366	1 MW	2	0.7 Million EUR
Netherlands	999	188,400	613–1027 MW	1446	733–1282 Million EUR
Norway	36	8170	2–14 MW	36	N/A
Poland	121	71,720	142–155 MW	136	2.5 Million EUR
Portugal	37	45,000	4.4 MW	69	17.93 Million EUR
Romania	5	750	5 MW	5	0.4–4.5 Million EUR
Slovakia	25	175	15 MW	56	26.374 Million EUR
Slovenia	11	77	0.3 MW	12	0.252–0.454 Million EUR
Spain	358	185,440	101–207 MW	370	65.8–113.8 Million EUR
Sweden	336	124,500	170–265 MW	375	229.5–369.3 Million EUR
Switzerland	297	84,470	50–94 MW	2580	344.4 Million EUR
United Kingdom	387	67,425	235 MW	533	260.5 Million EUR

Table 2. Selected country-level aggregates of citizen-led energy initiatives contributions in 30 European countries: number of initiatives, people involved, total number of energy projects, renewable capacities installed, and total funds invested. Most data collected are from 2000 to 2021.

for energy saved or other activities such as in mobility or information and awareness raising as this information is highly project-specific (and hence difficult to aggregate).

In general, more detailed information is available for larger initiatives, all of which we are likely to cover with a high level of detail. Over 70% of initiatives are officially registered and over 70% have a website. Information about members and production units is available for ~ 40% and ~ 50%, respectively. Countries with the best coverage include Belgium, Denmark, Germany, and the Netherlands, whereas less information is available from the Czech Republic, Finland, Croatia, and Switzerland. When data is lacking, low (high) estimates assume 0% (100%) ownership shares of production units to calculate renewable capacities (i.e., intended full load sustained output of a facility). The high estimates also include future planned projects at their currently projected costs. Investment data are based on reported investments and add estimated investments using technology cost and capacity values when possible. For details on aggregation methods in general and for individual countries, see Supplementary Note 1.

Relating these estimates to other figures gives a clearer picture of the relative impact of these initiatives. For example, compared to the population of Europe or individual countries, the numbers of people involved in these initiatives are marginal. We observe that citizen-owned renewable capacities generally represent a small percentage of total installed renewable capacities in a given country. In the higher range, we find Belgian citizen initiatives contribute about 5% of national renewable capacities, and Danish ones contribute as much as 2.3 GW

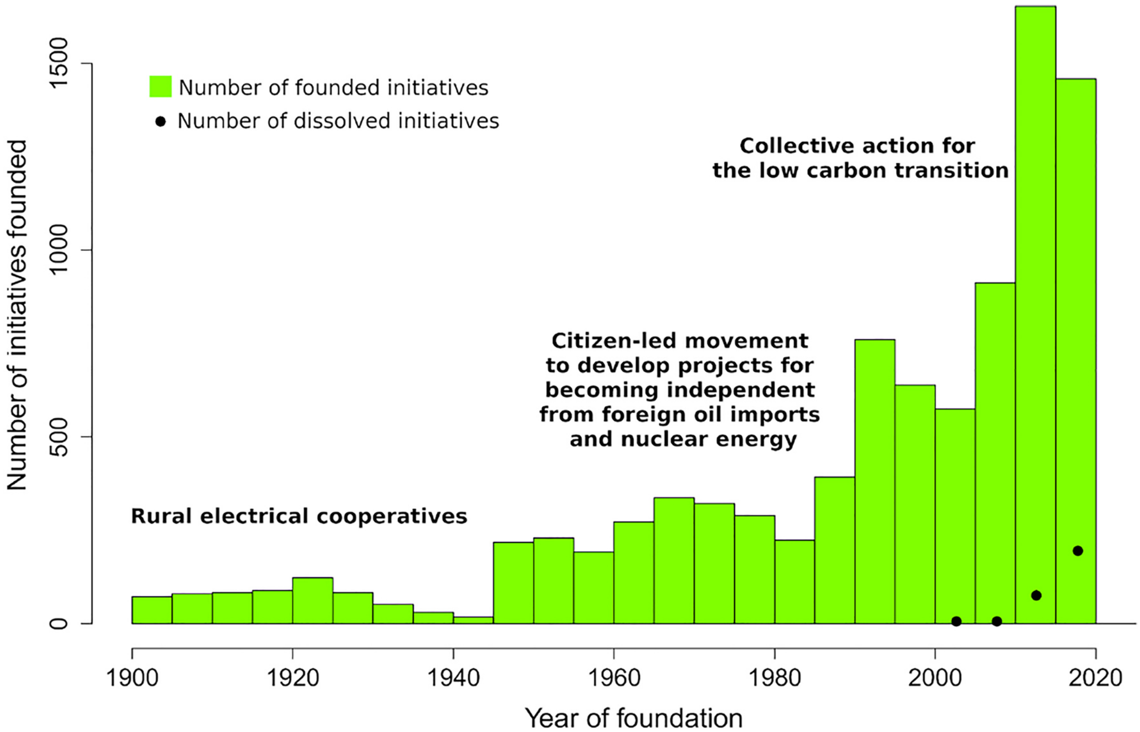

Figure 2. Development of initiatives 1900–2020 in Europe. Histogram with 5-year bins showing the number of newly founded and dissolved initiatives. Note that not all initiatives report the year of foundation/dissolution. Reasons for dissolution vary, including bankruptcy, merging with other organizations, or starting for-profit enterprises.

of installed district heating capacities, or roughly 75% of the country's total. Accounting for efficiency losses from the production to the consumption of electricity using a capacity factor of 27%, a rough calculation suggests that 8500–11,700 kWh are produced annually per person involved. This approximately covers the yearly electricity needs of a typical European household. That is, citizen-led energy projects have enabled renewable-based energy self-sufficiency for as many people as are engaged in the movement (households included). Note that initiatives also install renewable capacities in regions, and even countries, other than their own. Considering that the majority of investments was undertaken between 2009 and 2021, we can report that annual investments by citizen-led energy initiatives for the period ranged on average between 0.5 and 0.9 billion EUR, or about 1% of the total investments into renewable energy in Europe in that timeframe[3]. Most of these investments are in higher GDP countries, and we find an average per-member investment of 5700 EUR. Relating total investments to total initiative-installed renewable capacities, we find an investment cost of about 1.2 EUR/Watt which is within the usual order of magnitude of capital expenditure for renewable technologies. Note that due to uncertainty in ownership shares of production units, this cost figure is a lower estimate.

The evolution of European initiatives and topics of engagement. Figure 2 shows the number of newly founded, as well as dissolved, initiatives from 1900 to 2020. 89% of the initiatives in our inventory report the year of foundation, while dissolution years are seldom available, creating a bias. This suggests that the figure underestimates the number of initiatives that may have existed, and been dissolved, at some point in the past. However, we are confident in our coverage of the data available today. Figure 2 illustrates that many initiatives were founded during the past 30 years, particularly from 2010 to 2015, coinciding with the period when high feed-in tariffs were in place in many countries. These schemes were removed or lowered towards the end of this period. However, dynamics in each European country are different: while Danish initiatives strongly declined during the last decade, current trends for Croatia, Poland, Portugal, Slovenia, Italy, and Spain suggest sustained future growth. A thorough investigation of drivers and their relative importance for each country is an interesting subject for future research. It can be expected that the current ongoing implementation of EU Directives[18,19], as well as the greater urgency of ensuring energy security and efficiency, will likely trigger the foundation of new initiatives.

The number of people involved is perhaps the most important metric when holistically considering the impact of citizen-led energy initiatives. It is not clear to which other statistics we should compare the involvement of the approximately 2 million people we observe (e.g., volunteer participation rates or measures of the maturity of civil society). According to a 2017 systematic literature review by Berka and Creamer, there is evidence and theoretical justification for members gaining new knowledge in the technical, environmental, and economic aspects of renewable energy, acquiring experience in organizing and campaigning, and becoming better informed energy consumers (and prosumers), potentially changing their behavior[20]. And yet, the figures reported here certainly underestimate the degree to which these initiatives impact general public knowledge, opinions, and actions;

for every person who joins as a member, many times more will have been informed, solicited, and offered the opportunity to question their behaviors and place within the energy system. This informational halo effect, not quantified here or in the literature, could enter into considerations of the aggregate impacts of these initiatives.

Most of the 16,069 production units in the inventory are solar PV systems (82%), followed by onshore wind parks (9%), biomass-based electricity and heat production (7%), and hydropower (2%). Rarer energy production technologies include solar thermal, concentrated solar power, geothermal, and hydrogen production. While these findings reflect the fact that the former technologies are established and their kW-costs have steeply declined over the past two decades, the main driver of their adoption is that they are suitable technologies to be deployed by citizens who are volunteering part-time and may not have a background in energy. These are granular technologies, making them "more likely to scale through replication"[21] since they are small, variable in size, modularizable, and have low risks and investment costs per unit[21]. Moreover, once installed, they are easy to operate and maintain, supporting their uptake by citizens.

Solar projects in our dataset have an average unit size of 177 kW (covering ~ 1100 m^2). Note, however, that the median is only 29 kW (~ 200 m^2), as the majority of units are small. Moreover, as we found and as is supported by the literature[20], many initiatives use accumulated knowledge to sustain their activities in the energy transition, engaging in more than one project. At the same time, 68% of initiatives choose to realize just one project (representing 25% of all projects), considering their collective engagement fulfilled at project completion. Regarding wind projects, the average size is 4600 kW, with a median of 2000 kW. While Danish cooperatives were pioneers of wind parks, they have become increasingly alluring for investments by collective actions in other countries during the past decade. For example, once all current planned wind projects in the Netherlands are completed, total capacities installed by initiatives since 2000 will more than double.

Along with renewable-based electricity and heat generation, citizens also collectively engage in distribution and trade. Initiatives generating heat typically own the distribution infrastructure, while this is rare in the case of electricity production. This is partly because electricity distribution and trade comes with registration and compliance obligations regarding national grid codes, and still exists as an effective state-granted monopoly in some countries. Nevertheless, noteworthy ownership of grid infrastructure exists in Spain (16 initiatives) and in the Italian Alpine region (8 initiatives). More recently, initiatives have also invested into broadband and low-carbon mobility. For example, the number of EV charging stations installed and managed by citizen-led initiatives in Germany has been growing for the past 5 years (from 28 to 209), also in part because it provides them with an opportunity to utilize generated electricity when it is not possible to feed it into the grid.

Discussion

The uncertainty range for our estimate of the total financial investments by citizens into collective energy projects is considerable, due to the lack of harmonized statistics and reporting obligations. For example, it is not always clear whether figures include value-added tax, creating an uncertainty range of up to 20%. It should be noted that the range for our estimate remains conservative for several reasons. First, we only include investments if evidence shows that they are energy-specific, i.e. we exclude investments into agricultural production or forestry. We also do not account for unspecified investment figures if an initiative's primary purpose is not energy focused, and we only include investments by defunct initiatives if they can be linked to a renewable production unit or other low carbon energy project. Consequently, we rely on available information of related production units. This is why we do not include grid infrastructure investments by Spanish initiatives, for example. Second, we attempt to estimate investment costs based on renewable capacities installed where possible to counterbalance the lack of investment data. This works relatively well for photovoltaic systems and wind farms, but less so for generation technologies that come with high site-specific cost. For example, in Finland where activities mainly focus on heat generation, we have a fairly small sample and lack detailed information about parameters of single production units. Thus, reliable estimates cannot be inferred, and we do not report any investment contribution from Finnish initiatives. Finally, we do not count in-kind contributions by the members. To give an idea of the orders of magnitude involved, if every member invested one hour per month, assuming minimum wages between 2 and 14 EUR/h across Europe, yearly in-kind contributions would reach roughly 227 million EUR (adding 4% to our investment estimate).

In view of the energy transition challenges ahead and recent turmoil in energy and resource markets, citizens and governments in many countries are in search of new ways to increase energy security, develop sustainable energy, and mitigate energy poverty. Our aggregate estimates do not raise expectations that collective action could replace commercial enterprises and governmental action in the short or medium term without profound changes to policy and market structures. However, we find strong evidence for the emerging and current importance of citizen-led collective action for increased energy self-sufficiency, local sustainable development, greater citizen engagement, diversification of fields of activities, social innovation, and acceptance of transition measures. Collective action in the energy transition is experimenting successfully with new business models in the energy sector[22–24]. Notably, financial data collected in the inventory allow for a more detailed analysis for some countries, although reporting obligations and practices differ. Those citizen initiatives that publish financial reports, tend to do so in more detail than incumbent enterprises, hence contributing to higher transparency. Our inventory data allow us to analyze financial performance and investment decisions by these initiatives compared to the overall performance of established enterprises. For example, Wierling et al.[24] identify 9 successful business models for German initiatives active in the PV sector. Nevertheless, a comprehensive analysis across countries, new market actors, and fields of activities remains for future research. Thus, the dataset provides a unique and novel opportunity to study such questions.

Citizen initiatives are expanding their activities, as also evidenced in our inventory. Emerging fields for citizen action include community storage, e-mobility, virtual power plants[25], community-hosted and community-developed open software platforms and one-stop shops (e.g., on demand-response or energy efficiency, see also[26,27]). While these activities are still relatively niche, we can report, for example, 182 initiatives active in energy storage in Europe.

Continued decentralization of energy systems and more stringent decarbonization policies will increase the importance of these actors in the future. Citizen-led energy action has already played, and will continue to play, an important role. This deserves systematic statistical accounting in addition to single case studies which currently dominate the literature (c.f. case studies for Spain:[28], Austria:[29], Ireland:[30], UK:[31], Sweden:[32], Italy:[33], Netherlands:[34], France:[35], Germany:[36], and a rare study covering 16 countries[37]) and are alone insufficient to grasp the scope, extent, and future potential of citizen-led energy action[13,38]. As their total contributions to the low carbon transition have not been consistently and comprehensively estimated before, this study provides the first systematic aggregates at national and European scales, with such detail as is currently available. However, it should be recognized that substantially more work, automated data-mining, and standardized approaches will be needed to develop solid, intercomparable statistics.

Methods

Citizen-led energy initiatives are organizations, formal or informal groups, or projects housed within some larger entity that fulfill (to greater or lesser degrees) each of the following criteria: (1) citizen leadership, (2) non-economic benefits, and (3) active in energy services provision. Citizen leadership means that the initiatives are led by physical persons or by organizations who are themselves citizen-led and are independent in operations and governance from for-profit private businesses or governments. Implicit in this criteria is adherence to the One-Member-One-Vote principle, although we find variations. The second criteria requires that the initiatives either do not pursue profit for their members, or, if profit is pursued, it is a means to another end, i.e. the stated goal is to redistribute social, ecological, and/or economic benefits to their community or wider society. The third criteria defines the scope of contributions to the energy transition that we estimate. Of interest are initiatives that engage in the production and distribution of renewable energy, invest in energy efficiency projects, and campaign or consult on all such activities, including education and awareness raising to foster behavior change towards a sustainable, low carbon energy transition. Organizations that meet all three criteria are the focus of the data presented here.

Notably, our dataset also includes some initiatives that meet the first two criteria, but are not primarily active in the energy sector, such as in the case of large-scale photovoltaic rooftops on agricultural cooperative buildings. Other initiatives that only partially meet one or more criteria have been included, in particular in countries where citizen-led energy ecosystems are emerging. The inclusion of these initiatives is intended to provide users of this dataset with a complete and inclusive perspective at a moment when each country is formalizing directives from the European Union that aim to increase the participation of citizens by providing them legal grounds to get involved[11,39]. While important for the coverage of this study, and significant on a country level, the inclusion of these border cases does not significantly alter the aggregate picture of the contribution of citizens in Europe to the energy transition.

The definition of "energy community" for most countries adheres closely to the existing cooperative legal structure, while countries such as Poland and Greece have taken markedly different approaches. In France, various types of organizations can be recognized as energy communities as it is not necessarily a distinct legal form. This results in a patchwork of definitions with some overlap across borders and forms. Additionally, while some basic administrative information (identification numbers, economic activity codes, addresses) can generally be found in a centralized national business register, the depth, breadth, and degree of accessibility of this data also differs from country to country. Only some countries maintain detailed, open, and up-to-date records of organizations' finances and activities based on legally required annual reporting. For others, we have had to rely on voluntarily shared data collected and centralized by umbrella organizations or on information taken from the websites and online publications of the initiatives themselves.

The large degree of variation in the quality and sources of data gathered resulted in an extensive, four-year long collection of data from thousands of sources through manual information gathering and compilation. Before the data collection step, meta-studies of the energy systems and policy contexts for each country were undertaken to identify pertinent legal forms, literature, and data sources. To increase comparability across countries, we have developed an ontology and set up internal accounting standards. To foster the reuse of data, the inventory adheres to the FAIR data principles[40] which meant defining standards (e.g., for energy communities and their activities) where they do not exist. Data quality has been ensured by rigorous validation procedures, including the four-eyes principle, automated compliance checks, verification of data ranges, and, where possible, cross-checking of data with experts and against other publications and aggregated information sources. All data are published open-access with extensive documentation[41–43]. Details on aggregation methods and data collection for each country are described in the notes to the Supplementary Material (Supplementary Note 1, Supplementary Data 2 & 3).

Data availability

All data are available in the main text or the supplementary materials. The ENBP inventory "Energy by the People" is licensed under CC-BY 4.0 and available open access at dataverse.no, Link: https://doi.org/10.18710/2CPQHQ.

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PAPER III: STATISTICAL EVIDENCE ON THE ROLE OF ENERGY COOPERATIVES FOR THE ENERGY TRANSITION IN EUROPEAN COUNTRIES.

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Article

Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries

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Abstract: The share of renewable energy is increasing throughout Europe. Yet, little is known about how much can be attributed to different actors, other than those commercially active. This paper provides empirical evidence of activities by energy cooperatives in the field of renewable energy in four different European countries. It draws from a database consisting of 2671 entries, contrasting results from current literature. We find that energy cooperatives are important enablers of the energy transition. However, their role is shrinking in recent years due to a tightening or removal of supportive schemes. We conclude that it is necessary to develop a systematic accounting system to properly track and make visible the contributions by different actors. In turn, this will help to better model the likely speed of Europe's energy transition.

Keywords: energy cooperatives; cooperatives; community energy; energy transition; transition; social innovation; local actors; renewable energy; renewable; sustainability

1. Introduction

The transition to low carbon energy systems is on its way in Europe: Most countries are on track to achieving their specific 2020 targets and the share of renewable energy in final energy consumption at the European level has crossed 16% in 2014 [1]. However, there is a debate about how fast this process is going and to what extent it can be further accelerated [2–6]. There are two broad lines of approaching this issue, mainly under the labels of "techno-economic analysis" and the "socio-institutional analysis" [5]. The former, with its emphasis on the difficulty of changing existing energy infrastructures and connected established markets, generally points to longer transition times. Whereas the latter tends to be more optimistic, highlighting opportunities for a broad range of societal actors to be innovative curbing the energy transition beyond historically observed rates of transition. Techno-economic analysis is better quantifiable with the help of energy system models, while socio-institutional analysis poses difficulties for estimating at the aggregated level. The reason for this is due to the case studies that dominate in this field of research and implications aiming at the aggregate level stay qualitative.

This is the starting point for our quantitative investigation in which we focus on the role of the actor "energy cooperatives" in Europe to support the energy transition. Energy cooperatives are innovative social structures that find collective solutions to problems occurring during transition processes or provide testbeds for adapting low carbon energy technologies to local conditions and needs [7–10]. Various forms of energy cooperatives exist and the energy services they provide are broad, ranging from electricity provision to district heating, IT solutions and energy efficiency consulting. Their organizational structures differ across Europe due to country-specific regulatory frameworks and local needs. However, there are common denominators which clearly distinguish them from established commercial actors in energy markets, such as energy utilities. Common characteristics include the involvement of the wider public (enabling the direct participation and ownership of members), the pursuit of non-commercial benefits (such as the fostering of community spirit) and the motivation to accelerate the transition to sustainable energy systems (e.g., phasing out nuclear power, regaining local ownership and control of energy provision). The role of energy cooperatives in contributing and steering the energy transition is thereby important beyond the expansion of installed capacities, in particular through building acceptance for the necessary changes and through the finding and implementation of creative solutions that benefit the development of local communities. However, the contribution of energy cooperatives to the European energy transition has not yet been estimated at the aggregate level. This paper is the first attempt towards such an estimate. We focus on empirical evidence in selected European countries guided by two main questions:

1. Is there statistical evidence that energy cooperatives are important actors in the energy transition in Europe?
2. What are common reasons that support or hinder activities of energy cooperatives?

This paper aims to answer the above questions using statistical analysis and drawing from evidence provided in various literature. Doing this, we aim to fuel the discussion about developing a systematic accounting for actors of the energy transition beyond those commercially active (see for example [11] on differences between these two general types of actors). Our database of energy cooperatives comprises entries from Austria, Germany, Denmark, and the United Kingdom, totalling 2671 entries. We combine the statistical analysis with the review of case studies. It allows us to draw conclusions at the European and individual country levels on how to support energy cooperatives. To the best of our knowledge, we offer the most comprehensive statistical analysis on energy cooperatives in different European countries to date.

The paper is organized as follows. The next section reviews available literature on cross-country studies of energy cooperatives. Section 3 describes the methodology for building the statistical database. Section 4 presents results for cross-country statistics followed by the presentation of results from the analysis of individual countries. The results will be contrasted with other evidence found in the literature. Section 5 combines all results together to draw conclusions.

2. Literature Review

Community activities in energy production and their relevance for the sustainable energy transition have attracted increasing attention in research during the last two decades with a vast body of literature available. However, most of it focuses on single countries or case studies. In this study we specifically focus on organizational structures that can be labeled as "energy cooperatives" (refer to country-specific definitions in the Methods section). Recommended entry points to the literature are [10,12–14]. Recent country-specific entry points to the literature are: Germany [10,14], Denmark [15,16], Belgium [17], Sweden [18,19], UK [20], Finland [21], Spain [22], Italy [23], Austria [24,25], France [26], Netherlands [27].

Only 11 publications go beyond the study of single countries [7,11–13,18,19,26,28–31]. Denmark and Germany are the countries most often cited in these comparisons, coinciding with the fact that Denmark has been a pioneer country in the development of energy cooperatives since the

1970s, while Germany saw a boom in the foundation of energy cooperatives in the aftermath of the Fukushima disaster in 2011. Great Britain and the Netherlands are also focal countries. While energy cooperatives differ in size, strategies and success, the cross-country comparisons clearly document that there are common features among energy cooperatives in Europe. All publications stress the important role of community activities in the transition towards sustainable energy systems. An early example from the literature is [11] who looks at energy cooperatives in Denmark, Canada, the United Kingdom, and Germany. The author emphasizes the collective actions contributing to lowering the costs of renewable energy and to act as multipliers of renewable energy solutions. [12] identifies in addition the benefit of local community development in a study for Germany, United Kingdom and the USA.

However, energy cooperatives continue to rely on governmental support to play a role in liberal markets and against incumbents [7,12,19,29]. Many studies also agree in the identification of common barriers. This includes the lack of knowledge and financial infrastructures as well as a hostile institutional context [26]. Notably, a variety of solutions were found to overcome these barriers and that helped to feed a pool of best practices relevant across countries. However, community initiatives are less likely to be successful if their rationale for action is at odds with the government [29]. A qualitative study [7] on energy cooperatives confirmed the relevance of support instruments for renewables, planning policies, attitudes towards the cooperative model as well as local energy activism on the success and failure of energy cooperatives in Denmark, Germany, Belgium and the United Kingdom. The authors of that study emphasize that energy cooperatives are recently experiencing increased pressure due to changing policies and higher competition in local energy markets. In addition to adapting their activities, energy cooperatives are beginning to react to these challenges by establishing cooperation among single entities (see also [13] on "communities of interest". The authors study community activities in the United Kingdom, Italy, Spain, and Germany.). In addition to the fact that such new networking activities are a response to challenges, it underlines the transformative potential that energy cooperatives possess beyond the local level. [28,31] focus on the role of financial incentives and associated risks. The common finding is that regulatory uncertainty and decreasing financial support strongly undermines the foundation of new and the continued success of existing energy cooperatives.

Finally, an interesting common aspect is put forward in [30]. The authors analyze the influence of historical conditions on the founding of energy cooperatives in Canada and New Zealand. One key element is that many actors seem to belong to groups outside of the main stream (e.g., ethnic minorities). Often the founding of cooperatives by these groups coincides with a lack of awareness by the political establishment in these countries. Similar parallels can be drawn to European countries in that pioneers of energy cooperatives are also often built by societal groups that aim to demonstrate alternatives to established socio-political structures (e.g., anti-nuclear movement in Germany).

3. Methods

Our statistical analysis focuses on Germany, Denmark, the United Kingdom and Austria. Besides Austria, all countries are focal countries in the qualitative studies described in Section 2. These countries also have the largest numbers of energy cooperatives in Europe [7], justifying a statistical analysis of these actors. Moreover, these countries provide access to standardized sources of data about energy cooperatives. Good data coverage is also the rationale to include Austria. For each country, we selected those specific legal forms, which come closest to the concept of an energy cooperative (see specific definitions below). It is important to stress that we are far from providing a comprehensive accounting for energy cooperatives in the European union. However, capturing focal countries and well-known regulatory frameworks in each of them, we are able to provide a profound lower estimate for the aggregate contribution of energy cooperatives in Europe.

We generated a multi-country database of energy cooperatives which contains 282 entries for Austria, 1109 entries for Denmark, 965 entries for Germany, and 315 entries for the United Kingdom. The database has been constructed from accessing national official registries of energy cooperatives that typically detail the date of foundation (and cancellation), their addresses and sources for further information. We searched for registered cooperatives active in the field of renewable energy to build an initial list [32–38]. We extended entries for further information on member statistics, finances, and the evolution of cooperatives.

Table 1 provides methodological details for each of the countries and sources of information. In addition to the main registries shown, we also collected information on single cooperatives from self-profiling websites, discussion forums, newspaper articles etc. In cases of deleted energy cooperatives, we further accessed archived webpages available from archive.org. Since the availability of open data on cooperatives varies from country to country due to legislative differences and the amount of voluntary information provided by cooperatives, it was not possible to obtain the same level of detail for all countries and all entries. However, we have a complete set of data for all countries for the date of foundation, cancellation and location of each cooperative. Furthermore, for each country, the basic data set could be extended further, which led to our choice of analysis foci for each country. Firstly, for Denmark we were able to collect detailed data on membership (including type and residence of members), secondly, for Germany the field of activities, evolution of membership and financial shares and, thirdly, for United Kingdom the evolution of financial resources. For the sake of a concise paper, we only briefly cover Austria.

In order to ensure high quality data, we have verified the statistical information on single cooperatives with different sources of information wherever possible. For example, regarding cooperatives from the United Kingdom the list of societies has been compared with a recent review by coops.uk [39]. For the final creation of database entries, we further applied the four-eyes principle checking for typos, duplicate data and completeness of entries.

Table 1. Energy cooperatives included in the database: Overview on methods of search, sources and information collected.

Definition of Cooperative	Main Sources of Information	Search Terms	Information Collected
		Austria (282)—Focus on Case Studies (Default)	
eingetragene Genossenschaft	Compass Verlag Gmbh (firmeninfo.at), Firmen ABC Marketing GmbH (firmenabc.at), HEROLD Business Data GmbH (herold.at)	Wärmeversorgung, Elektrizität, Kraftwerk, Solar, Sonne, PV, Photovoltaik, Energie, Windkraft, Wasserkraft	addresses, dates of incorporation/cancellation, type of activities
		Denmark (1109)—Default Focus, Statistical Focus on Membership	
Interessentskap	Central Business Register (datacvr.virk.dk), Danish Energy Agency (ens.dk)	vindmøllelaug, møllelaug	addresses, dates of foundation/cancellation, type of activity, geographic information on members (incl. type and residence of member), local production capacities from wind
		Germany (965) —Default Focus, Statistical Focus on Activities and Membership Dynamics	
Genossenschaft	Trade Registry (handelsregister.de), Business Registry (unternehmensregister.de)	Energie, Bürgerenergie, Energiegenossenschaft, Wasserkraft, Windkraft, Elektrizitätsversorgung, Energieversorgung, Strom, Solarstrom, Sonnenstrom, Kraftwerk, Windenergie, Windpark, Solarpark, PV, Photovoltaik, Wasserkraft	addresses, dates of foundation/cancellation, evolution of shares and membership, type of activities, production capacities (partly)
		United Kingdom (315)—Default Focus, Statistical Focus on Finances	
BenCom (registered under the Co-operative and Community Benefit Societies Act 2014)	Financial Conduct Authority (fca.org.uk), Companies House (beta.companieshouse.gov.uk)	energy, solar, wind, wood, heat and hydro	date of foundation (cancellation), address, number of members and amounts raised (incomplete), production capacities (incomplete)

4. Results and Discussion

4.1. Cross-Country Results

Building on the compiled database as described in the previous section, Figure 1 shows the development of the number of active energy cooperatives in the last four decades for Austria (AUT), Germany (DEU), Denmark (DNK) and Great Britain (GBR). Although our data for Denmark only includes wind energy related cooperatives, the country has very clearly been the pioneer in establishing energy cooperatives in early years and also in absolute numbers. This is remarkable in view of population numbers: AUT—8.4 million, DEU—81.8 million, DNK—5.5 million, and GBR—62.0 million (all are given for 2010).

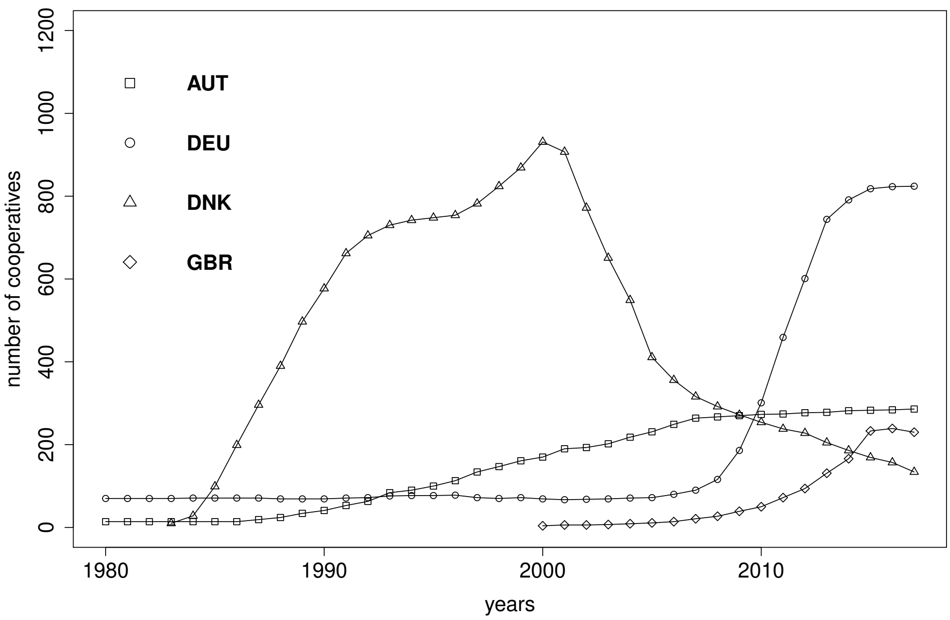

Figure 1. Number of energy cooperatives in Austria (AUT), Germany (DEU), Denmark (DNK) and Great Britain (GBR) for a given year. Source: database compiled by authors, for original sources see Table 1 and methods section.

However, a stark decline in the number of Danish energy cooperatives can be observed from around 2000 onward. As of June 2018, Germany has the largest number of active energy cooperatives with 824, reaching numbers close to Denmark's former peak in 1999 which was at 931. While the increase in Germany has only taken speed over the past decade, the number of active energy cooperatives is on a slow increase in Austria since the late 1980's and Great Britain since the late 2010. The latest numbers for both are 286 and 230, respectively.

Figure 1 can be compared with a snapshot for 2014 derived from a database owned by the European Federation of Renewable Energy Cooperatives (REScoop.eu), refer to [7]. The network is a sector association of Cooperatives Europe and has currently about 1500 members from the European Union. The 2014 snapshot of the number of cooperatives active in REScoop counts for around 800 energy cooperatives in Germany (in this paper: 791), 650 in Denmark (here: 186), just below 400 in Austria (here: 282), slightly above 100 in Netherlands and Sweden, about 80–90 in Finland and Italy, less than 70 in France and Great Britain (here GBR: 166), between 10–20 in Spain and Belgium, and not more than 5 in Ireland, Portugal, Croatia, Greece and Luxembourg. Germany, Denmark, Austria and Great Britain alone account for about 80% of the total energy cooperatives in the entire European Union. Differences between the numbers from REScoop and our compilation stem from our focus on specific cooperatives (see definitions in the previous section). For example, we only account for wind energy related cooperatives for Denmark, disregarding cooperatives active in district heating or solar. However, in the case of Germany, we came close to the number of REScoop entries. Also tracking cooperatives that have been terminated, we know that those terminated are exceptionally high in Denmark, while rates are more modest in Germany. This may suggest that REScoop did not remove terminated energy cooperatives from its compilation. Furthermore, since the REScoop database is not publicly available, differences can not be fully clarified. On the other hand, considering the development shown in Figure 1, the focus on just four countries for the analysis in this paper is a good representative share of energy cooperatives active in Europe.

Figure 2 presents the share of renewables in total final energy consumption for the four different countries between 1990–2015. Clearly, the shares have been steadily increasing from very low numbers in the 1990's (below 10%) for all countries except for Austria (25%), where hydro power traditionally plays an important role. The fastest increase can be reported for Denmark, echoing the early activities of energy cooperatives in the small country. The lowest share number of energy cooperatives was reported in the United Kingdom, with initiatives under 10% in 2015. Again, this mimics the low numbers in energy cooperatives. The following is an in-depth discussion to better understand energy cooperative developments in several individual European countries.

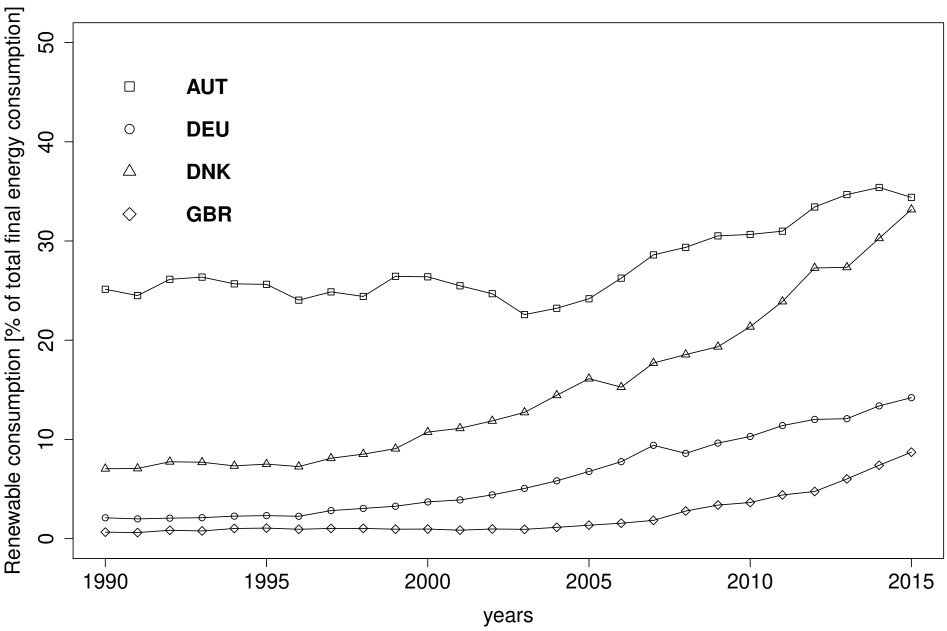

Figure 2. Renewable energy consumption as percentage of total final energy consumption in Austria (AUT), Germany (DEU), Denmark (DNK) and Great Britain (GBR) for a given year. Source: The WorldBank DataBank 2018.

4.2. Denmark

Prior to the 1970s oil crisis, Denmark was reliant on imported petroleum for nearly 80% of its energy needs. After the embargo, Denmark began to shift away from fossil fuels in order to promote energy security [40]. Collective anti-nuclear networks formed the basis for cooperatives [15]. Geographically, Denmark has abundant wind resources, and wind cooperatives were successful in bringing the costs of turbines down and generating public acceptance of renewable energy. By 2017, 49% of the electricity produced in Denmark originated from wind-based energy; 6214 turbines were in operation as of April 2018 (see also Figure 3 for the development of installed capacities based on data from the Danish Energy Agency [41]). In 2002, energy cooperatives owned about 40% of the then installed turbines, revealing that energy cooperative initiatives were important for the Danish energy transition [42]. Moreover, 150,000 households participated in wind power cooperatives underlining the great support from the broader society (ibid.).

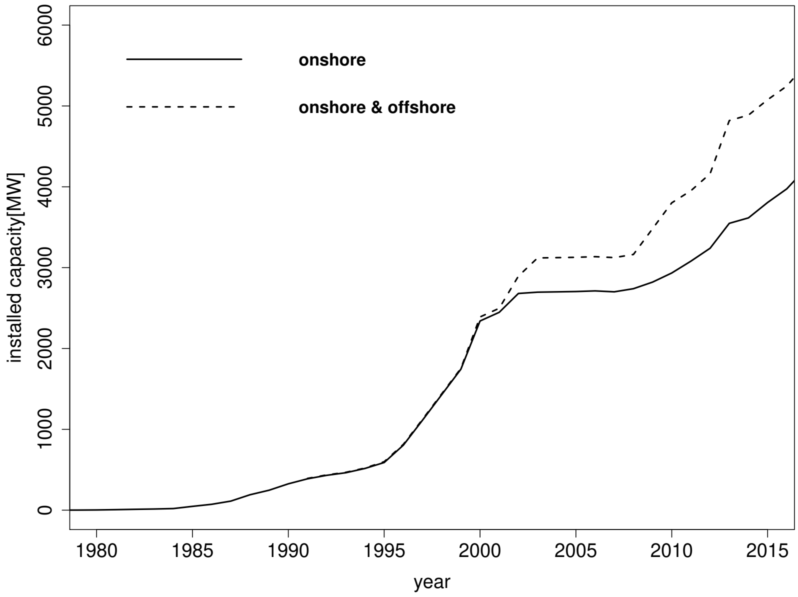

Figure 3. Installed capacity of onshore and offshore wind farms in Denmark. Source of data: [41].

By the 1990s, there was a diminishing role for the collective ownership model, shifting toward more private ownership, typically by farmers [43]. This was supported by a 1992 feed-in tariff program for wind, and guaranteed interconnection and power purchase at a "fair price" at 85% of retail rates [44]. Additionally, wind projects were eligible for a refund from the Danish carbon tax and a refund on the energy tax, essentially doubling the payment for wind power [45]. In 1999, the Danish parliament ratified the Energy Supply Act, which among other measures, gave customers the freedom to choose their electricity provider and promoted a quota system for renewable energy through certificates. This required consumers to purchase a certain share of renewable energy in order to further establish the market [46].

However, in 2002, the newly elected centre-right Danish parliament announced the end of feed-in tariffs for wind energy. They argued that wind was mature enough as a technology to not warrant further government support and pushed for market liberalization as an attempt to increase competition and lower consumers' electricity costs. The tariff was phased out in 2004, resulting in a substantial decrease in wind energy cooperatives. This suggests that the technology had reached a level of maturity that economies of scale were achieved. This made it economical for larger companies, such as energy service providers, to enter the market. However, this was not the case for existing cooperatives, which owned a smaller number of turbines. These developments coincided with technological improvements and legislative changes that favored larger wind park installations. The size of turbines grew from 55 kW to 3.3 MW and beyond, and their height doubled. Furthermore, the typical investment size changed from 0.5–0.8 million euro to about 15–22 million euro [47]. These developments marked the start for the sharp turn in support for wind cooperatives in Denmark. This is clearly mirrored in the data.

Our database contains 1109 registered wind energy cooperatives in Denmark (i.e., all windpower-related 'interessentskap' registered under the Danish law). In addition to the development of the number of cooperatives in the last four decades already shown in Figure 1, Figure 4 adds information contrasting the date of foundation with the dates of termination for Danish wind cooperatives. From both figures, it is evident that two waves of foundation can be observed: The first appearing between 1985–1992 and the second between 1998–2002. Afterwards, the majority of energy cooperatives were terminated at an exponential rate. The developments correlate strongly with political decisions made since 2002 which were likely anticipated before enacted. Furthermore, 2003 marked the beginning of the era of commercial offshore wind park investments (refer to Figure 3). Cooperatives that were driving onshore wind developments, were not able to enter the offshore wind markets at the same time.

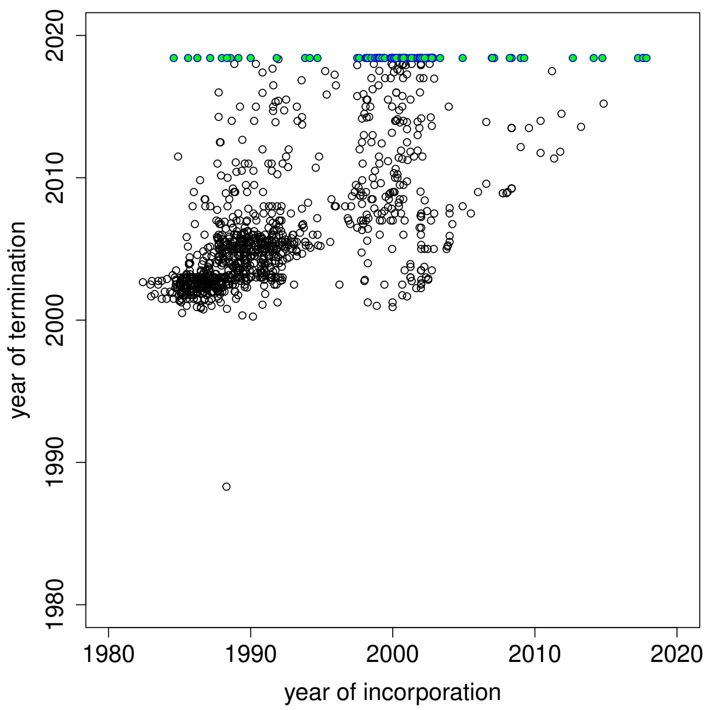

Figure 4. Timing of wind cooperatives in Denmark shown by contrasting the date of foundation with termination dates. Wind energy cooperatives which are still in operation are marked blue, the date of termination is set equal to June 2018. Source of data: own database building on [37].

Today, only 12% out of the 1109 cooperatives still exist and data indicates a continuation of this trend. Our data are in line with the observation by the Danish Wind Turbine Owners Association, reporting that in 2010 only 15% of all turbines in Denmark were still owned by cooperatives [48]. While many turbines had reached their end of life, others were also sold to utilities [15]. These firms are also investing in land, often discreetly, and have the advantage of large legal teams to secure their interests [49]. Technologically, it is hard to argue against: large-scale developers are efficient businesses that do a lot investment in land with high wind potential, and the cooperatives have a difficult time competing with these. Obviously cooperatives—the early pioneers of wind development in Denmark—had lost ground. The Danish parliament took note of this development and tried to stimulate local ownership. In 2009, the Danish Renewable Energy Act (DEA) introduced the Option to Purchase wind farm Shares Scheme (OPSS) which stipulated that 20% of the shares of a new wind project must be available for sale to residents within a 4.5 km radius of a new wind project (Promotion of New Energy Act, 2009). While a survey-based study has suggested that this has had a positive impact on co-ownership, it has not solved everything in terms of acceptance since it is only aimed at people with sufficient liquidity of funds [50]. Likewise, support for the scheme is largely dependent on demographic variables (ibid). We do not find any response from the OPSS in the data.

We can shed new light into what happened by analyzing the development of membership numbers (i.e., the number of fully liable participants) and the distribution of addresses. Figure 5 shows the percentage of cooperatives sorted into 5 different size classes, with the smallest having only up to 5 members and the largest more than 200. Data for the whole sample of cooperatives are shown as well as the sub-sample of those still existing. In both, small cooperatives dominate. However it is especially the medium-sized cooperatives that disappear. Figure 6 investigates this further by analyzing the percentage of existing cooperatives in different size classes. The majority of the largest cooperatives survived, since only 4 out of 9 have been closed down. However, the smallest size class with up to 5 members and the second-largest size class with 51–200 members lost as much as 85%, even surpassed by the medium size classes with 5–50 members, loosing more than 92% of the cooperatives. This suggests that smaller- and medium-sized energy cooperatives were unable to survive the trends towards larger projects and higher market competition (coinciding with less governmental support) by discontinuing their engagement in the wind energy market.

Figure 7 shows the geographic distribution of energy cooperatives founded in a particular municipality since 1980. Associated shares of the full sample are indicated by different colors. Thisted, a municipality located at the Western coast of Jutland, is the most active municipality in hosting wind cooperatives, with 8% of the country's share. Overall, most cooperatives were founded in the northwest, while the distribution is rather equal in the rest of the country. The picture is very different today, as can be inferred from Figure 7. The blue diamonds mark the existing wind cooperatives across the 98 Danish municipalities as of June 2018. Those still existing cluster around the northwest, the island Funen and along the border with Germany. Most of the former cooperatives from Falster, Lolland and Zealand disappeared.

The findings from Figure 7 are connected with the decisions on where to place wind turbines. In the 1980s and early 1990s, turbines were placed throughout the landscape and not necessarily in the areas with greatest wind potential. This resulted in a situation where the turbines had a large visual impact on the landscape, with many smaller turbines in sub-optimal locations from the perspective of the national wind potential [51]. To counteract this development, wind planning zones where established in 1995 [51–53]. Also, in 2001 the scrapping schemes were designed to rectify the situation, and municipalities were tasked with planning the siting of wind turbines. They took advantage of the areas with the greatest resource potential while at same time taking into account residential, environmental, cultural, and landscape considerations [51]. Concurrently, Denmark reduced the number of turbines in two waves. During the period from 2001–2004 the numbers went down by 1208, while at the same time, increasing wind power capacity by 202 MW [52]. In the period from 2004–2011, subsidy schemes were installed to incentivize owners of turbines to replace smaller ones (25 kW for domestic turbines, 450 kW for grid connected turbines), for up to 175 MW pooled capacity [54]. Eventually, municipalities tended to favor fewer and larger turbines. Consequently, wind cooperatives disappeared in areas with low wind yields concentrating in others, which is in agreement with data shown in Figure 7. Notably, Thisted is located in the region with the highest wind yields in Denmark.

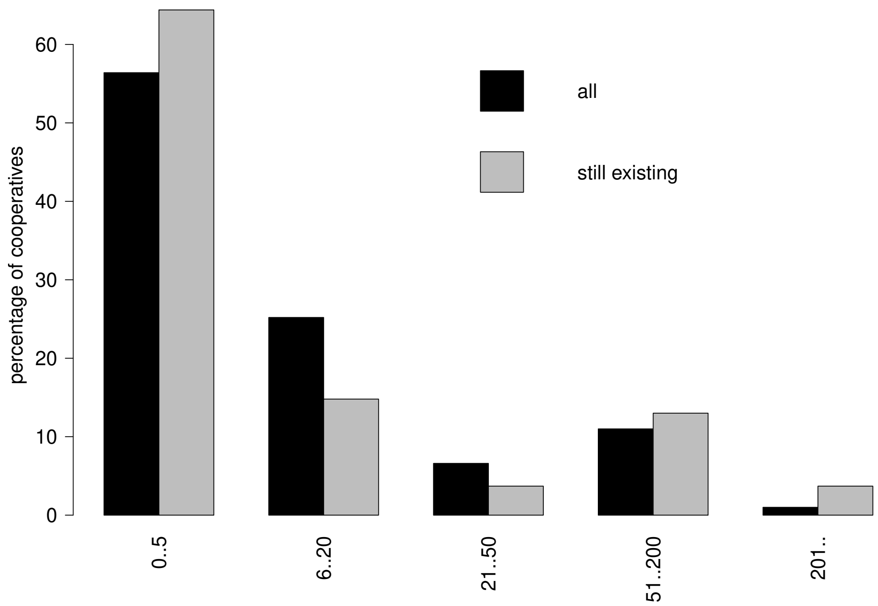

Figure 5. Membership size of wind energy cooperatives in Denmark in five different size classes. Source of data: own database building on [37].

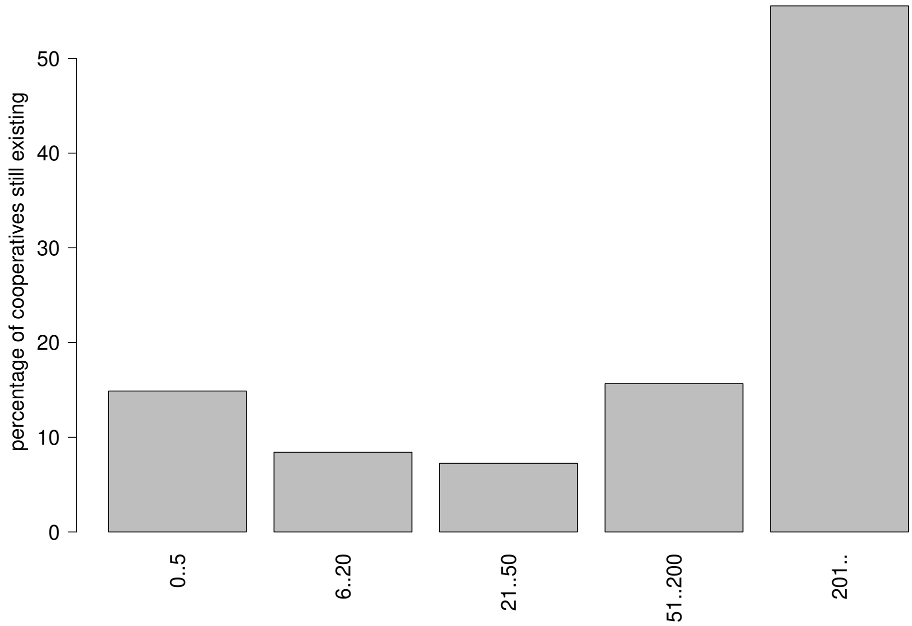

Figure 6. Percentage of cooperatives still in operation in five different size classes. Source of data: own database building on [37].

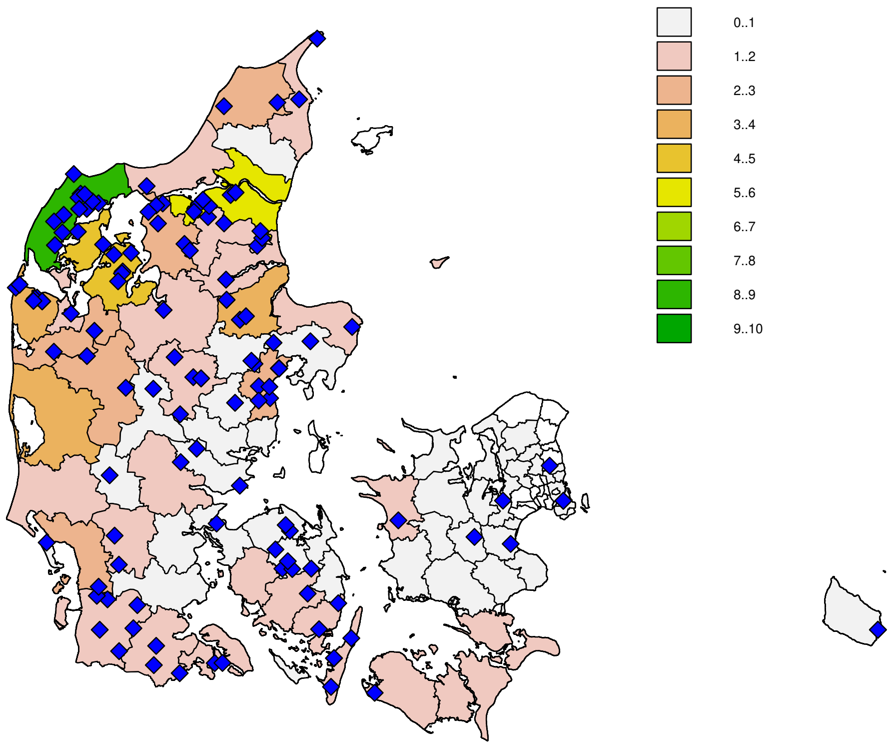

Figure 7. Geographical distribution of existing wind cooperatives (blue diamonds) across the 98 Danish municipalities since 1980. The color coding marks the percentage of energy cooperatives in the full sample (incl. terminated ones) that are associated with a specific municipality. Source of data: own database building on [37].

The role of the early pioneers of the Danish energy transition is likely to become further marginal. Beginning in 2019, onshore will be ruled by tendering processes for all sizes of wind farms, which means that cooperatives will be placed at an even greater disadvantage against large-scale developers. Developers are buying houses to clear out more available land, expecting a return on investment, so they are expected to be quite competitive in the tendering process. In interviews, cooperative leaders expressed concern for what this means for the cooperatives on their respective islands, e.g., Samsø and Ærø (personal communication from the authors). To date, these cooperatives have largely been referred to as success stories in providing sustainable energy while generating income to the islands' residents. Few efforts exist to sustain the wind cooperatives in Denmark by providing legal and financial information.

Finally, in the 2018 energy agreement, the Danish government outlines a strategy to further reduce the impact on the landscape and more than halve the number of onshore turbines by 2030, from 4300 to 1850. Furthermore, the provision of new turbines will be dependent on the number of turbines removed. Direct support for household turbines is also discontinued after 2020. This is a clear move away from the cooperative model for wind energy in Denmark.

However, recent research argues that these incentive schemes are at odds with a sustained provision of electricity in a 'high wind future'. Hvelplund et al. (2017) [16] expect that the continued decrease of wind power prices at the spot markets will prevent profitability of wind farms in Denmark. The authors suggest as a countermeasure to push investments into advanced infrastructure, also integrating of the transport sector with wind-to-fuel technologies. Furthermore, local acceptance [50,55] is key for achieving the necessary changes. Here, new opportunities for cooperatives may open up to influence the transition once again.

4.3. Germany

Our database encompasses 965 energy cooperatives for Germany, most of which have been established since 2010 (see Figure 1). This development is to a large extent a reaction to the Fukushima Daiichi nuclear disaster in 2011 which led to the decision to phase out nuclear power in Germany by 2022. At the same time it was decided to accelerate the low carbon energy transition, known as "Energiewende". The Renewable Energy Resources Act, which was enacted in the year 2000, has been the key policy, granting fixed feed-in tariffs and priority feed-in for electricity that originates from renewables. This enabled other support mechanisms such as loans and grants at better conditions, leading to the notable growth of energy cooperatives and other forms of citizen-led energy initiatives [7,11,56–58]. All of these initiatives contributed 47% of renewable energy capacities installed by 2012; the share of energy cooperatives was 9% [59].

Cooperatives, including energy cooperatives, have a long tradition in Germany. Most of the 8100 cooperatives with 21 million members are engaged in the banking and trade sector. It was largely energy cooperatives that were driving the electrification of rural areas in the beginning of the 20th century [60]. Our database contains 72 energy cooperatives that were founded before 1950. 70% of those established during the 1920s (i.e., 27) are still existing today. Cooperatives are organized in the German Cooperative and Raiffeisen Confederation (Deutscher Genossenschafts- und Raiffeisenverband e.V., short: DGRV). This confederation also conducts yearly surveys among its members and publishes reviews and data.

We start by comparing our base data with those published in the most recent survey [61]. As of 2016, we have information about memberships for 601 cooperatives. As much as 197,686 persons are organized in these cooperatives, corresponding to a number claimed by the DGRV which reports 165,000 persons in 2015 (ibid.). The lower number is likely caused by the statistical error due to the low response rate of only 34% in the DGRV survey. Our mean number of members equals 329, which again is higher than 221 as reported by DGRV. The number of total shares invested in the cooperatives amounts to 596,383,202 euro, a number which is based on information available from 566 out of the 965 registered energy cooperatives. In comparison, DGRV reported 655 million euro in total capital invested by members, a number comparable to our data.

While the number of energy cooperatives in Germany are similar to Danish cooperatives during the 2000s (see Figure 1), the fields of activities are much broader. 360 (60%) are active in solar PV, 186 (31%) in heat and wood-based renewable energy, 120 (20%) in onshore wind energy, 90 (15%) in energy trade, 52 (9%) in biogas, 22 (4%) in hydro power, and 46 (8%) engage in consulting. Note that numbers can be higher than 100% because multiple activities are possible. New fields of activities include the provision of broadband internet access, e-mobility and car sharing. However, the numbers in these new fields are still small. 31 of Germany's energy cooperatives possess their own electricity distribution network. Total numbers of installed capacities are often not available since this information is not required to be reported officially. However, an estimate from 2012 amounts to 6.7 GWh [59].

Although the data underscores the importance of energy cooperatives for Germany's energy transition, the number of newly founded energy cooperatives has declined recently. Klagge and Meister [58] refer to it as the "end of the boom". Our data also confirms this decline in newly founded cooperatives (see the blue markers in Figure 8). However, the observed backward trend in the number of newly founded cooperatives does not necessarily signify a decline in engagement. For many cooperatives in our database, the number of members in existing cooperatives is indeed continuing to increase, albeit the overall slowdown in growth. The red markers in Figure 8 show these rates of membership increase per year for a subsample of 300 cooperatives. The gain in membership peaked in 2013, along with a peak in the growth in assets held by energy cooperatives. The data show that the decline in the growth rates is stronger for the number of cooperatives and less pronounced for membership and assets.

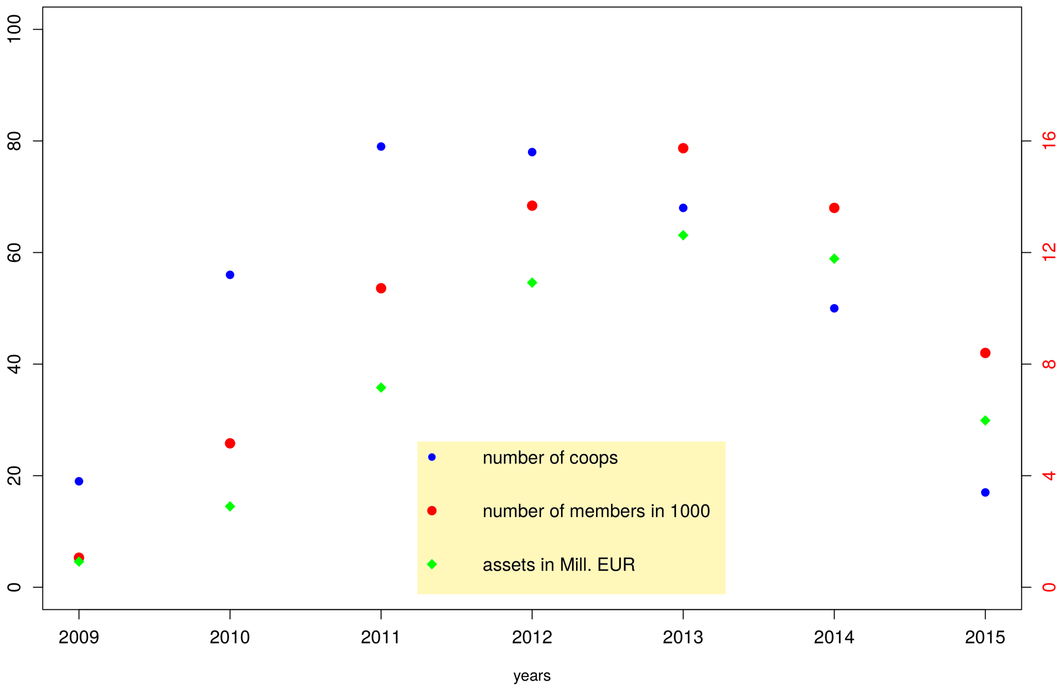

Figure 8. Increase in number of newly founded cooperatives (blue marker) and invested shares (green)—see the axis to the left—and new members (red)—see the axis to the right. Source: own database building on [35,36].

The backward trends strongly coincide with revisions in the Renewable Energy Resources Act in 2012, 2014 and 2017. A central reason for the revision was related to the stability of the electricity grid despite the high penetration rates of fluctuating renewable energies along with rising electricity prices. This led to the introduction of a cap for the prioritized feed-in tariff (FiT) from renewable sources from 2012 onwards. In addition, the FiT schemes were revised in 2014. The latter was discussed as one of the main reasons for the termination of activities [58,61]. The FiT was gradually replaced by a tendering system for most of the renewables, a development also seen in Denmark. As of 2015, the auctioning system was enacted and established 3–4 bidding rounds for solar PV and wind each year. In order to support citizen-led initiatives, small-scale installation are exempted.

Our database also provides an overview of membership dynamics. Figure 9 shows the evolution of memberships for 495 out of 965 energy cooperatives (normalized to the year 2016). Different types of dynamic patterns can be distinguished. These are indicated by different colors. Red is the group of cooperatives that increase most rapidly in membership, followed by green, blue, and gray. Those indicated in black hardly change in the number of members over the years. As expected, older cooperatives tend to be more stable in size. While most of the cooperatives show a continued increase, few of them declined recently. To investigate whether there is a correlation between the dynamic patterns and the size of the cooperative, Figure 10 plots the average rate of increase in membership size versus the size of the cooperative in 2016. As seen from the figure, the growth in membership is rather independent from the size of a cooperative. Figure 11 shows the relationship between the change in number of members from 2015 to 2016 against the change in the number of shares during the same period. Additionally, the size of the energy cooperative is indicated by the color coding, ranging from light colors signaling small cooperatives to dark blue signaling large cooperatives with 500 members or more. Most of the data are located in the first quadrant indicating a growth in both dimensions. Also note that some of them are growing more than proportionally (see the area in the upper left corner). There is no example found in the lower left area, because new members always have to sign a minimum share in a cooperative.

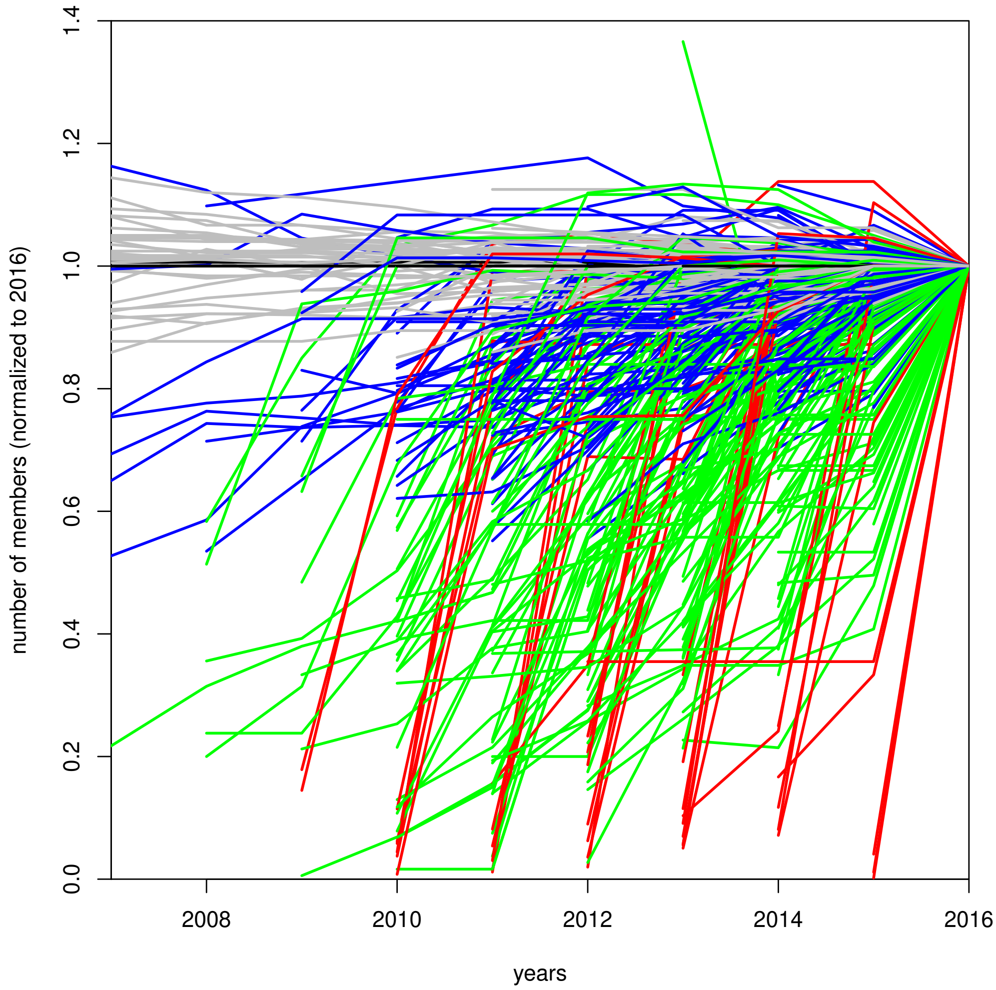

Figure 9. Dynamic patterns of membership among German energy cooperatives. Source: own database building on [35,36].

The number of terminated energy cooperatives amounts to 136 (14%) in our full sample and they are equally distributed over all Federal States of Germany. Analyzing the timing of terminations, we find that most were terminated after 2014, refer to Figure 12. There is a clear response to the change in supportive legislation. With the help of data collected from websites, reports and other sources, we can further shed light on the reasons for the termination. We start with reasons that can be considered as a failure of the cooperatives' purpose. The most common were financial reasons, such as the lack of finances to cover unexpected risks and uncertainties due to unanticipated longer project times, higher costs, or difficulty to acquire projects. Others resigned their activities due to unfavorable legislative changes or the inability to raise enough shareholder capital in the beginning. Management problems also contributed to cooperatives' failure, such as disagreements between and within executive boards and members on the future of the cooperative, lack of management capacities or competences as well as insufficient capacity to adapt to new situations. Finally, some of the terminated cooperatives report problems of public acceptance and also the inability to gain significance. Among the reasons for termination that would not be labeled as unsuccessful are fusions or mergers into enterprises or other legal forms as well as changes in location.

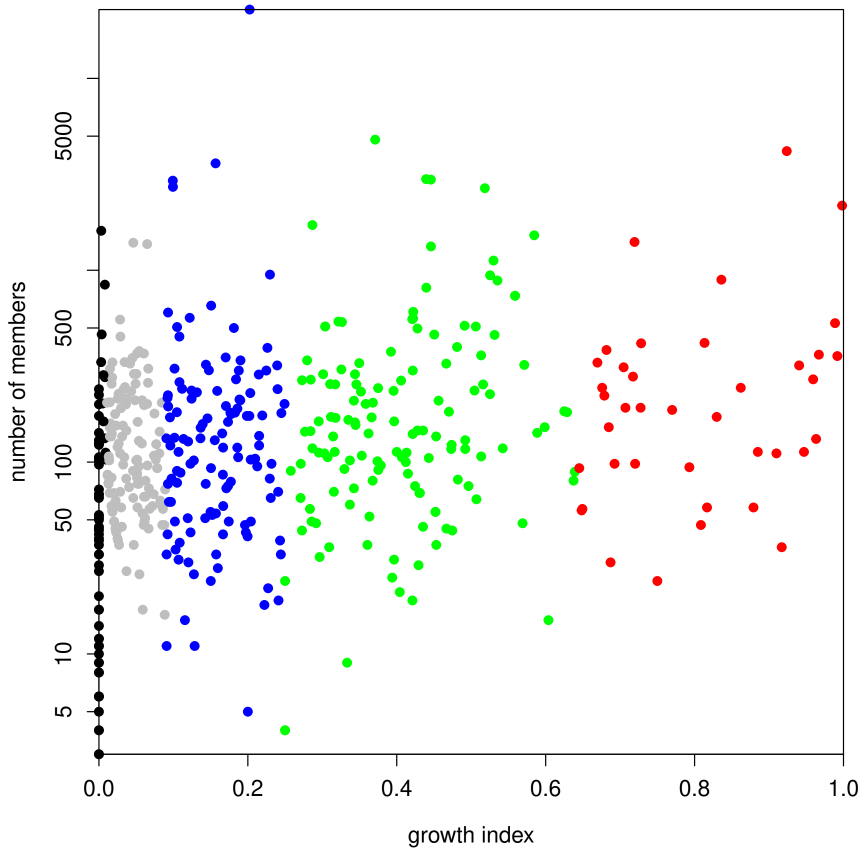

Figure 10. Average rate of increase in membership size versus the size of the cooperative in 2016. Source: own database building on [35,36].

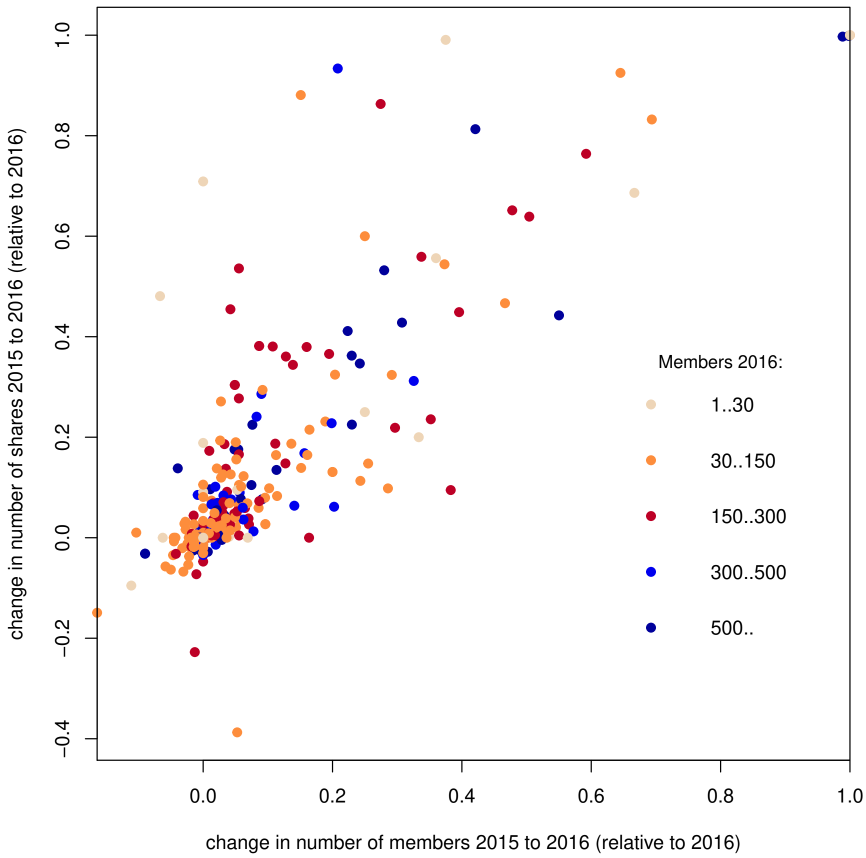

Figure 11. Change in number of members from 2015 to 2016 versus the change in the number of shares during the same period. Source: own database building on [35,36].

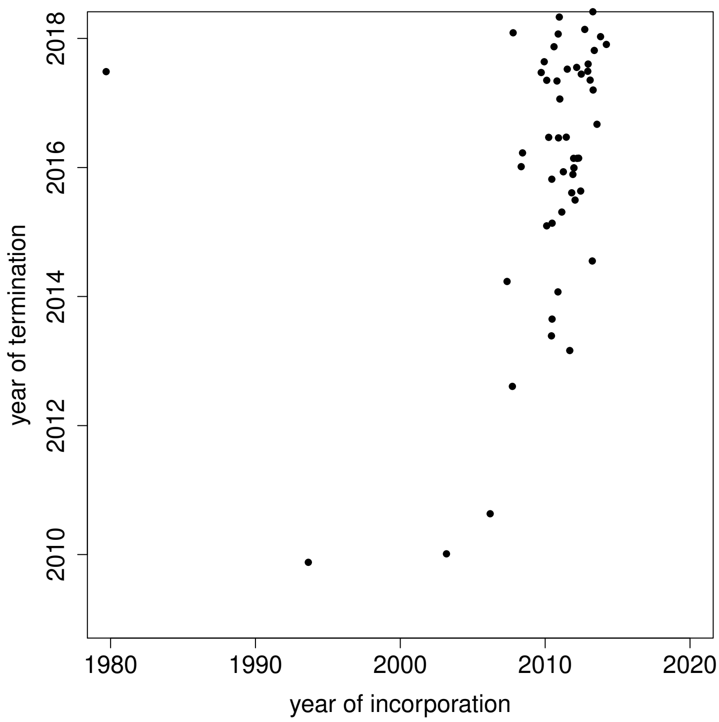

Figure 12. Incorporation dates versus termination dates for closed German cooperatives. Source: Own database building on [35,36].

4.4. United Kingdom

Renewable energy technologies were taken up relatively late in the United Kingdom (UK). In 2014, just 19% of electricity were generated from renewable energy technologies. This number is 2.8 times higher in Denmark and 1.4 times in Germany [28]. For the scope of this paper, we specifically focus on initiatives that are registered under the Co-operative and Community Benefit Societies Act from 2014 [62]. Initiatives founded in earlier years have been reassessed under these new regulations. The majority of the 315 initiatives that we have collected data from engage in solar PV (40%), consulting activities (20%), hydro power (16%), and onshore wind (14%). Of course, the activities may overlap for each cooperative.

In Figure 13, we present the distribution of the year of establishment for these energy cooperatives. Most were founded in the period between 2010–2015. The increase in energy cooperatives in the United Kingdom coincides with the introduction of feed-in tariffs (FiT) in 2010 [63,64]. The UK FiT scheme has been introduced to support the deployment of small-medium scale renewable energy generation (i.e., below 5 MW) in addition to the Renewables Obligation (RO) mainly supporting large-scale generation. It has also been introduced with the aim of allowing distributed generation and empowering people by giving them a direct stake in the transition [65]. It has made distributed energy projects more profitable with relatively low risk by allowing stable returns on the investments. Energy cooperatives have thus benefited of such favorable energy policy support. In addition to FiT, community energy initiatives have also been benefiting from the Enterprise Investment Scheme and the Seed Enterprise Investment Scheme tax relieves, which allowed investors to reclaim income tax on their investment at the rate of either 30% or 50%, respectively. This additional economic benefit comes on top of the predicted interest rate that investors would receive on the investment. Thus, it also played an important role in encouraging green energy investments in the UK.

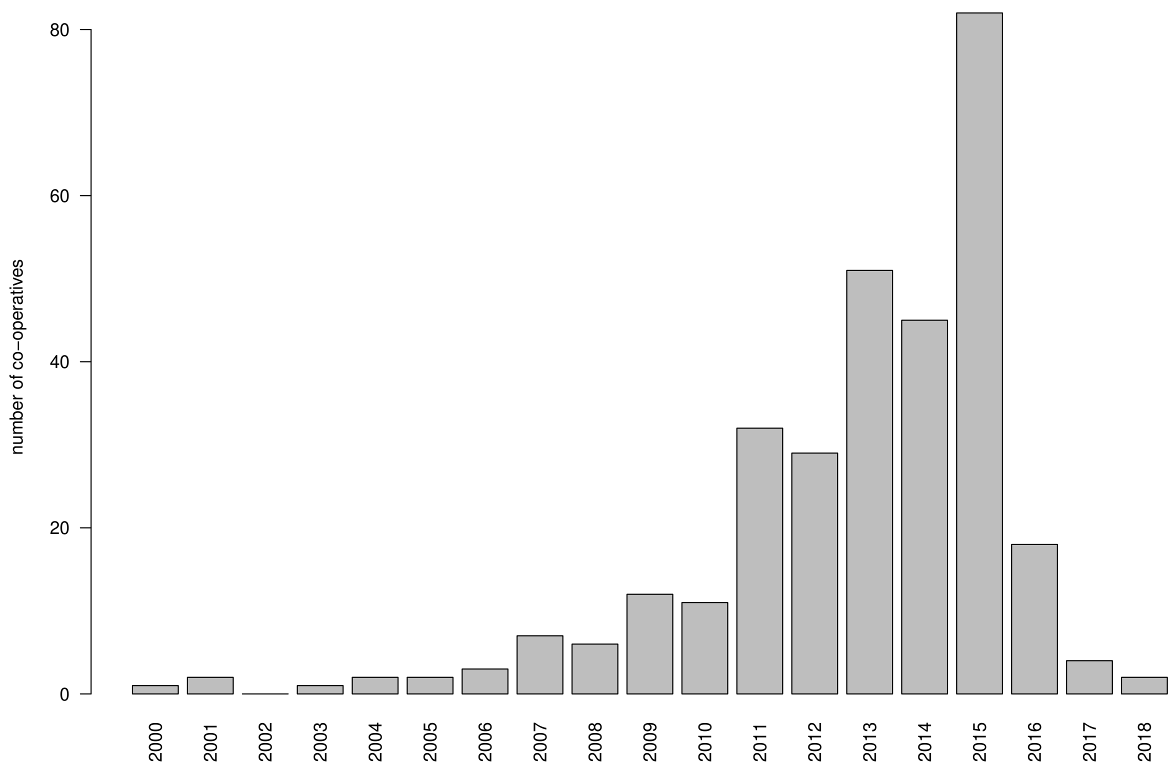

Figure 13. Number of societies newly registered under UK's Co-operative and Community Benefit Societies Act 2014 in a given year. Source of data: own database building on [38].

Nonetheless, complexity of planning and the lack of finance have been mentioned as inhibiting smaller scales of generation and the growth of community-led schemes [63,66–68] even within the already small scale of the UK FiT [64]. For example, Wales established the Rural Community Energy Fund to provide feasibility grants, while Scotland has the Community and Renewable Energy Scheme, improving access to capital through preferential loan conditions, and England operates the Rural Community Energy Fund [7,63,69,70]. In addition, crowd-funding and community share offers (issued by cooperatives or community benefit societies) have been increasingly used to finance community energy. Crowd-funding escalated since 2015, because individuals can place investments in Individual Savings Accounts to obtain tax-free returns.

Figure 13 shows a spike in 2015 and a rapid decline in the number of newly founded energy cooperatives thereafter. The likely reason for this phenomenon is the change in both FiT and direct policy support to community energy. In 2014, Her Majesty's Treasury announced that both the Enterprise Investment Scheme and the Seed tax relief would be removed from projects that qualify for FiT, RO or the Renewable Heat Incentive [7]. This may have led to a rush in founding energy cooperatives to still benefit from the advantages. Furthermore, in 2016 the FiTs for small-scale installations were drastically reduced and deployment caps introduced, leading to a remarkable reduction in distributed energy installation, in particular solar PV [65].

In addition to data on the incorporation (and termination) years of initiatives and their geographical location, our database comprises further details on a subset of entries. 104 cooperatives (33%) provide details on the size of renewable energy installations. They range between a modest solar roof-top installation of 8 kW to 16,300 kW large wind farms. It is interesting to note that hydro power installations are limited by law to 100 kW. Furthermore, the preferred choice of hydro power technology is the Archimedes screw. The argument put forward by cooperatives using this technology is the intention to use the most fish-friendly turbine. A similar preference was found for hydro power projects in Switzerland [71]. The typical size of installations in the small sub-sample is around 200 kW, mainly being larger solar panels. 32 cooperatives (i.e., 10%) also provided information on the number of members, which ranges between 49 to 2260 spiking at around 300 and 700–800 members. Again, in view of the small sample size, this can only serve as an indication of the size of cooperatives. 49 cooperatives (i.e., 15%) published information about the funds raised in order to realize their project. The amounts range from 62,000–3,700,000 GBP concentrating at around 800,000 GBP.

Contrary to the stark decline in the number of energy cooperatives as observed in Denmark, the cancellation rate is comparably small among British energy communities. Out of the 315 initiatives, only 62 (i.e., 20%) have been terminated as of today. Figure 14 shows the number of cooperatives terminated in a given year. A systematic pattern is not obvious from the figure. Instead, the number of closed cooperatives was similar over the years. It can be inferred that changes in the governmental support schemes did not affect the decision to terminate a cooperative, as it has affected the decision to establish one. For 13 of 62 terminated initiatives (i.e., 21%), details about the reasons to terminate activities are available online. The reasons vary from public acceptance issues (Cardigan Community Energy, Easterley Wind Energy, Devon Community Wind Co-operative), organizational and technical barriers (Kingston Community Energy Limited, Bridport Energy Services), problems to raise enough funds (Abergavenny Community Energy, Mapledurham Community Energy Limited), underestimated demand (Wallingford Community Energy Limited), financial risks due to complexity of planning (Abingdon Hydro), financial problems (Abindgon Hydro, Dove Valley Eco Power Limited), disagreement on purpose or missing focus (Bude Community Power Limited, Wembrook Energy Limited), to changes to other legal forms (Ongarhill Wind Energy Co-operative).

The analysis of the sample from the United Kingdom shows that energy cooperatives registered under the specific act played a role in fostering the introduction of distributed renewable energy in the past years. Therefore, as termination rates are comparably low, future opportunities exist. By mid 2018, the total contribution in terms of installed distributed renewable energy can be estimated from our database to amount to around 150 MW. This is a rough estimate derived by information available from a third of the cooperatives. However, in view of the tendency that mostly larger cooperatives publish such data, we expect this to be a reasonable lower bound. Indeed, it is in the range of data published by Berka and Creamer [20]. The authors report an installed operational capacity of 105 MW for projects run by energy cooperatives and energy trusts in 2014. Bauwens et al. [7] emphasizes that only 0.3% of UK's generated electricity does not originate from one of the six large utilities. With 303 TWh of electricity produced in 2016, this corresponds to a capacity of 104 MW. This is again of similar size to our estimate.

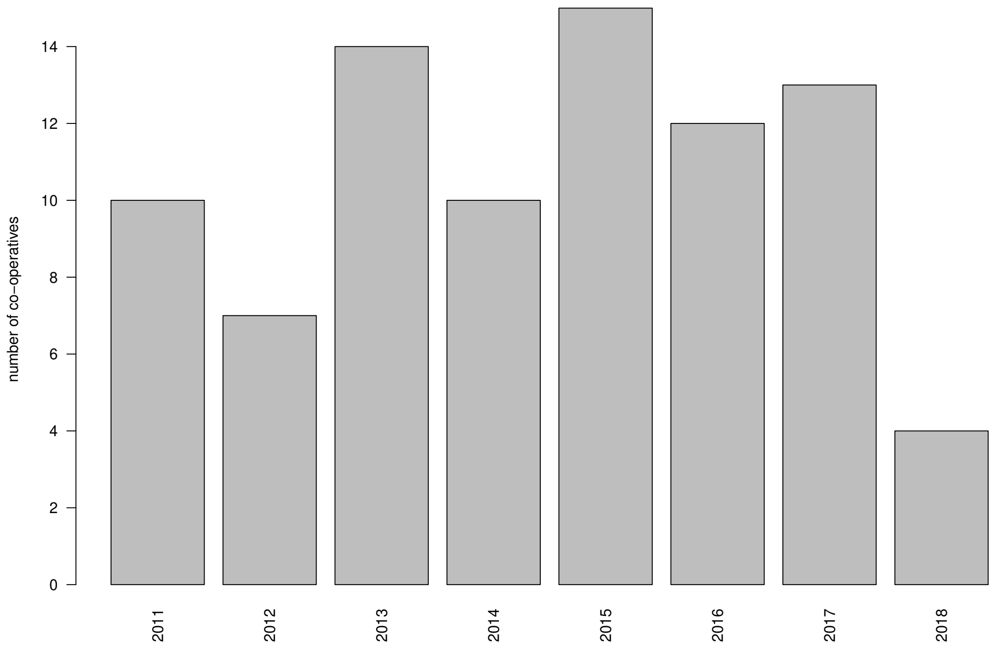

Figure 14. Number of terminated societies registered under UK's Co-operative and Community Benefit Societies Act 2014 in a given year. Source of data: own database building on [38].

4.5. Austria

Austria's electricity system is traditionally based on hydro power. In 1970, around 75% of domestic generation came from hydro power plants. Energy cooperatives were important enablers in rural areas. Our database of Austria contains 9 cooperatives founded during these years and still exist today. The remaining 25% of domestic power generation was supplied by thermal power plants powered by gas, brown coal and oil. Today, hydro power has a share of 36.5% among the renewable energy sources. Similar to other EU countries, the environmental movement in the 1980s and early 1990s was an important positive cultural factor. These groups favored wind and solar energy despite the announcement of the Austrian government to disregard the development of wind energy due to sub-optimal wind yields in the country [24].

However, the engagement of communities led to a notable increase in wind power from around 200–600 kW in the mid 1990s to currently around 1000 MW [72]. Experts estimate that around 80% of installed wind power capacity in the mid-1990s in Austria were owned by them. In 2010, collective citizen ownership of wind farms still accounted for around 40–50% of total installed capacity [73]. Most of the community initiatives active in the wind industry are organized as shareholder societies, or they are collaborating with existing utilities. This particular form is known as the citizen power plant ("Bürgerkraftwerk"). Still, wind energy only makes up 4.8% of renewable energies in Austria.

The second most important renewable fuel after hydro power (having a share of 36.5%) is wood with 29.6% [74]. With Austria being rich in forest land, the country has one of the highest shares for biomass in Europe. This was achieved by a considerable ramping up of biomass-based district heating in the 1990s and 2000s. For example, the number of installed plants increased four-fold from 1999 to 2010 [75]. 45% of the overall district heating output were supplied by these plants [74], and cooperatives were an important actor in the scaling up. In 2010, 66 percent of the plants were run by farmers' cooperatives [76]. The role of district heating is likely to further increase in the future. In its Renewable Energy Action Plan submitted to the European Commission, Austria plans to increase district heating by a factor of five. The target is to enable 175 PJ of district heating.

Seiwald [77] provides a thorough review about historic developments in the upscaling of district heating. The developments coincide with the evolution in the number of energy cooperatives in Austria contained in our database (see Figure 1). 95% of the registered energy cooperatives are active in the area of district heating, typically run in rural areas. Biomass-based district heating started as a niche in the 1990s by sawmill owners. A ramping up of district heating followed, when farmers seized the opportunity to use residuals from the wood industry to generate additional income. They organized themselves in cooperatives to share financial burdens. These cooperatives were also eligible to receive capital grants and soft loans, allowing to cover of up to 50% of the investment costs [78]. Additionally, the Green Electricity Law, which was introduced in 2002, guaranteed feed-in tariffs for biomass-based electricity generation. This explains the continuous growth in the number of cooperatives shown in Figure 1. However, by 2005 district heating plants were established in many locations without considering basic network connections and local demand. A corrective measure was the introduction of efficiency targets for district heating plants of 60% by the Austrian government in 2006. This resulted in a leveling off in the number of newly founded energy cooperatives in the years after, as seen in Figure 1. From our database, we infer that solar PV is only an emerging activity for energy cooperatives in Austria (see also [79]).

5. Conclusions

For all countries studied, our statistical evidence confirms the importance energy cooperatives play in the transition toward renewable energy systems. An important finding is that the historic development of the number of energy cooperatives coincides with the development of supportive schemes in the different countries. Our quantitative analysis thus confirms the qualitative findings of the eleven cross-country studies briefly summarized in Section 2. One of the most important contributing factors to the successful establishment of energy cooperatives is the financial support schemes. In particular, guaranteed feed-in tariffs proved to be most effective. In all countries studied, a removal of the supportive schemes caused a remarkable downturn (or at least slowing down) in the founding of new energy cooperatives. Statistical evidence shows how drastic these developments are. Having over 900 energy cooperatives in its peak time, Denmark has meanwhile lost 88% of the energy cooperatives. In Germany, these developments are less pronounced but the yearly number of newly founded energy cooperatives is continuing to drop. Having access to membership and data on financial shares, we were further able to show, that the quantities react much slower.

We find that the fields of activities of energy cooperatives largely align with the national energy system profiles: wind energy dominates the field of activities for cooperatives in Denmark, biomass-based district heating is most important for cooperatives in forest-rich Austria, while Germany has cooperatives active in many different fields reflecting its diverse energy landscape. The same holds true for the United Kingdom. At the same time, since the investment costs for solar PV are particularly low in recent years, a higher number of cooperatives are engaged in this particular technology (regardless of the country profiles). As a reaction to the removal or tightening up of the incentives schemes, energy cooperatives responded with diversifying their portfolio or increasing the numbers of shares and members, as an alternative to completely terminating all activities. However, there are only very few examples of energy cooperatives with members beyond several thousand. Most energy cooperatives keep their field of activities in the region. This makes them vulnerable to legislative changes that target the optimization of the energy system from the perspective of the national level, shrinking leverage possibilities to adjust. Most importantly, energy cooperatives will have to face fierce competition when corporate actors finally enter the new promising markets, which were only opened by pioneering cooperatives. Larger energy cooperatives may provide a solution to this dilemma. Yet, it is important to keep the minimum financial engagement low enough to ensure the participation of diverse social groups. This also supports the local acceptance for the necessity to transition to low carbon energy systems [80,81]. A stronger tie to social opinion can also break the dominant position of established actors and counteract a revival of non-renewable energies [82].

While we acknowledge that our statistical analysis is far from being a complete account of activities of energy cooperatives across Europe, we provide a lower estimate justified by analyzing focal countries and well-covered forms of cooperative action in Denmark, Germany, Great Britain and Austria. Furthermore, we shed light into current shortages of systematic reporting and how to design aggregate accounting schemes in the future. Our empirical analysis clearly confirms such a need of systematically measuring the contribution by these important non-commercial actors. The lack of data can be eliminated through collaborative efforts, the establishment of an open source database that is shared within the research community and through the development of a sound method able to fill data gaps with proper estimates. The most promising indicators able to capture the contribution by energy cooperatives (and other forms of decentralized collective and individual action) are: the number of people involved in these organizations, the number of associations founded in different legal forms, the number of finances mobilized, the number of jobs or off-spin companies created, the amount of energy services provided (including the amount of energy saved). We suggest to lend from the idea of accounting for ecosystem services [83] to account for social system services.

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PAPER IV: WHO PARTICIPATES IN AND DRIVES COLLECTIVE ACTION INITIATIVES FOR A LOW CARBON ENERGY TRANSITION?

Who participates in and drives collective action initiatives for a low carbon energy transition?

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Abstract: Broad acceptance by and support from the society for the sustainable energy transition is indispensable. Public participation and ownership - in particular through collective action initiatives - is seen as a means to foster this support. Starting with the origin of the cooperative model, we present how it has been evolving until today. We then discuss how energy CAIs are classified and discuss the legal underpinnings and how they related to democratic participation of the membership within CAIs. Statistical analysis with data from Sweden, Denmark, and Germany, questions whether they are as inclusive, just, and democratically controlled by their members as often deemed. We find that energy cooperatives are typically initiated by well-off, rural, male sexagenarians. The participation between women and men (including in decision-making) is below parity. Concluding, in practice, the mechanism of recruiting and engaging members falls behind the theoretic ideal of socially sustainable development. Although being a promising tool to curbing sustainability, current practices rather encompass a narrow perspective of sustainable development that is geared towards technological change. We conclude with a perspective of how this may be rectified in the future.

Keywords: energy transition, collective actions, energy cooperatives, public ownership, sustainability.

Collective action initiatives - Joining forces to solve local problems

Definition

A cooperative is a common form of a collective action initiative (CAI). It unites people voluntarily to fulfill economic, social, and cultural needs its members have in common. This is done by a jointly-owned and democratically-controlled organization (ICA, 2018). “In general, a cooperative comprises a voluntary network of individuals who own or control a business that distributes benefits on the basis of use or ownership where ownership is largely weighted equally across individual members” (Altman, 2009). In defining cooperative organizations, three essential criteria are distinguished based on the explanation of who is a member. First is “the user-owner principle”. Individuals who own and finance the cooperative are its users. Second is “the user-control principle,” which means that those who shape the decision-making process are users. Third, “the user-benefits principle” implies that cooperative users are gaining from being part of the organization (Barton, 1989). A normative definition of cooperatives suggests that they should be “founded on the values of self-help, self-responsibility, democracy, equality, equity and solidarity” (Gibson et. al, 2005, 2).

The origin of the cooperative model in Europe

Throughout human history, people worked together to adapt and change their societies. There is no agreement between scientists when the phenomenon of cooperativeness developed (Nilsson, 1996). The anthropology perspective suggests that this form of organization is already present in primary organizations. For example, Margaret Mead (1935) observed among the Arapesh people the sharing of garden plots. Examples of cooperation and collective resource management can be found in fieldwork done by Bronisław Malinowski (1922) and Alfred Radcliffe-Brown (1952).

Many studies suggest that the phenomenon of cooperatives developed during the Industrial Revolution in nineteenth-century Europe, especially in Britain, France, and Spain (Altman, 2009; Gibson et al., 2005). This form of economic organization has spread in Western countries due to tensions arising from industrialization processes (Forno, 2013). They are structures created to protect the interests of social classes with limited access to the means of production or power.

The Rochdale Society of Equitable Pioneers, established in 1844 in the North of England, is regarded as the prototype of modern cooperatives (Altman, 2009; Fairbairn, 1994; Mayo, 2017). Its formal principles are known as the Seven Rochdale Principles. Founded by 28 workers of a cotton factory, this initiative was intended to improve their material situation by joining groups of consumers to buy food products at better prices. The created store was not only intended to facilitate access to products, but also to create a system of dependencies based on mutual respect, commitment, and openness. The primary mechanism was to allow customers to decide what the sales profits were to be used for, and the clients were also shareholders (Fairbairn, 1994).

The Rochdale Society's success initiated the implementation of the model in other sectors of the economy. In 1863, nearly 400 cooperative associations were operating in Britain (Seth & Randal, 1999). The universality of the model resulted in the fact that in 1895, the 1st Cooperative Congress took place. The event was already of international significance. There were delegates from Argentina, Australia, Belgium, England, Denmark, France, Germany, Holland, India, Italy, Switzerland, Serbia, and the USA. A result of the congress was the establishment of the first international organization, the International Cooperative Alliance (ICA).

The cooperative model inspired a variety of forms across Europe, which spread to different sectors and were also applied in different social orders. Today, cooperatives influence a variety of different markets: marketing/producer, consumer/retail, worker/employment, housing, services, and finance (Gibson et al., 2005). Applications range from Kibbutzim (a cooperative form of farming in Israel), consumer cooperatives and non-voluntary agro-cooperatives in socialist countries to cooperatives who fight for the rights of women and minorities. We refer to them in general as "collective action initiatives (CAI)". We discuss next how the cooperative model has affected the energy sector through energy CAIs.

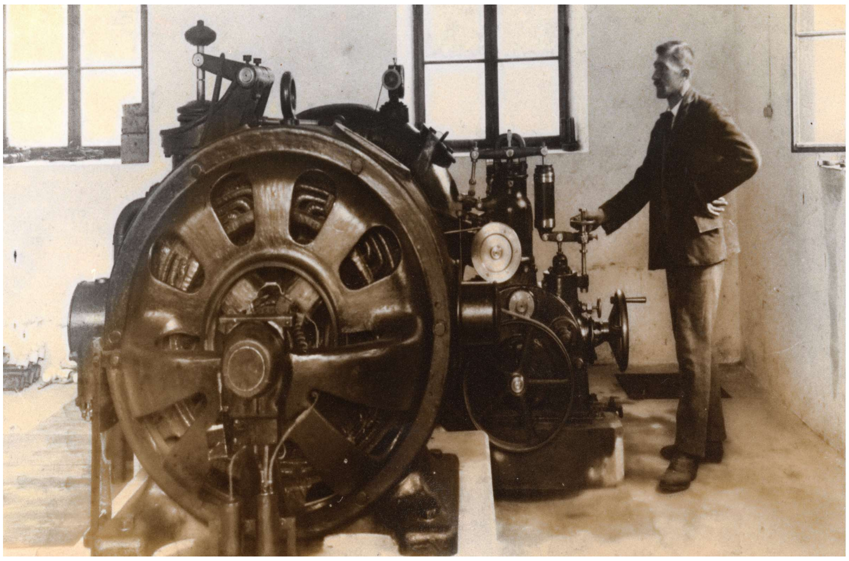
The spreading of the cooperative model to the energy sector

With the electrification at the turn of the 19th to the 20th century, the cooperative model also expanded towards the energy sector. In the early 20th century, several energy cooperatives have been constituted with the aim of providing electricity to population in rural areas, particularly in the alpine region including Germany and Italy (Yildiz et al, 2015; Spinnici, 2011). A compelling case of an electricity cooperative from 1920 is the Samerberg Cooperative in rural Bavaria, which was initiated by a priest (Figure 1). Its hydropower plant with 40 km of electricity grid, 70 motors, and 2500 lamps served about ten communities with more than 1000 inhabitants. The local newspaper "Rosenheimer Anzeiger" reports[1]: "*The far-sighted of the Samerberg can look back with pride*

[1] From www.e-werk-samerberg.de/historie/12-rueckblick-auf-75-jahre-eg-samerberg.html (24.11.2019).

on what has been accomplished. The importance of community-benefits and the cooperative, mutual support is very apparent at the Samerberger plant. In no other way could the unified supply of the remote villages and scattered individual farms of the local area have been carried out. Here, everyone had to stand for one and one for all."

Figure 1: *Electricity cooperative from 1920, started by a priest*



Source: OVB-online (2019).

During the second half of the 20th century, awareness about environmental problems, resource limitations, energy security, and environmental pollution was growing, exacerbated by the repercussions of the oil crisis in the 1970s as well as the nuclear arms race during the Cold War. Cooperatives were seen as a means to tackle these sustainable development problems and - last but not least - to make local voices heard and seen through providing testbeds for societal change. A prime example is the transitioning of Denmark away from fossil fuels to renewable energy, which was strongly driven by local wind energy cooperatives that grew out of networks formed from 1970s collective anti-nuclear campaigns (Mey and Diesendorf, 2018). In the 1980s, the first cooperatives started, snowballing to about 600 by 1990 and about 1000 cooperatives by the year 2000 (and declining afterward, see Wierling et al. 2018 for an exploration). For more details, see also the recent study of Gorroño-Albizu et al., 2019.

Today, examples of CAIs engaged in the sustainable energy transition can be found all over Europe, and the fields of activity and forms are investigated in the next section. A very recent example is the cooperative *E-Dörpsmobil* in rural Northern Germany. The name underlines the strong local ties, since "Dörp" is low-German for village ("Dorf"). This cooperative addresses two problems at the same time. The first concerns the lack of grid capacity for selling excess wind power, and the second is the improvement of rural mobility through shared electric cars. As of today, the model has been spreading in Schleswig-Holstein, involving 22 other communities under the motto "Dörps-mobil - we move the village. Northern lights drive e-green".

Figure 2: Electric mobility for rural areas - the "Dörps Mobil".

Source: doerpsmobil-sh.de.

The cooperative *Qvinnovindar* is an example from Sweden, which approaches the sustainable energy transition in a particular holistic way. In 2007, Wanja Wallemyr, encountered significant barriers for acquiring access to financial resources as a rural, female entrepreneur in sustainable energy. Many other women were prevented from getting engaged in this field due to banks' inexperience and, thus, reluctance in providing entrepreneurial loans to women. In response, she created a network of nine other women, who pooled their resources to purchase a share in a local wind park. She thereby launched a women's only collective, *Qvinnovindar*, to promote a better gender balance in the energy sector and to better empower women economically. The collective has since grown to over 80 members. The cooperative spun off a second similar women's energy-based cooperative, *Q2*, and has also attracted interest from other countries.

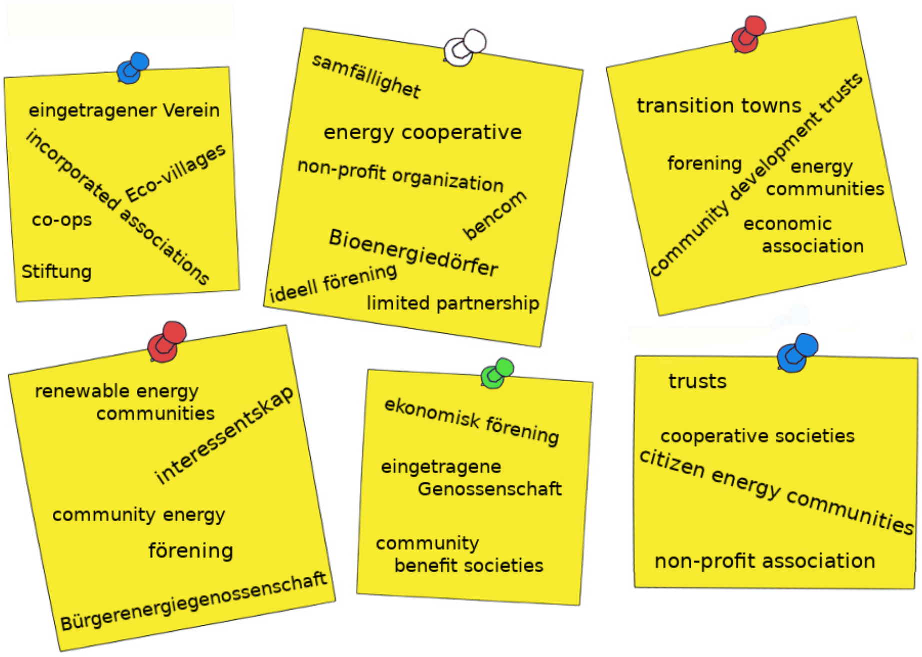
The structure and classification of energy CAIs

A number of frameworks (both from the legislative bodies and scientific literature) attempt to define and classify CAIs within the energy transition. Some focus on their specific forms, such as energy cooperatives, adopting the general definition for cooperatives provided by the International Cooperative Alliance (ICA, 2018), or local energy communities, as in the Communication of the European Commission (COM, 2016). Others zoom in on community energy (Hicks & Ison, 2018; IRENA Coalition 2018). A commonly-used classification framework for energy CAIs proposed by Walker and Devine-Wright (2018), uses two dimensions: the process and the outcome dimension. The process dimension refers to the organizational structure of the initiative (i.e., Who decides and who is involved?); whereas the outcome dimension refers to the purpose of the initiative (i.e., What are the type of community benefits generated and for whom are they intended?). In this section, we adopt these dimensions and explore the outcome dimension first (fields of activity) and then discuss the process dimension (participation structures of energy CAIs).

Fields of Activity

The historical and recent examples of CAIs presented in the previous section indicate that various forms have been and are being tested to cooperatively address local problems. Each period led to the evolution of its specific modes of organizing; and the same holds for different countries across Europe since societal characteristics, legislation (at national and/or regional level), and, last but not least, the local problems at stake strongly influence the preferred model for collective action. The outcome of a CAI is dictated by the shared collective interests of the membership, and serves as a unifying force to create an identity and establish autonomy within the community (Gregg, et al., in press; Bomberg and McEwen, 2012). Figure 3 illustrates the variety of responses to local circumstances found by creative citizens exploring the cooperative approach.

Figure 3: Variety of collective action initiatives across Europe



Source: own figure.

Pivotal to understanding the structure of CAIs are the participants' motivations and their role within the organization (both as a user of the services and products provided and as a decision maker); a CAI's form is ultimately shaped by the members' motivations (Gregg, et al., in press). CAIs generally foster and strive for a host of economic, environmental, social, political, and infrastructural goals. In the view of the energy sector these include aspirations to: reduce home energy bills, generate income for the communities, reduce energy poverty, promote local economic development, develop local skills, create jobs, reduce carbon emissions, improve the local environment, enhance health and well-being, support education, enhance social cohesion and social inclusion, promote volunteerism, empower the community, influence energy policy, gain community leadership, strive towards energy independence, and to refurbish buildings (Seyfang et al., 2013). Out of these goals, the top three found to be most significant in energy communities were reducing household energy bills, reducing emissions, and striving for energy independence (Seyfang et al., 2013). These motivations can manifest different fields of activity of CAIs in the sustainable energy transition in the following ways:

- Community owned generation assets *[2] The idea is to produce and sell energy to a supplier. The income from the operation is shared among the CAI members or reinvested in one or

[2] The first three fields of activities are referred to by CEER (2019), which we take over here (indicated with a star).

another way. Thus the motivations here are community autonomy, sustainable energy, and financial benefits.

- Virtual sharing over the grid*. The CAI owns and manages assets, shares the profits and the energy produced among their members. This can be organized through a common supplier that is in charge of matching supply and demand. The motivation in this case is similar to the community owned generation assets, but with less emphasis on community autonomy and more on the financial benefits. The goal of providing more renewable energy to the grid is also a motivation.
- Sharing of local production through community grids*. A community grid is developed, allowing locally sourced energy to be shared within the community. The motivations would be to attain energy self-sufficiency and collective autonomy over community energy decisions. Micro-grids and district heating are typical examples.
- Distribution and operation of electricity. Electricity is collectively purchased at the market and redistributed to members or other customers. The idea is to use the community leverage to realize economic savings or to guarantee the origin of electricity. The motivation here is collective bargaining power resulting in lower energy costs and perhaps the reduction of energy poverty.
- Light contracting. The provision of street lighting in the community is organized. A motivation is to use locally generated electricity. Often the switch to light contracting comes together with the retro-fritting of existing infrastructure (e.g., LED technology).
- Energy consulting. The idea is to provide information services to the local society on a variety of topics, ranging from the planning of renewable installations, training of operations, and energy efficiency measures to energy businesses models. Aside from promoting renewable energy, the motivation here is to develop skills and jobs to boost the local economy.
- Financial support to improve the energy efficiency of households. The idea is to enable funding schemes for low income households to improve energy efficiency. The motivation here is to reduce energy poverty within the community. This appears to be a popular field of activity for Irish energy cooperatives.

This distinction accounts for alternative technology preferences across Europe. For example, while solar energy is currently the dominant technology for energy cooperatives in Germany, wind power is more popular in Denmark and The Netherlands (Oteman et al., 2014). Furthermore, it recognizes historical developments, since the local problems addressed by CAIs are changing alongside with the society and the prevailing energy paradigm. For example, Transition Towns in the United Kingdom do not advocate for specific technologies. Instead, they emphasize the need to transition away from fossil fuel sources (Seyfang & Haxeltine, 2012). Likewise, the energy transition in Germany was influenced by elements within the civil society that opposed nuclear power after the 2011 Fukushima disaster (Moss et al., 2015).

The goals (i.e., outcome dimension) of a CAI can also be shaped by laws and regulations, e.g, stipulations on how the benefits are distributed among the members. For example, in Sweden, some CAIs are legally defined as economic associations, *ekonomisk förening*, which are created to focus on the financial interests of the membership. Non-profit associations, *ideell förening,* on the other hand, preclude member profits, and thus the focus of the association is on intrinsic social benefits (Bolagsverket, 2019a, 2019b). There is a similar distinction in the UK between cooperative societies (co-ops) and community benefit societies (bencoms), the latter of which focuses on social benefits (BIS, 2011).

Participation Structures of Energy CAIs

Similarly, the process dimension of Walker and Devine-Wright (2018) is dictated by the legal form the CAI adopts. Relevant forms for CAIs include associations, cooperatives, limited partnerships, foundations, and incorporated companies. These forms depend on the country; for instance, some countries, such as Denmark and Sweden, do not distinguish between cooperatives and associations (both are forening /förening), whereas in Germany there is a legal distinction (eingetragene Genossenschaft versus eingetragener Verein).

In the Clean Energy Package of the European Union (COM, 2016), the concept of local energy communities is defined in Article 2(6), being an "… association, a cooperative … or other legal entity which is effectively controlled by legal shareholders or members and is generally value rather than profit driven; although it performs its activities at the local level this may extend across borders …". Two forms are differentiated by their spatial and technological focus: Citizen Energy Communities (CEC) and Renewable Energy Communities (REC). REC are stricter regarding locality as all members need to be "located in the close proximity of the renewable energy project" (COM, 2018). Additionally, while CEC are technology-neutral, though limited to the electricity sector, REC foster the promotion of renewable energy technologies in the entire energy sector (CEER, 2019). In the final European legislation, the concept of Citizen Energy Communities is taken up in the directive on common rules for the internal market for electricity (EU, 2019), while the Renewable Energy Communities are defined in the directive on the promotion of the use of energy from renewable sources (EU, 2018).

Among the CAIs in the energy sector within Europe, energy cooperatives are generally the most common form seen, because this form has the best legal structure to support local ownership and equitable participatory processes (Huybrechts & Mertens, 2014; Yildiz et al., 2015). The "one-member - one-vote" is a fundamental principle to the cooperative structure, which aims to share decision-making power equitable amongst the membership (ILO, 2013; Viardot, 2013; Huybrechts & Mertens, 2014; Yildiz et al., 2015). This principle of democratic inclusion within energy collectives is codified within most European countries' laws. Out of the 28 EU member states, plus Norway and Switzerland, 17 countries have national laws that strictly require the "one member – one vote" principle for cooperatives. Three countries (Sweden, Germany and Finland) additionally allow a proportional voting system, while Slovakian law only allows proportional votes based on membership shares. Luxembourg and Portugal generally adhere to the "one member – one vote" concept, however it is possible for some members to obtain several votes and Poland only requires it for cooperatives with solely natural persons as members. Only six European countries - Belgium, Bulgaria, Hungary, Ireland, Malta and the Netherlands - do not require specific governance structures for cooperatives (Cocolina, 2016; Karakas, 2019).

The fact that there is a legal underpinning to the "one member - one vote" principle leads to a prevailing conclusion that energy CAIs engage in the energy transition not only to promote the deployment of renewables, but also to support just and inclusive participation. In the next section, we explore this notion in more detail by investigating empirical evidence on "Who participates and who drives the collective model to engage in the energy transition?". The focus countries for the statistical analysis are Sweden, Denmark, and Germany.

Investigating the claim of inclusive, just, and democratic control

As shown above, CAIs in the energy transition can take various forms regarding technological focus, organizational structure, legal forms, and approaches to distribute the benefits generated to their members and the wider community. Yet, one main theme can be found in all of them - the key element of inclusive, just, and democratic control that members of the initiatives are possessing (e.g. Hicks & Ison, 2018; IRENA, 2018; ICA, 2018; Walker & Devine-Wright, 2018). For this reason, CAIs are often seen as a way to enable "energy democracy" (e.g Klagge & Meister, 2018, Stephens, 2019), a concept, which most commonly refers to the transformation of the currently centralized and monopolized energy markets into economically and socially just, inclusive markets (Burke & Stephens, 2017; Van Veelen & Van der Horst, 2018; Szulecki, 2018).

This vision is, however, recently being challenged by questioning whether CAIs in the energy transition are indeed as inclusive as deemed. Van Veelen criticises that the current literature on energy democracy and community energy "often assumes rather than demonstrates that the forms of governance it promotes are more democratic than the status quo" (Van Veelen, 2018). Dilger et al. highlights a duality of goals of European energy cooperatives, i.e. community orientation and market efficiency, which have implications for the different business and organizational models implemented and, in turn, for the forms and levels of citizen's inclusion and participation (Dilger et al, 2017). Candelise & Ruggeri find that in Italy community energy initiatives promoted by commercial actors or more inspired by market logics tend to have lower levels of citizen's involvement and co-determination, even when the cooperative is chosen as legal form (Candelise & Ruggieri, 2017). A further issue relates to the aspect of how "community" is being defined in related community energy projects. Simcock (2014) argues that decision processes should include all who are affected by the decisions. Yet, CAIs largely only enable democratic control for their members; the wider community, which is still affected by the decisions taken, is often left out. An example provided by Simcock (2014) is the decision on where to place new wind turbines.

The following section therefore investigates data from Sweden, Denmark, and Germany. The objective is to provide quantitative insights on who engages in and who takes decisions in the initiatives. We investigate membership structures of renewable energy CAIs in regards to income levels, age, gender distribution, location, and the composition of board members.

Collective action initiatives - Who participates and who decides?

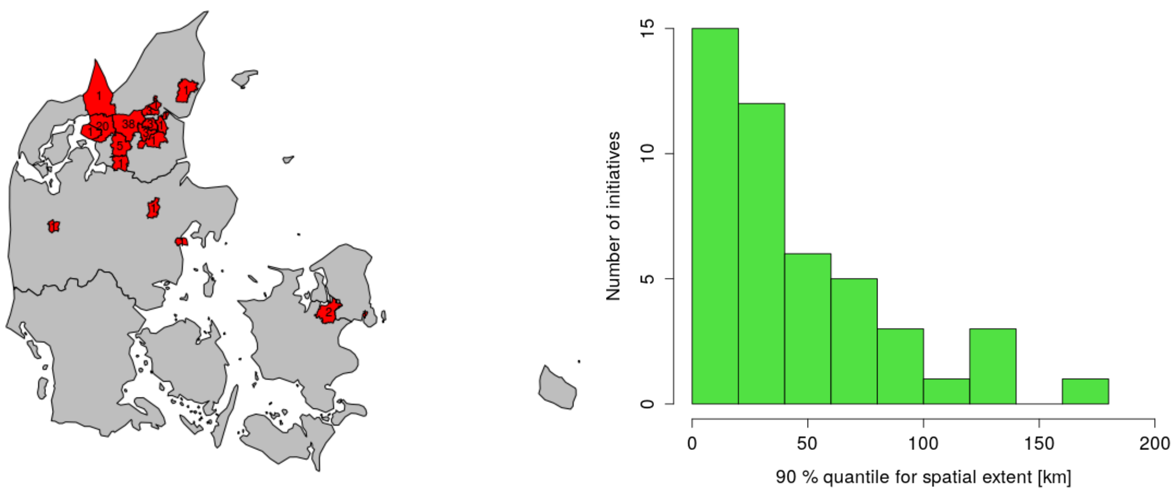
A statistical snapshot from Sweden, Denmark, and Germany

Denmark. For the statistical analysis, we query the Danish Business Register (datacvr.virk.dk). We deploy a sub-sample of partnerships (Interessentskap) engaging in wind energy (vindmøllelaug, møllelaug). In order to separate collective actions from enterprises run by individuals (prosumers), we select those where no individual owners are identified, as otherwise, it is a matter of private and not collective ownership. Excluding also initiatives with fewer than five members, the sample for

Denmark contains 46 entries. For all of them, places of residence of all members are obtained. Analyzing postal codes, we derive a locality measure. In the first step, the surface centroid is determined from the postal codes. Then the 90% quantile for the distances of the individual places of residence is calculated.

Figure 4, l.h.s., is an example of the statistical analysis undertaken for each of the 46 CAIs. Numbers equal the number of CAI members living in the same postal district. In the example shown, the CAI has 87 members altogether. The majority clusters around Northern Jutland. On the r.h.s. of Figure 4, the histogram for the full sample is shown. The majority of CAI members are located within a 50-km range.

Figure 4: The locality of collective wind partnerships in Denmark: Number of members in the same postal district (l.h.s.) for one exemplary CAI. Distribution of CAIs with members located within a specific range (r.h.s.).



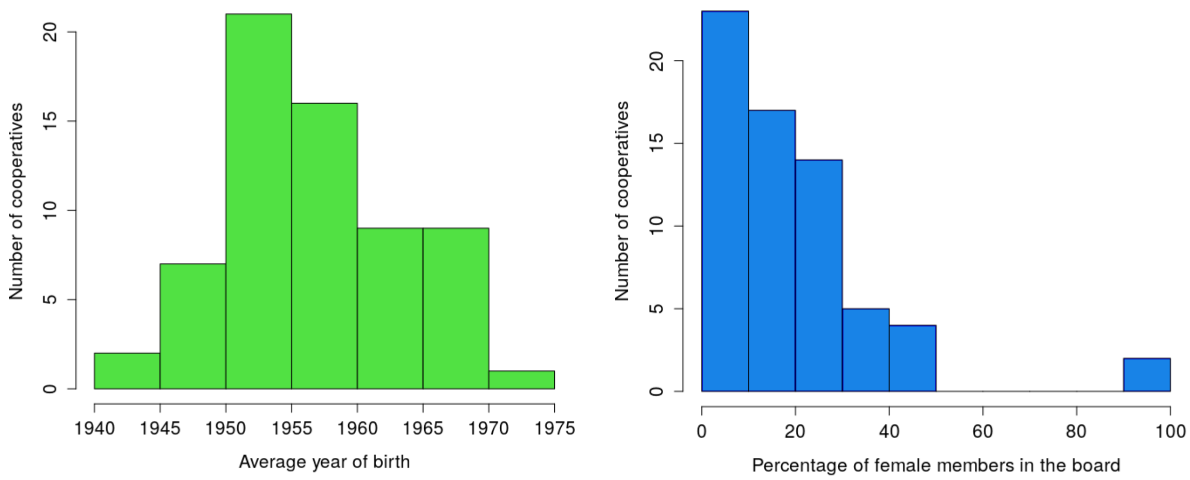
Source: Own figure, for sources of data, refer to the text.

Sweden. In the statistical analysis, we consider incorporated associations (ekonomisk förening), non-profit associations (samfällighet), and non-profit organizations (ideell förening). Swedish data are sourced from allabolag.se and vindstat.com; the former is an information service provider for Swedish companies and the latter a website providing wind statistics. Additionally, self-reporting of the initiatives on websites was used, and yearly reports were analyzed to collect information on membership data. The Swedish inventory comprises 182 entries.

Seventy-seven of the cooperatives are active in the area of wind energy, 27 in electricity distribution and trade, 17 in hydropower, 10 in solar energy technology, 8 in biogas, 8 in energy consulting, and 35 are eco-villages. As of 2016, collective energy projects owned about 2% of the total 6468 MW installed capacity of wind power in Sweden (96 out of 3342 installations).

We focus the following analysis on the subset of Swedish wind cooperatives, who are obliged to report data on members and board (65 data entries for incorporated associations). They typically have several hundreds of members, but there are few with several thousand members, and some have just a few tens. The numbers did not significantly change over the years, which is also linked to the business model of the energy cooperatives in Sweden. The purchase of a wind turbine is financed by the sale of shares ahead of the project (typically of 1000 kWh/year). Members of cooperatives purchase several shares, which is primarily driven by their own electricity consumption. Once the total costs for a wind turbine are realized, shares are no longer for sale. Our results are in agreement with those reported in Magnusson & Palm (2019).

Figure 5: Member of board demography and participation in decision-making in energy cooperatives from Sweden



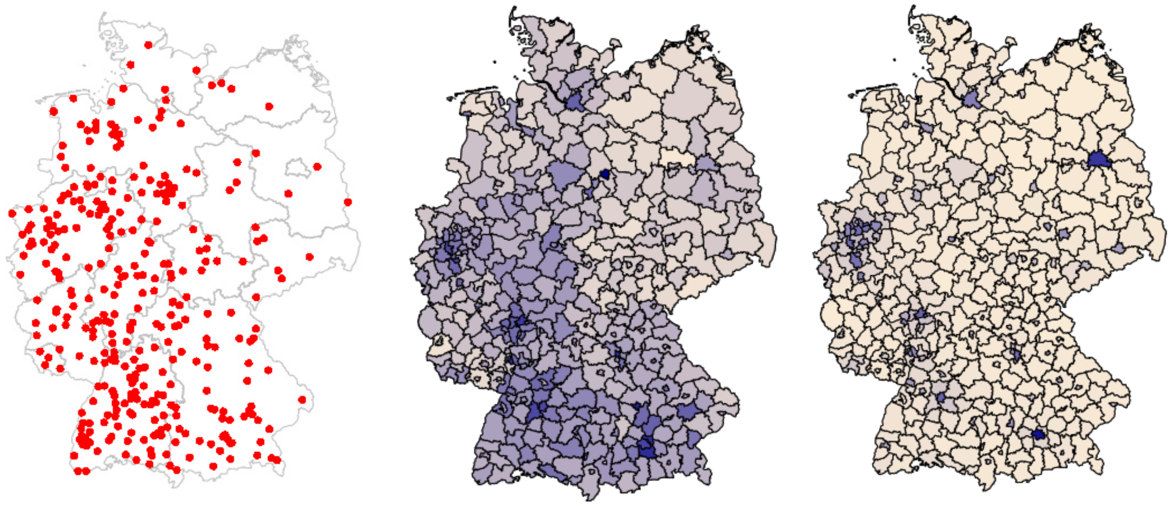
Source: Own figure, for sources of data, refer to the text.

In Figure 5, we take a closer look into the demographics of board members of wind cooperatives. As the left-hand side of the figure shows, the average age of all board members is around 63 years (as of 2020). This suggests that citizens engaged in cooperatives are comparably well off, and this can be confirmed when mapping the location of the cooperatives to the average income distribution in the respective communities (see also the case of Germany, where we show the data in Fig. 6). A similar analysis reveals that most of the cooperatives are located in rural areas. The right-hand side of Fig. 5 shows that the participation of females in the board of cooperatives is clearly below parity. The exception comes from two aforementioned women cooperatives, *Qvinnovindar* and *Q2*. Finally, we also report statistics on the participation of members in yearly meetings, which have been collected from reports of cooperatives published online (18 cases). On average, less than 15% of the members participated in the yearly meetings.

Germany. For the German sample, data are sourced from the German Business Register (www.unternehmensregister.de). We consider cooperatives active in photovoltaic installations and map their legal addresses with socio-economic data on the NUTS-3-level (Eurostat). Altogether, 407 different cooperatives with 3322 different PV installations between 1993 and 2019 were compiled. The total installed capacity is about 540 MWp.

Figure 6 shows the location of the collaborative energy projects (red dots pin their addresses at the right-hand side) vis-a-vis with the income distribution (middle) and population density (right-hand side). The cooperatives are active in rural, high-income areas.

Figure 6: Collaborative PV projects in Germany (addresses - l.h.s.) vs. gross wages in Germany (middle, light blue: low income, dark blue: high income) and population density (r.h.s.: middle, light blue: low income, dark blue: high income).



Source: Own figures, data on collaboratives from own inventory, demographic data from landatlas.de

Discussion of research findings

Who participates in cooperative energy projects?

From the examples, review, and statistical analysis, we find that dedicated individual and grassroots activists focusing on unmet needs are prominent initiators of CAIs. These typically surround a desire to have a stronger voice in the energy system and to promote sustainable energy technologies. The most important enabling factors are the change of perception towards sustainability and identity creation around the CAI. This gives a community sense of purpose among the members and a growing member base with increased visibility. However, insights from the statistical analysis indicate that members of CAIs are not representative of society. From the Swedish sample of energy CAIs, we infer that the typical member is male, with an average age above 60. All our country samples hint towards rural areas as being the core regions of activity. The Danish sample further confirms that initiatives are mostly local (falling into the 50 km range). Mapping of the German sample with income distributions at the NUTS-3 level, we furthermore find that the location of cooperatives coincides with high-income regions. Summarizing, participants in energy related CAIs seem to be well-off, rural, male sexagenarians. Our findings of limitations of inclusiveness to the membership of CAIs are in line with a recent study commissioned by the European Parliament's Policy Department for Citizens' Rights and Constitutional Affairs. The study stresses that gender inequalities are "preventing women from the involvement in the energy transition and career advancement in this area" (Clancy and Feenstra, 2019). Similarly, are the case study results presented in Fraune (2015), Rommel (2018), and Łapniewska (2019), who observe a general under-representation of women in CAIs active in the energy sector. We can add that the same seems to hold for younger generations and, in tendency, for groups with fewer financial resources available.

Our finding has consequences for the innovative potential of CAIs, which may not be tapped to the fullest extent possible. The reason is that the most significant innovations of CAIs are social innovations: the collective decision-making processes and education of local community members, both of which benefit when they are representative of the entire community and both of which support the social pillar of sustainable development. In particular, technological innovation serves as an enabler but is not sufficient on its own to build a successful movement and gain traction. In this light, a successful sustainable energy transition is more dependent on social innovation - and inclusive participation.

Who drives decisions?

The statistical analysis of the Swedish sample revealed that only a sub-group actively engages since not more than 15% on average are participating of the members are participating in the yearly meetings (AGM). This coincides with findings from interviews conducted in Van Veelen (2018, 651), who notes that "... *members are often content to leave staff and directors of the community organization 'to just get on with it' (CG2, general member). Groups' reports of low attendance figures at their AGMs and their difficulty in attracting new directors appear to confirm this assertion that many members have no desire for greater involvement.*" Furthermore, analyzing the composition of the boards of the Swedish CAIs, we find that the participation of female members is below parity.

It serves our point to quote Van Veelen (2018, 652) again: "*The frequent involvement of a small number of people in community projects can also raise concerns regarding these leaders' representativeness of the wider community, not least because community leaders often were similar in age, gender and/or socio-economic background.*" Our quantitative results provide corroborating evidence that the social dimension of sustainable development is not well addressed.

Limitations of the statistical analysis

The dataset compiled is not complete, since reporting duties vary across countries. The measure of locality is a work in progress, as boundary effects are not yet controlled. Hence, quantitative results should be used with care and not without context. Data only indicate trends. Also, we only have information on boards members for the Swedish CAIs and are aware of the fact that this may not be representative for the demography for the members itself.

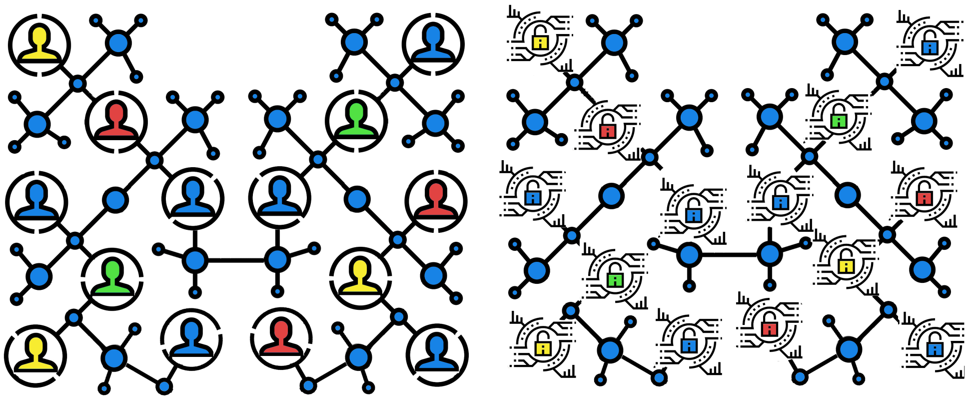
Summary and outlook

We find that collective action initiatives (CAIs) are an essential tool and testbed to solve local problems and to curb the sustainable energy transition in Europe. Moreover, the number of initiatives as well as their members are growing, and the fields of activities are broad.

While case studies may provide deeper insights into selected cases, a statistical analysis offers the possibility to identify generic features. With the availability of new and comprehensive data on CAIs, it is worthwhile to investigate their role in the sustainable energy transition beyond case studies to provide aggregated evidence. A starting point is the statistical evidence compiled by Wierling, et al. (2018), which is one of the first attempts in that direction. This chapter represents a follow up to that paper, and looks more in depth into democratic participation elements that underlie energy CAIs in Europe. We therefore question whether the often-heard claim that local collective actions are particularly democratic can be supported by statistical evidence or not (e.g., Kunze and Becker 2014).

Regarding the social sustainability of energy CAIs, we find there is still much room for improvement within Europe, particularly in regards to representativeness of the CAI participants. CAIs are typically initiated by well-off, rural men of age 60+, and it is only a core group of members that drives decisions. Moreover, the participation between women and men (including decision-making) is below parity. Altogether, participation in collective energy projects is not inclusive when compared to the cross-section of society. Concluding, in practice, the mechanism of recruiting and engaging CAI members falls behind the theoretic ideal of socially sustainable development. Although being a promising tool to curbing sustainability and reaching an impact beyond their members and locality of the initiative, current practices rather encompass a narrow perspective of sustainable development that is primarily geared towards technological change, such as the switch from fossil to renewable sources.

Figure 7: Collective action vs. distributed ledger. Both share basic features - people are interacting with each other, in the latter case through, e.g., blockchain technology.



Source: Own figure.

Future Perspective. As a continually developing social innovation, the cooperative model is flexible and well suited to address current problems, both within the energy transition and with regard to social sustainability. One means of rectifying the participation disparities would be more stringent legal frameworks for energy collectives, requiring that the founding group be demographically representative of the local community. This could have adverse effects, however, and preclude traditionally underrepresented groups and minorities from forming their own collectives (e.g. *Qvinnovindar*). Legal regulations could also enforce voting quora among the membership. However, not only would this be difficult to enforce, it would likely be a disincentive for individuals to join collectives due to the high level of demands and participation expectations. Thus, soft solutions to the representativeness issue have to be considered with great care and caution.

However, new innovations will likely have some impact in this regard. Here, it is interesting to point to the similarities between cooperative networks and other technological as well as social innovation trends such as distributed ledgers (e.g., blockchain technology; refer also to Figure 7) or the use of crowdfunding platforms in the energy sector. The former translates the concept of the 19th century into the 21st century. Through peer-to-peer contracts and trading, distributed ledgers enable activity without hierarchies and intermediaries. All participants collaborate on equal ground in the jointly operated network. As for energy cooperatives, crowdfunding platforms dedicated to energy involve citizens and other stakeholders in energy projects allowing them to invest and benefit from the return on the investment itself. The use of crowdfunding in the energy sector has in fact begun as a fairly niche application to grassroot and community energy projects, acting as a facilitator of the latter by both supporting their funding needs and opening up local initiatives to a broader group of members. The potential of crowdfunding to both support CAIs expansion (Dilger et al. 2017) and provide funding needs to the energy transition (Vasileiadou et al. 2016), as well as other such innovations, will be fruitful areas of exploration in the coming years.

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PAPER V: THE CONTRIBUTION OF ENERGY COMMUNITIES TO THE UPSCALING OF PHOTOVOLTAICS IN GERMANY AND ITALY.

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Article

The Contribution of Energy Communities to the Upscaling of Photovoltaics in Germany and Italy

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Abstract: Energy communities (EC) are among the new actors in the energy market, playing an important role in the uptake of photovoltaics (PV) in European markets. This paper estimates their aggregate contribution to the low-carbon energy transition in terms of installed capacities for PV and evaluates their economic performance comparing with market prices. We compiled a database of PV facilities with 3672 entries for Germany and 64 entries for Italy. Our statistical analysis does not support an economic under-performance of EC. The aggregate contribution of EC currently amounts to 600–838 MWp installed capacity in Germany and 10.6 MWp installed capacity in Italy, which makes 1.2–1.7% and 0.07% of all PV installations in Germany and Italy, respectively.

Keywords: energy cooperatives; community energy; energy transition; energy market; renewable energy; market performance

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1. Introduction

With the EU directives 2018/2020 and 2019/944 [1,2], citizen-led energy initiatives, such as energy communities (EC), have been formally defined. Cooperatives are an example of the most often used legal form as they encompass both the social and economic dimension in their scope and are characterized by a "one head one vote" decision-making process [3,4].

In Europe, the first energy cooperatives date back to the end of the 19th century when they were founded to support the electrification of settlements in rural areas due to a lack of national grids and an overall prioritization of urban areas by commercial actors [3,5,6]. More recently, the progressive liberalization of energy markets and the development of decentralized energy systems allowed energy communities to establish themselves as new actors in the energy market; refer to the work in [7] for statistical evidence.

While the benefit of individual EC is well documented (c.f. [4,8–11]), their aggregated contribution to the energy transition at national and European level is an open question. There are only a few attempts in this direction. Wierling et al. [7] is an example for one of the first systematic attempts at compiling and analyzing statistical evidence for Germany, Denmark, the United Kingdom, and Austria. The findings also show that EC activities are strongly depending on political and financial frameworks. In particular, feed-in tariffs (FiT) were driving developments, see in [3,12] among others.

Besides the lack of reliable quantitative estimates, the economic performance of EC has been questioned. The lack of skills, expertise, and technical and commercial capabilities have been highlighted in the literature as key barriers for the EC in planning and developing renewable energy (RE) plants, along with difficulties in accessing finance [13–15]. It has also been questioned whether, as a consequence, EC end up facing higher costs in the development of energy projects as compared with the market. The report by the International Energy Agency [16] reviewing EC developing wind and solar projects in Australia, Canada, Denmark, Germany, and the UK finds that EC tend to face higher development costs than comparative commercial actors and higher construction costs for facilities of any size. An exception for this statement only regards smaller facilities in Germany (<30 kWp). The finding of IEA-RETD [16] is based on a small sample of just 26 community wind projects and 39 solar projects in total, which were collected in these five countries altogether. We find this insufficient to back up the general statement made.

This paper critically addresses above issues by collecting and analyzing the aggregate contribution of energy communities in the PV sector to the energy transition in Germany and Italy. Community energy sectors in Germany and Italy in fact show similar trends, in particular the strong focus of EC on PV deployment. Since the mid-2000s, both countries have implemented generous FiT for PV. Indeed, in Germany 474 of the 635 production cooperatives have PV deployment as a major activity, while in Italy 16 out of 17 initiatives have been reported to focus on PV installation [3,8,10,12]. For this reason, we focus on energy communities and the PV sector in our comparative analysis. Besides a detailed cross-country comparison, we explore a larger database to scrutinize the results in [16]. We deploy a database of 3672 entries for EC owned PV installations in Germany and 64 entries for Italy to answer the following questions.

1. Relevance of citizen-led PV projects: What is the aggregate contribution of energy communities (EC) in Germany and Italy to the upscaling of PV in terms of installed capacities?
2. Performance of EC: Do energy communities pay more for realizing PV projects compared to established actors in the energy market?
3. Profiles of EC: Where are these energy communities located and where are they active to installing PV production units?

The paper is structured in the following way. First, we provide the description of data and analysis methods. Section 3 presents the results for both countries, Germany and Italy. We provide the overall profiles of EC active in the PV sector, study the locations of activities, and explore their market performance. The paper is concluded with the discussion in Section 4.

2. Materials and Methods

2.1. Framing the Space of Action for Energy Communities in Germany and Italy

We are particularly interested in energy communities (EC) primarily active in the PV sector. Overall, their activities are mainly governed by two legislative fields: The first is the business law, specifically the laws on cooperatives which regulate the legal form. In the case of Germany, the Genossenschaftsgesetz [17] sets the legal framing of cooperatives, while in Italy it is the Decreto Legislativo [18] that reformed the regulation of corporations and cooperatives. In addition, regulations and policies influencing the deployment of PV technology also impact activities of EC.

The German Renewable Energy Sources Act [19] is the most relevant legal framework for the development of renewable energy. Its first iteration came into force in 2000, introducing FiT and market premiums, as well as ensuring grid access for RE facilities. It has often been stated as a best practice example of national RE policies and has led to a major increase in RE deployment. Yet, the German Renewable Energy Sources Act has since gone through major changes in 2004, 2009, 2012, 2014, and 2017, gradually reducing financial support for renewables as investment costs for installations decreased. Furthermore, RE technologies were introduced into the auctioning system and the maximum installed capacity that is financially supported was capped. Subsequent subsidy cuts and newly implemented restrictions negatively impacted EC activities after around 2012 [4,7]. More recent legislative changes (e.g., major EEG revision in 2021) do not affect the analysis of this paper. A detailed overview over the milestones of German RE policy-making can be found in the Supplementary Material, Section S1.1.

Since 2006, Italy has implemented FiT called "Conto Energia" to support the development of PV technologies [20]. These have been fairly generous and uncapped, guaranteeing fixed long-term tariffs and net-metering for PV system owners. The schemes have come in five different waves between 2006 and 2013, becoming more effective since 2008. They facilitated a rapid expansion of the Italian PV market, adding over 3.5 GWp/year in installed capacities between 2008 and 2013 [21]. Similarly to Germany, PV support tariffs were reduced as turnkey prices for PV systems fell. In 2013, the schemes were discontinued. More details are provided in the Supplementary Material, Sections S1.2 and S1.3.

2.2. Data Sampling

The German sample comprises EC that are legally registered as cooperatives ("eingetragene Genossenschaft", abbreviated as "e.G."). Data about cooperatives are available from the German registries [22–25], annual financial reports, and individual websites. We narrowed the sample by only including EC with an energy-related primary purpose, thus excluding agricultural, housing, or banking cooperatives, etc., that still may own PV production units. We have also excluded PV installations which already reached their end of lifetime or which were discontinued for other reasons. For each EC, we sourced administrative information (i.e., date of foundation, name, and address of the cooperative) and production data (i.e., number and location of PV units/PV power installations, installed capacities, investment costs, and shares in units held). Installed capacities are computed as effective capacities, i.e., accounting for the actual share an EC holds in jointly owned production facilities. Ownership share information for production units was sourced either directly from EC websites or through relating EC financial investment to total cost of the production unit. We also provide total capacities, which can be considered as an upper bound for all installations EC are involved in. Investment costs were collected from self-reporting on websites, newspaper articles, press releases, and financial reports (certified audits) if available. In general, EC publish this information more often than established utilities, which also aligns with their commitment to transparency about activities. Where possible, the information has been validated with secondary sources for coherence. Table S3 in the Supplementary Material gives a detailed overview. The final data set for Germany comprises 470 entries with 3672 production units (see Figure 1, l.h.s.). For 445 out of the 470 entries of EC, the location of production units could be identified. Information on the timeline of EC activities could be collected for 453 of the EC. Reliable financial information is available for 464 production units.

The Italian sample has been constructed by merging data from different sources. Administrative information (i.e., year of foundation, name of the EC, and the geographical location) has been sourced from Spinicci [5], Candelise and Ruggieri [12] and supplemented in addition. Production data (i.e., the number and location of PV units, investment costs, and installed capacities) were collected from different websites: data concerning PV units come from web-based searches, analysis of statutes, annual assembly reports, and direct contacts with founders and members of EC. Note that installed capacities are not computed as "effective capacities" in the case of Italy. Information on headquarters and local branches are originating from the InfoCamere [26]. Table S4 in the Supplementary Material reports the details for the whole sample. The final Italian data set contains 37 entries of EC with 64 production units (see Figure 1, r.h.s.). However, only for 46 of these production units, we were able to identify data on installed capacities, and only for 17 out of 37 EC, information of production data is complete. Note that one production unit discontinued in 2016 is not included in the sample. Financial information is available for 29 production units. Additional information provides Sections S2 and S3 in the Supplementary Material.

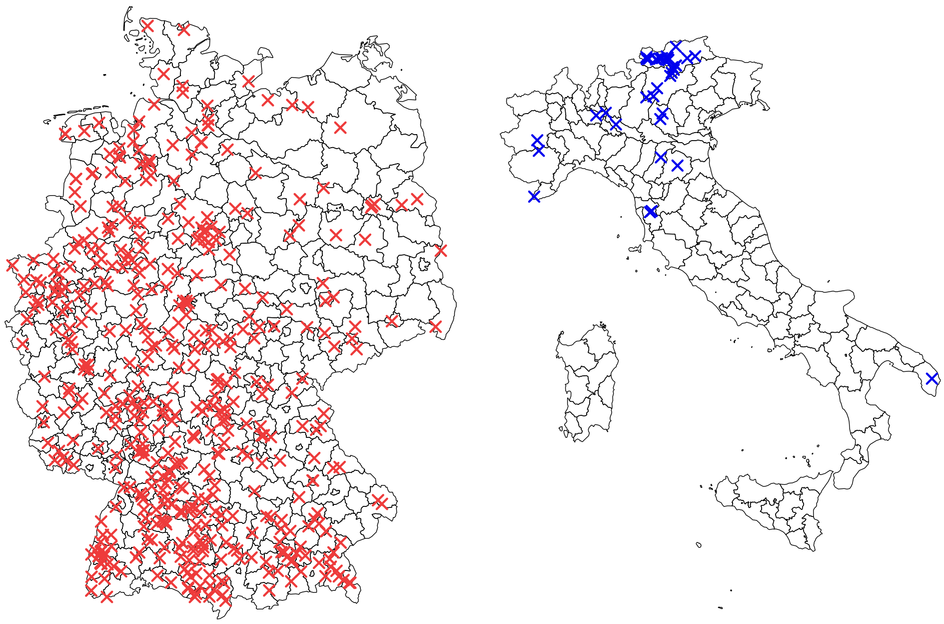

Figure 1. Data samples for Germany (l.h.s, 470 entries) and Italy (r.h.s., 37 entries). Crosses mark registered addresses of headquarters of energy communities.

2.3. Data Uncertainty and Validation

A complete list of collected attributes, data sources, connected uncertainties, and possible data quality issues is available in the Supplementary Material, Tables S3 and S4. Note that data are largely subject to self-reporting, having a limited degree of standardization. This holds for official and voluntary registries or websites alike, constituting the main limitation for the collected data. For example, the varying degree of accuracy in which EC report show up in installation dates of PV units. In some cases, dates are only reported by specifying the year, not the day, and what is being reported differs (e.g., date of installation or date of grid connection). However, the range of uncertainty is insignificant to the results presented in this paper. Where available, data were checked for consistency across different data sources.

2.4. Operationalization of Terminology Used for Classifications

Following Lam and Quattrocchi [27], the geographical scope of EC activities is assessed applying an operational scale perspective that refers to the territorial level at which relevant processes operate, namely, the spatial distribution of PV installations. We use NUTS-3 Classification [28], the LAU Classification [29], and the regional typology EUROSTAT [30]. The latter distinguishes between three classes, which are "predominantly urban" (NUTS-3 regions with more than 80% of the population living in urban clusters), "intermediate" (NUTS-3 regions with more than 50% and up to 80% living in urban clusters), and "predominantly rural" (NUTS-3 regions with at least 50% living in rural grid cells).

We are aware that this approach represents a strong simplification of the definition of territorial scales. In line with the most recent developments in human geography, it should be avoided to consider scale as an ontological given category. Instead, scales should be seen as a social product, defined by the social actors themselves [31–35]. However, according to the operational scale approach mentioned above, the adoption of NUTS classification allows in any case to go beyond the mere geographical hierarchy by considering the different levels of observation at which the socio-economic processes and practices are shaped and constituted. Furthermore, this paper analyses overall trends, and as the results will show, it is not necessary for our analysis to introduce complex territorial scale definitions. Therefore, for classifying EC activities as local, we test if all productions units of a single EC fall within just one NUTS-3 region. For those active in more than four NUTS-3 regions, we review case by case whether they qualify as predominantly regional (i.e., all production units are located in neighboring NUTS-3 regions) or whether they are rather nationally active (i.e., covering many and separate NUTS-3-regions, well spread over the country). Below that threshold, EC are typically active in just one region or they just cross the nearest border.

For a classification of the size of installations, we adapt Fraunhofer ISE [36]. They separate into four size classes: 1–10 kWp (residential rooftops), 10–100 kWp (medium sized rooftops on commercial and public buildings), 100–500 kWp (large industrial rooftops), and >500 kWp (ground mounted facilities). Note that the descriptions of the size classes come from the authors and are not taken from Fraunhofer ISE [36]. The rationale for adapting the classification is connected with data availability.

2.5. Energy Market Measures

In order to check whether EC have been paying more than established commercial actors in the energy market when realizing PV projects, we compare the financial investment made by the EC with annual turnkey market prices for PV installations. We use annual PV market prices to account for the progressive PV price reductions along the learning curve [37]. Moreover, while PV module prices are generally set and monitored at a worldwide level, turnkey PV market prices can differ among countries as the balance of system costs of a PV system can differ. The reasons behind this are differences of PV market supply chains, concerning their maturity as well as national characteristics [38]. Therefore, different PV system prices are used for the comparative analysis of Germany and Italy. For Germany, we have used data sourced from Bundesnetzagentur [25] and individual websites of EC, and we compare with PV market data available from Fraunhofer ISE [36] and IEA-NSR [39] (annually issued per country). For Italy, PV market data come from IEA-NSR [39]. A difference between the countries concerns the role of the PV secondary market. In Italy, several PV plants owned by an EC have not been built in the first place by the EC, but were acquired by them on the PV secondary market. For these specific data entries, we compare the reported price for the acquisition of the PV plant with annual prices in the PV secondary market. Details of the Italian PV secondary market prices and dynamics are provided in the Supplementary Material, Section S1.3.

3. Discussion of Results

3.1. Profiles and Evolution of Energy Communities Engaging in the PV Sector

Figure 2 shows the distribution of accumulated installed capacity across EC active in Germany, and Figure 3 shows the distribution for the size of single production units owned by an EC. Respective results for Italy are presented in Figures 4 and 5.

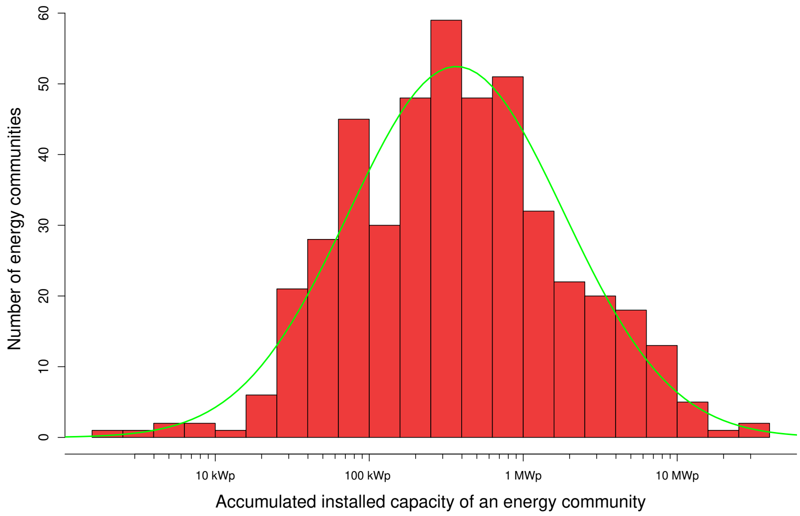

Figure 2. Number of EC in Germany for given bins of accumulated installed capacity. The green line is a normal distribution fit.

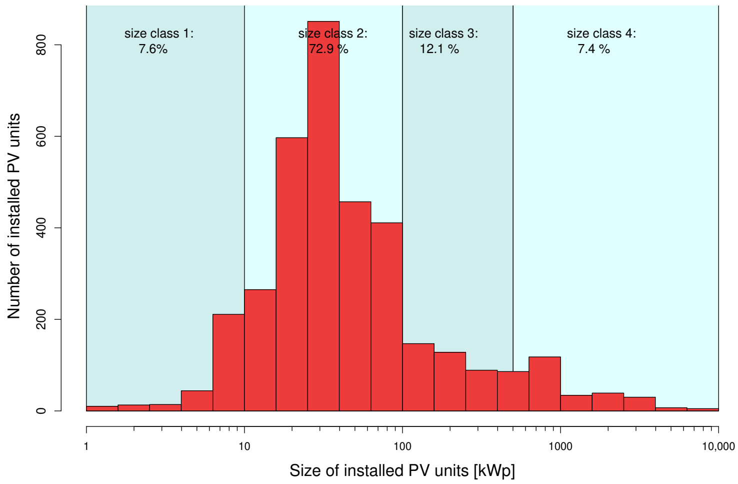

Figure 3. Number of units with certain sizes managed by EC in Germany. Azur fields indicate the size classes of single PV installations.

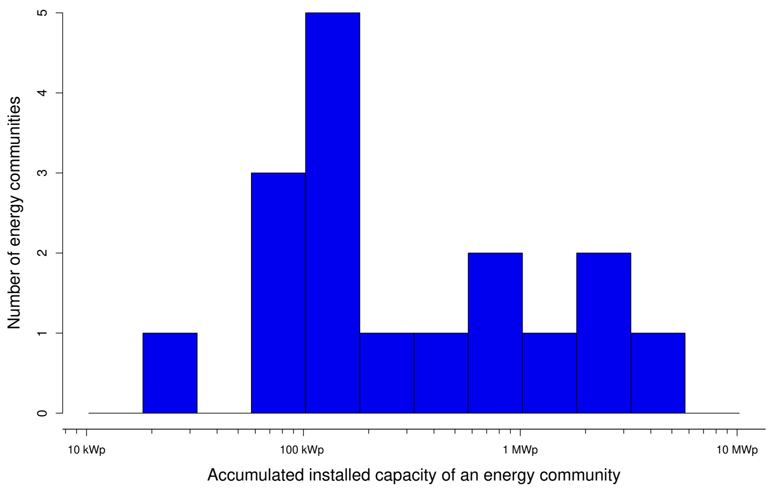

Figure 4. Number of EC in Italy for given bins of accumulated installed capacity. Note that the sample is limited to available data for capacities.

For the German sample, a single EC tends to manage on average 1292 kWp of installed PV capacities (as of 04/2020). However, the median is just 320 kWp, confirming a skewed distribution (Figure 2). A similar result is found for the mean size of effective capacities (mean: 169 kWp, median 32 kWp). For Italy, we find 787 kWp for PV capacity managed on average. The green line added to Figure 2 shows a normal distribution for the log-scaled capacities, strikingly resembling the German sample very well. Overall, EC in Germany tend to manage medium to large-size installations (refer to the classification categories added to Figures 3 and 5). Italian EC own smaller production units with the average being 291 kWp [12]. All production units where EC have been participating amount to a capacity of 838 MWp, whereof 600 MWp are directly owned by EC (we refer to this as effective capacity, correcting for shares). This amounts to 1.2–1.7% of the total PV capacities installed in 2020 in Germany. In Italy, EC have installed about 13.4 MWp of PV capacities (0.07%). As regards the number of production units managed by a single EC, additional figures are included in the Supplementary Material, Section S3, Figures S1–S4. The mean (median) for Germany is at 8 (5) units per EC, and 84 EC (18%) only manage a single PV production unit. The top runner is BürgerEnergieGenossenschaft e.G., Wetter, with 110 units. For Italy, 30 EC have just one production unit. The top runner "Energia Positiva" manages 11.

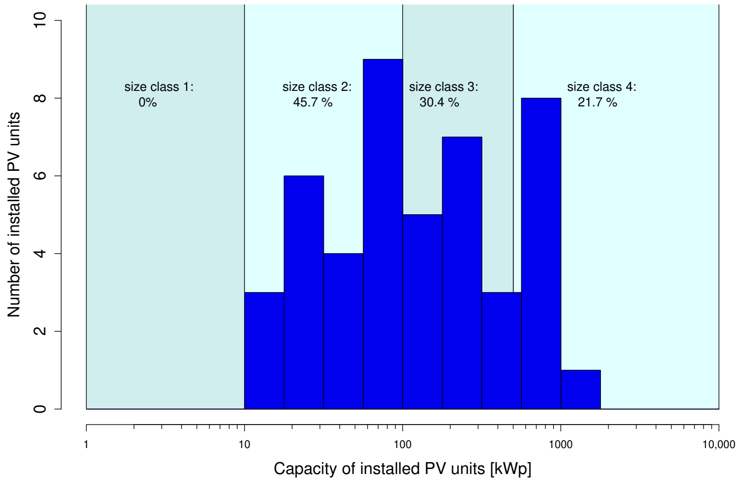

Figure 5. Number of units with certain sizes managed by EC in Italy. Note that the sample is limited to available data for capacities.

Figures 6 and 7 (as well as Figures S3 and S4 in the Supplementary Material) add to the analysis by exploring the evolution of EC active in the PV sector between 1994 and 2020 in Germany and 2007 and 2020 in Italy. Note that for 2020 only the first four months are included in the data. Overall, a trend towards larger installations can be observed in both countries. In the early phases (approximately until 2000), in Germany the few newly installed facilities fell within size class 1 (residential rooftops, 1–10 kWp). From 2000 to approximately 2007, EC started to install facilities belonging also to size class 2 (commercial/public rooftops, 10–100 kWp), while only occasionally size class 3 facilities were owned by EC. After 2007, both in Germany and in Italy, size classes 3 and 4 (i.e., large industrial rooftops, 100–500 kWp, and ground-mounted facilities, >500 kWp) gained relevance in the capacity mix. In Germany, the by far most deployed size class has remained the 10–100 kWp, while in Italy a clear trend is less pronounced, although the most recent years show a growing presence of size class 3. Finally, in both countries, 2011 was the peak year for adding capacities by EC as well as for the total amount of capacity installed. In both countries, the last decade has been most productive in expanding activities, with added yearly capacities exceeding 30 MWp in Germany and 1 MWp in Italy. This coincides with an overall drop in the cost of PV installations [38], stabilizing at approximately 30–40 MWp added yearly in Germany and approximately 1 MWp in case of Italy. In both countries, the development is strongly governed by the revision of FiT, respectively, regulated in the Renewable Energies Resources Act [19] and the Conto Energia. The revision caused an overall decrease in the number of newly founded energy communities in Germany [7]. In Italy, only three larger initiatives have continued developing PV projects after the discontinuation of support schemes, leading to the uptake of a secondary market, as further discussed in Section 3.3.

In Table 1, we compare the size of production units owned by EC with all installations in a country. As a first remark, the distribution of PV units by capacity installed shows a relatively higher capacity in Italy (highest concentration in size class 100–500 kWp) compared with Germany (highest concentration in size class 10–100 kWp). EC in Italy reinforce this tendency by concentrating more than 70 percent of their capacities in the highest size class (>500 kWp).

Table 1. Contribution by size class to the total production, comparison of the EC sample with the national sample.

Size Classes	German EC	Germany [36]	Italian EC	Italy [40]
<10 kWp	0.3%	14.2%	0	19.6%
10–100 kWp	16.5%	38.2%	7.9%	20.9%
<100–500 kWp	16.3%	14.1%	21.7%	37.8%
>500 kWp	66.8%	33.5%	70.4%	21.7%

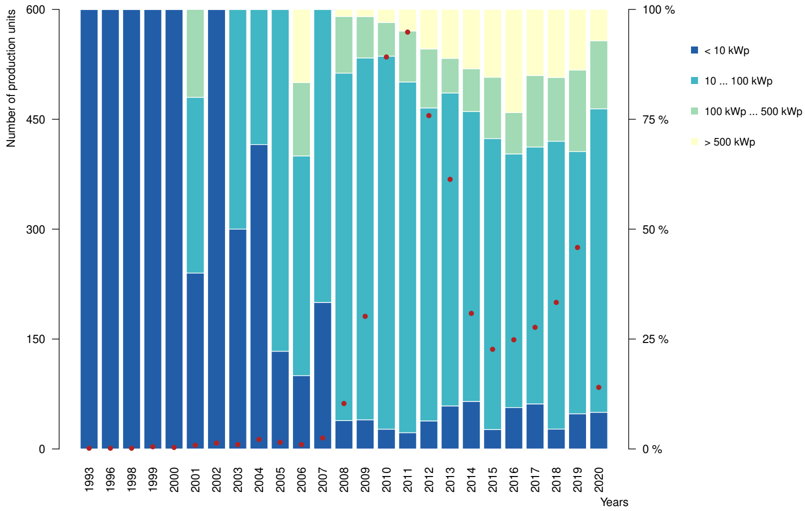

Figure 6. Change in number of PV units (red dots and axis to the **left**) and distribution of size classes in a year for Germany (see axis to the **right**).

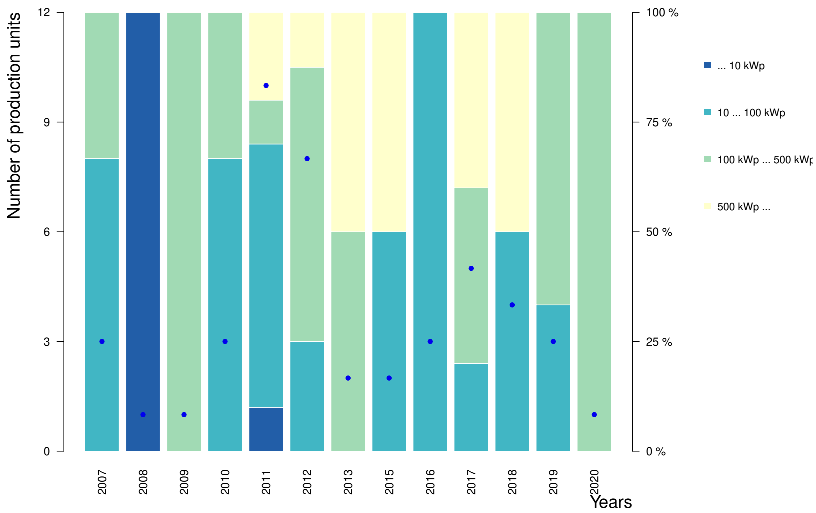

Figure 7. Change in number of PV units (blue dots and axis to the **left**) and distribution of size classes in a year for Italy (see axis to the **right**).

3.2. The Geography of PV Installations

In this section, we analyze the spatial distribution of EC activities. We study the distribution of activities across NUTS-3 regions, across urban–rural categories, and we test if activities of EC correlate with population densities and available income per household.

The statistical analysis of the location of production units belonging to a single EC reveals that the majority of EC are active within just one NUTS-3 region (see Supplementary Material, Section S3, Figures S5 and S6). For Germany, it is 289 out of 440 EC (66%), and for Italy, it is 31 out of 34 EC (91%). On this basis, we can consider that EC are predominately active on the local level. In Germany, these EC have altogether installed 191 MWp, thereby contributing 32% of all capacities installed. For those EC that are active in more than three NUTS-3 region, we see a clear tendency of being nationally active. In Italy, only three EC are active in more than one NUTS-3 region. Two of them show a stark spread of units across Italy.

Next, we analyze whether EC activities correlate with population densities (see Figures 8 and 9). We compare the distribution of population density across NUTS-3 regions of the country with the distribution of population density within the sample constructed by active production units of an EC. We find that activities are more often located in areas below the median of population density in both countries. In Germany, the distributions roughly follow the same patterns, suggesting that population density distribution is a proxy for EC activity. For Italy, the exceptional spike is caused by the autonomous province of Bozen, which is a mountainous and sparsely populated area, coinciding at the same time with a traditional hot-spot for EC.

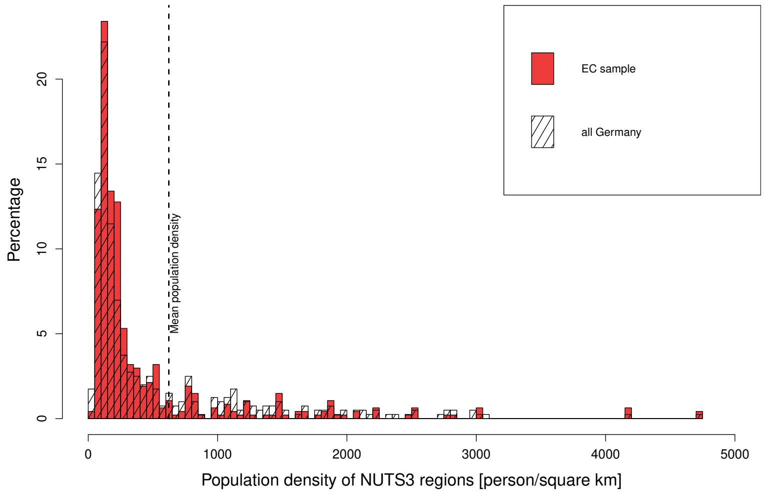

Figure 8. Comparison of the distribution of population density at country level and for the EC sample in Germany.

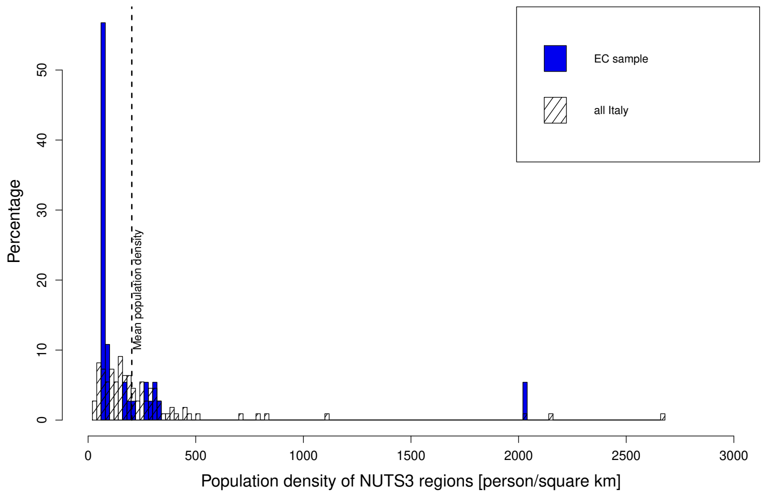

Figure 9. Comparison of the distribution of population density at country level and for the EC sample in Italy.

Figures 10 and 11 show the results for repeating the same analysis with the income distribution, allowing us to understand whether EC are predominantly located in richer regions. Figure 10 therefore shows two distributions: one being the distribution of available income for households for all NUTS-3 regions in Germany (hatched bar), and the other being the distribution of available income for households for the regions where EC are active (red bar). We find that the distribution following from regions where EC are active is centered around higher average incomes, underlining that EC are more often active in richer regions. To confirm this visual observation, we perform a Welch's t-test [41]. In this test, the null hypothesis is that the two distributions have the same mean values. We find a p-value of 10^{-4} and therefore reject this null hypothesis. A similar result can be inferred from Figure 11 for Italy. Indeed, the difference is even more striking, corresponding to the fact that EC are predominantly located in Northern Italy.

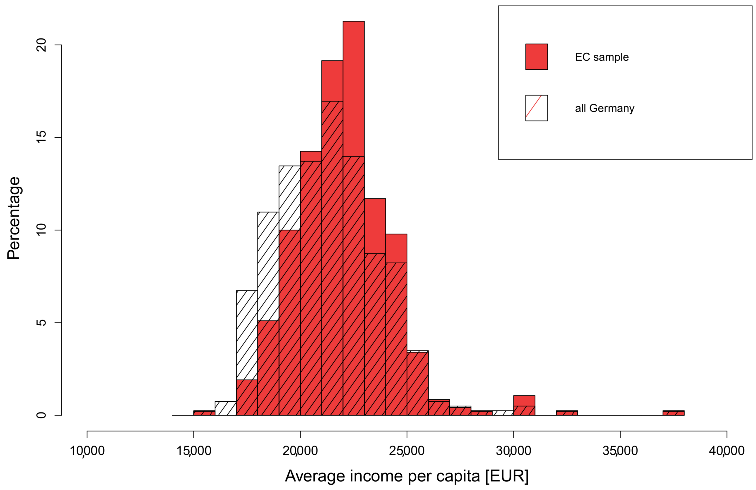

Figure 10. Comparison of the distribution of available income for households for all NUTS-3 regions in Germany (hatched bar) with the distribution of available income for households in NUTS-3regions where EC are active (red bar). The year for comparison is 2015. Source: Income data from [42].

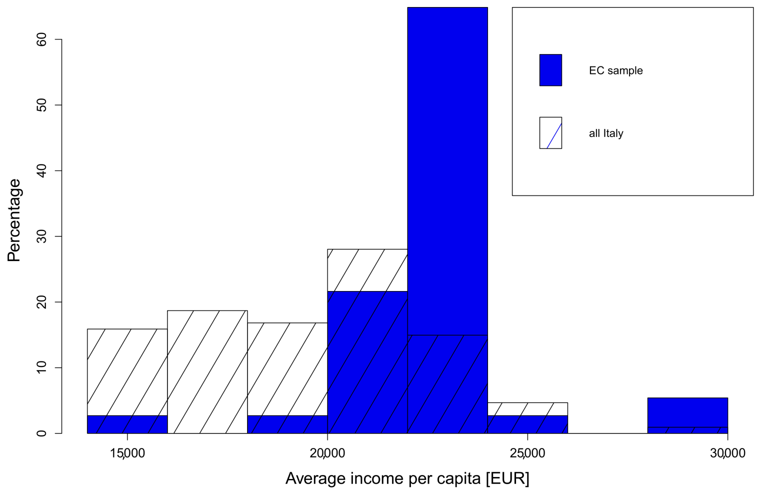

Figure 11. Comparison of the distribution of the regional income for all NUTS-3 regions in Italy (hatched bar) with the distribution of selected NUTS-3 regions where EC are active (blue bar). The year of comparison is 2015. Source: Income data from [43].

Next, we turn to the question of whether EC are predominantly active in urban, intermediate, or rural areas (see Section 2.4). Figures S7 and S8 in the Supplementary Material show this analysis for Germany and Italy, respectively, comparing the distribution in the EC sample with the distribution of the 3-category classification at national level. We infer that activities are predominantly intermediate and rural ones. In the case of Germany, both distributions are rather similar. A similar result was found in Volz [8]. The author shows a similar distribution for EC activity in the boom phase in the PV and other sectors. In the Italian case, we observe a bias towards intermediate and rural when comparing to the national distribution. Investigating this further, we repeat the analysis using LAU-definitions, which are the building units of NUTS-3 regions. In Italy, the differentiation between the level of aggregation (NUTS-3 vs. LAU) matters for some southern regions, because they are classified as urban and rural, respectively. However, we still find that activities are predominantly rural and intermediate. Nevertheless, we perform the analysis for both levels of aggregation to test the robustness of results. Note that the bias when comparing to the national sample is tilted towards urban and intermediate activities when using LAU. This indicates that EC activities, although predominantly not located in urban areas, are not falling into clear geographical classes.

3.3. Turnkey Prices and Market Performance

3.3.1. The Case of Germany

Figure 12 presents a comparison of market prices for PV systems with the average price paid by EC in Germany. We exemplary show the results for size class 2 (10–100 kWp), the size class with the most entries. However, the results are consistent for all size classes. Ranges of market prices are taken from Fraunhofer ISE [36] and IEA-NSR [39]. A singular value of 1586 EUR/kWp for the year 2012 is found for the German market in Strupeit and Neij [44]. This reference also provides an overview of more detailed cost categories and studies the influence of unit sizes in detail. Generally, their analysis shows decreasing costs over time and with increasing capacity, indicating economies of scale. However, the study is restricted to the timeframe of 1991–2012 and therefore of little direct value in out context. In addition to the average values of prices paid by the EC for each year in the given size class, we also show the range given by the standard deviation (1σ). The data show a stark decrease in prices by a factor of three within one decade. Overall, prices paid by EC are not significantly different from market prices. An exception concerns the years 2011 and 2012, where prices paid by EC are higher than market averages. However, the explanation for the year 2011 is the following. The market price given by IEA-NSR [39] is not specific to size class 2 for this particular year. Instead, the report summarizes prices for all installations above 10 kWp. As regards the prices obtained from Fraunhofer ISE [36], we still see that prices paid by EC match market prices within the standard deviation. For 2012, market price dynamics are playing out. This year saw a stark fall in prices for PV systems, and thus it matters whether an installation has been purchased at the beginning or end of the year 2012. Moreover, Fraunhofer ISE [36] report the price for the fourth quarter of the year. Having only 91 entries for 2012 in our sample, a reliable quarterly estimate is not possible. Note that the size of the sample used by Fraunhofer ISE [36] is unknown. Furthermore, note that for this particular year no national report by the IEA has been issued. Finally, we just mention here that the prices on the secondary market in Germany are considerably higher than the primary market prices, but follow a similar decreasing trend. An analysis of the secondary market and its role for German PV is subject to future studies.

3.3.2. The Case of Italy

Figure 13 compares the investment costs per installed capacity seen by Italian EC with average prices for PV installations. The analysis differentiates between installations smaller then 500 kWp (crosses) and those which are larger (dots). Albeit the data set is limited, we see that Italian EC roughly purchased within the corridor of market prices.

After the cancellation of FiT for PV in 2013, the primary market slowed down and the secondary market expanded (see also Supplementary Material, Section S1.3 for further information on the Italian FiT schemes). Indeed, only the three largest initiatives—Energia Positiva, WeForGreen Sharing, and Retenergie—continued developing PV projects thereafter. They managed to do so by enlarging their scale at the national level, achieving economies of scale which have allowed them to involve and hire professionals as permanent staff and progressively enhance the services provided. This higher level of competences has allowed them to expand their activities and projects acting on the PV secondary market [12]. In Table S1 of the Section S1.3, the details of the PV plants acquired on the secondary market are listed.

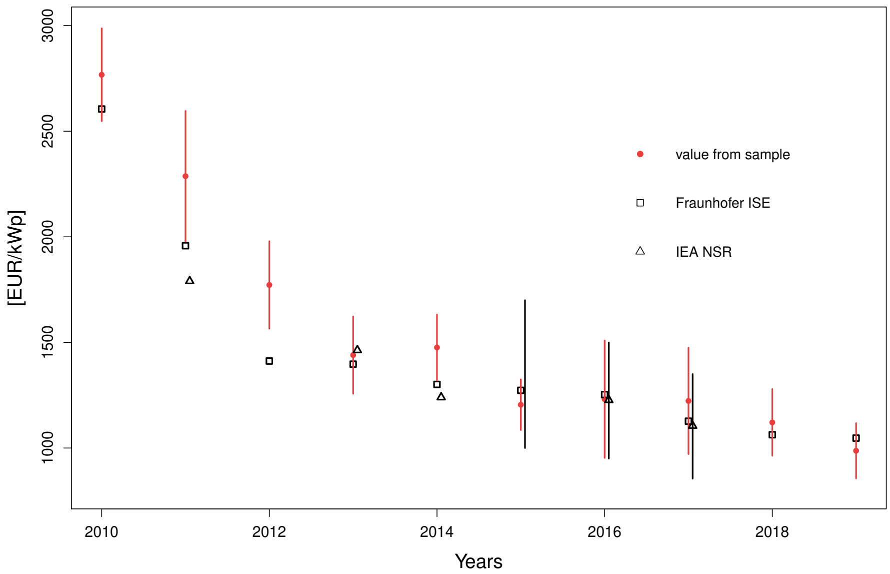

Figure 12. Market prices of PV installations compared to average prices for PV installations managed by EC in Germany (size class 2). Market prices are taken from Fraunhofer ISE [36] and IEA-NSR [39]. If available from the sources, the uncertainty ranges are added, indicated as black lines. Red lines show the 1-σ error range of our calculations.

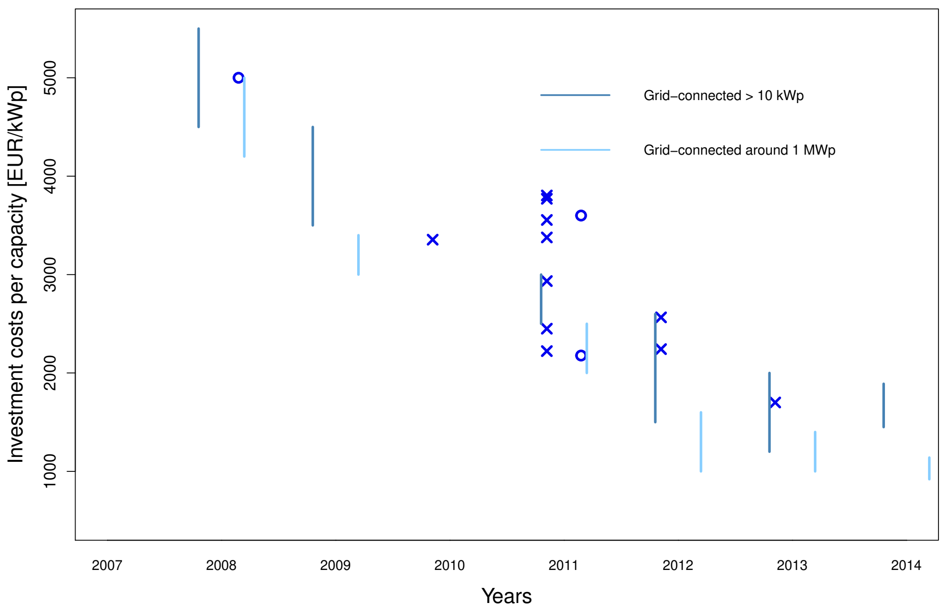

Figure 13. Investment costs per installed capacity by EC compared to the range of prices in the primary market in Italy. Ranges for market prices are taken from in [39] and shown as lines. Crosses indicate grid connected units >10 kWp and circles >1 MWp (own data sample).

For each PV plant acquired by these EC initiatives, Figure 14 compares the acquisition price faced by the community energy initiatives on the secondary market (black histograms) versus the difference between the acquisition prices and the secondary market prices (gray histograms). On the horizontal axis, we report the year of acquisition on the PV plants. If the gray histograms take negative (positive) values, the community energy initiatives paid a lower (higher) price for the PV plants compared to the secondary market price. The figure shows how in the majority of cases, the price paid by the initiatives to acquire a PV plant is lower than the secondary market price (i.e., the majority of gray histograms have negative values). However, the secondary market prices used in the analysis date back to 2014 [45], whereas the Italian EC initiatives have been acquiring PV plants mostly after 2014 (as shown in Figure 14). For the purpose of the analysis, we assume that prices decreased over time since 2014. Thus, while taking into consideration the limitations of the data used, we can assume that the Italian community energy initiatives have been, on average, aligned to the secondary market prices. This shows that the larger and more structured initiatives have been able to effectively compete on the secondary market of PV with more commercial actors. In Supplementary Material Table S2, prices for the secondary markets under the different FiT support schemes are reported.

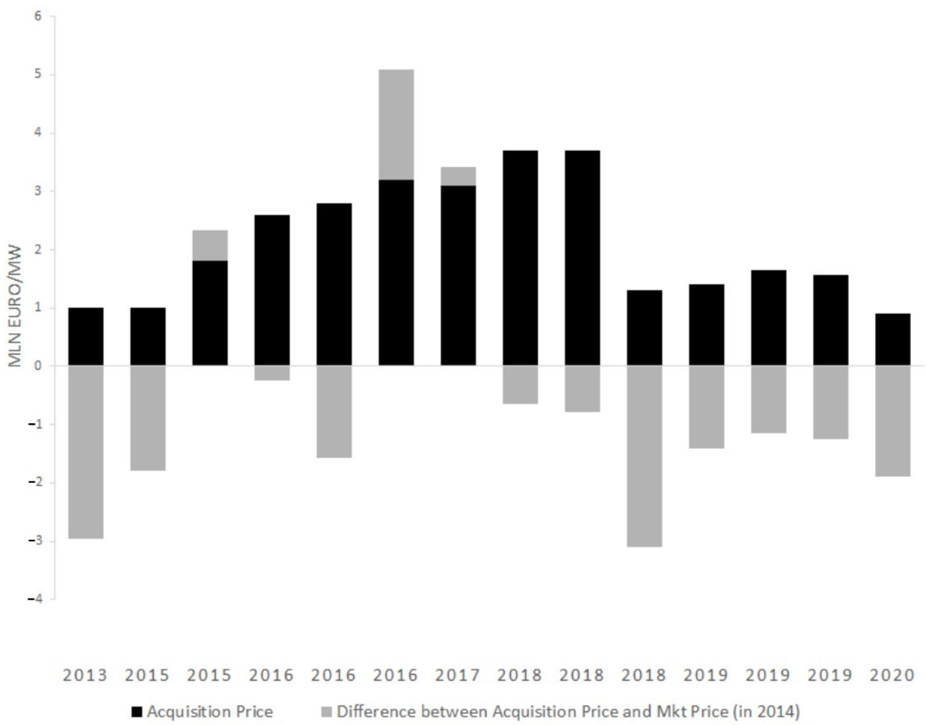

Figure 14. Acquisition prices faced by community energy initiatives vs. the difference between acquisition prices and the secondary market prices.

4. Conclusions

This paper investigated the evolution of energy communities (EC) and their contribution to the upscaling of PV capacities in the past two decades as a tool to exploit their potential for energy transition. To the best of our knowledge, the analysis is the first database attempts to quantify their aggregate input at national level. Utilizing two databases, we compared their activities in Germany and in Italy. We find that energy communities have added altogether approximately 0.85 GWp, establishing more than 3700 PV plants in both countries, with Germany accounting for over 3600 of the plants. Although a remarkable quantitative difference exists between the two countries, the mechanisms behind this growth are similar. The growth in EC has been facilitated by both FiT in support of PV installations and remarkable reductions in prices for PV modules and installation costs since 2010. These conditions have made PV investments profitable and relatively low risk, creating favorable conditions for the development of EC initiatives investing in the PV sector, both in Germany and Italy. Most importantly, while energy communities are still emerging actors in the PV sector, our analysis does not find evidence of an under-performance in the market as published by IEA-RETD [16]. Overall, a trend towards expanding activities as well as financing larger installations can be observed in Germany and Italy. However, the growth of EC activities slowed down with the reduction of policy support schemes. Our findings also have methodological consequences as they allow estimating PV investments from capacity data, which are often better known and more reliable.

The statistical analysis furthermore revealed that EC activities coincide with regions where households have a higher income at their disposal. Moreover, EC can largely be considered as local initiatives, and they are in particular active in rural and intermediate rural–urban areas. This finding is further supported when analyzing the correlation between population density and the location of EC activities. Specifically, the distributions of population density across the whole country compared to its distribution within the EC sample roughly follow the same pattern, suggesting that the distribution of population density is a proxy for EC activity.

Our analysis has several limitations. Most importantly, the systematic collection of data is still in its infancy and many entries rely on error-prone self-reporting as well as on the merging of data from different sources. Therefore, the results of the statistical analysis should be seen as a rough estimation and trend analysis.

The investigations in this paper provide novel insight into the assessment of EC activities in Europe and their current and potential relevance to supporting a citizen-led transition to renewable energy through the enhancement of PV diffusion. Three perspectives of research deserve to be further developed: With respect to EC model diffusion, attention should be first paid to the actual involvement of citizens in quantity (as EC members) and in quality (as regards decision making processes for activities and benefit distribution) as conditions that might favor or hamper EC development. Then, with respect to the relevance of EC for PV exploitation, the role of geography for starting and organizing EC should be better understood and quantitatively linked to the potential upscaling of renewable technologies and other energy services, e.g., for the urban penetration of PV or the reorganization of public transport in rural areas. Third, the sustainability of business models used by EC for adopting PV technologies should be better assessed. The business models are currently challenged by lower FiT and policies favoring large-scale enterprises. The future will show how EC will be able to adapt to these new market conditions.

Supplementary Materials: The following are available online at https://www.mdpi.com/1996-1073/14/8/2258/s1.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open-access journals
TLA	Three-letter acronym
LD	Linear dichroism

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PAPER VI: BUSINESS MODELS OF ENERGY COOPERATIVES ACTIVE IN THE PV SECTOR—A STATISTICAL ANALYSIS FOR GERMANY.

RESEARCH ARTICLE

Business models of energy cooperatives active in the PV sector—A statistical analysis for Germany

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Abstract

Energy markets have opened up to new actors and business models. We perform an empirical investigation of energy cooperatives (EC) investing in the photo-voltaic (PV) market. Deploying a unique database for Germany with 584 EC covering two decades of activities, we provide statistical evidence on their businesses, members and customer segments, production units, and financial status. The analysis yields that German EC active in the PV sector have invested about one billion EUR, managing more than 4400 PV installations with an aggregate capacity of roughly 700 MWp. Nine different business models currently prevail. The latest developments show that EC are adapting to changing market conditions, expanding their activities, and searching for new investment and business opportunities.

Author summary

Electricity markets see an ongoing liberalization since 1990' and new actors engage in electricity production. As of today, German energy cooperatives have invested about one billion Euro to install about 4400 PV units with a capacity of about 700 MWp. Cooperatives are legal vehicles, where the members decide on projects and finances, following the one-member-one-vote principle. This democratic decision-making structure alters the conventional type of business models. We investigate in this paper, what business models energy cooperatives have been developing over the last years. Building on a database with activities of 584 energy cooperatives in Germany, we provide statistical evidence on their businesses, members and customer segments, production units, and financial status. We also lay open how the activities of energy cooperatives are influenced by governmental support schemes.

energy transition and social innovation), and No 952851 (project DRES2Markets - Technical, business and regulatory approaches to enhance the renewable energy capabilities to take part actively in the electricity and ancillary services markets). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Introduction

Purpose and outline

Electricity markets continue to undergo stark changes triggered by the liberalization of energy markets in Europe during the late 1990s and further fueled by revolutionary developments in the Information and Communications sector, as well as by the necessity to reduce green house gas emissions and to switch to sustainable pathways. The transformation of the energy system coincides with fast technological progress of photo-voltaic systems, making them economically competitive with fossil fuel-based electricity generation [1, 2]. With this, the diversity of actors in the energy markets has increased and the pressure on incumbent enterprises to adapt to changing market conditions has been growing. In parallel, opportunities for economic ventures of individual citizens and collective actors in electricity markets arose, including energy cooperatives (c.f. [3]). As a result, purely market-oriented business models are being expanded by additional value propositions, such as community and environmental benefits.

To the best of our knowledge, this paper is the first offering empirical and comprehensive investigations of the business models deployed by energy cooperatives (EC) investing in the photo-voltaic (PV) market. We provide statistical evidence for the case of Germany, because it is the largest country by population in the EU, many EC are active, and unique access to data through the official market registry 'Marktstammdatenregister' exists. With our empirical investigation, we address the lack of quantitative studies in the field [4–6]. Our research contributes to filling this gap by deploying a unique database of 584 registered energy cooperatives active in the PV market, which draws from a number of sources. To structure our statistical analysis of their business models (BM), we utilize the canvas originally developed by Osterwalder and Pigneur [7]. We seek to answer the following questions:

1. What business models are deployed by energy cooperatives (EC) in Germany investing in the PV sector?
2. What is characteristic of their business models (BM) and which one dominates?
3. What is the evolution of investments undertaken by EC and how sustainable are the BM?

In the following section, we first briefly characterize EC and sketch their room to maneuver in the German PV market. Section 2 details our method for the empirical analysis, which is structured along a business model canvas for renewable energy. Results are presented in Section 3, followed by a discussion of answers obtained to the questions raised above. The paper concludes with Section 4 on the implications for future opportunities of EC as actors in the energy market.

EC as member- and market oriented business organizations

Energy Cooperatives (EC) are business organizations governed by cooperative law [8]. While many have been founded in recent decades, some of them have been part of this tradition for over 100 years. German EC active in the PV sector are regulated by German Cooperative Law, Genossenschaftsgesetz (1889/2017) [9]. Cooperative Law regulates the formation, operation, and closure of an EC. It builds on cooperative traditions as well as on the principles of the International Co-operative Alliance, which are 1) Voluntary and open membership, 2) Democratic member control, 3) Member economic participation, 4) Autonomy and independence, 5) Education, training, and information, 6) Cooperation among cooperatives, and 7) Concern for community [10]. EC differ from profit-oriented business associations in that they offer a value proposition and promotion for their members. Therefore, EC are member-oriented corporations, although the degree of market- vs. member-orientation may differ across EC [5].

The strong orientation towards members has consequences on how decisions are made in an EC. Herbes, Brummer, Rognli, Blazejewski and Gericke [4] stress that the management acts much less autonomously than the management in private enterprises, e.g., requesting approval of decisions from its members even if not required by the statutes of an EC. It should also be noted that EC occasionally change their legal forms, becoming private corporations or the other way around.

While the cooperative form differentiates EC from for-profit enterprises and investor-owned companies, all are strongly influenced by regulations that frame business actions in the energy markets. The German Renewable Energy Sources Act [11] is the most important legislation for the development of PV. Its first iteration came into force in 2000, introducing feed-in tariffs and market premiums, as well as ensuring grid access for RE facilities. It has often been presented as a best-practice example of national renewable energy policies and has led to a major increase in their deployment (c.f. [12]). The German Renewable Energy Sources Act has since gone through major changes in 2009, 2012, 2014, and 2017, gradually reducing financial support for renewables as investment costs for installations decreased. Furthermore, renewable energy technologies were introduced into the auctioning system for bidding on new energy projects and the maximum installed capacity that is financially supported was capped. Subsequent subsidy cuts and newly implemented restrictions negatively impacted EC activities after about 2012 [6, 13–15].

In this regard, the development of PV module costs becomes crucial; c.f., Strupeit and Neij [1] for a detailed analysis of German PV market prices. EC choose different methods to deal with the consequences, e.g., avoiding thresholds or splitting installations to avoid requirements that come with larger scale. Indeed, it is only very recently that cost efficiency gains from cumulative experience with PV technology have become strong enough to compensate for the low feed-in tariffs [14, 15]. Accordingly, past studies have shown the need for cooperative enterprises to switch to more flexible business models to adapt to changing market environments [16–18]. To our knowledge, this paper provides the first comprehensive review of the characteristics and evolution of business models used by EC active in the PV sector.

Materials and methods

Analysis framework: Business model canvas

For our analysis, we modify the customer-centered business model canvas (BMC) developed by Osterwalder and Pigneur [7], which is well-suited to study markets in transition. The BMC is a tool that helps to structure and develop business models; it can fit on just one page but it can also be complemented by additional sections detailing its components. The simple structure features pivotal components of any business endeavour, including 1) key partners, 2) key activities, 3) key resources, 4) value proposition, 5) customer relationships, 6) channels, 7) customer segments, 8) cost structure, and 9) revenue streams. The business model canvas of Osterwalder and Pigneur [7] has been broadly applied by practitioners, but it is also used by researchers as a structuring framework [19, 20].

Dilger, Konter and Voigt [5] and Mazzarol et al. [19] apply Osterwalder's BMC to the context of EC. The latter present a thorough comparison between the investor-owned business model and the co-operative and mutual enterprise business model, emphasizing the importance of social objectives alongside the economic ones and the central role members play. Therefore, a canvas for cooperatives should specifically account for purpose, member value proposition, and share structure. Dilger, Konter and Voigt [5] add the member-orientation that is specific to cooperatives to the original model of Osterwalder and Pigneur [7], prompting a reorganization of the canvas along key partners, customers, and members; although the

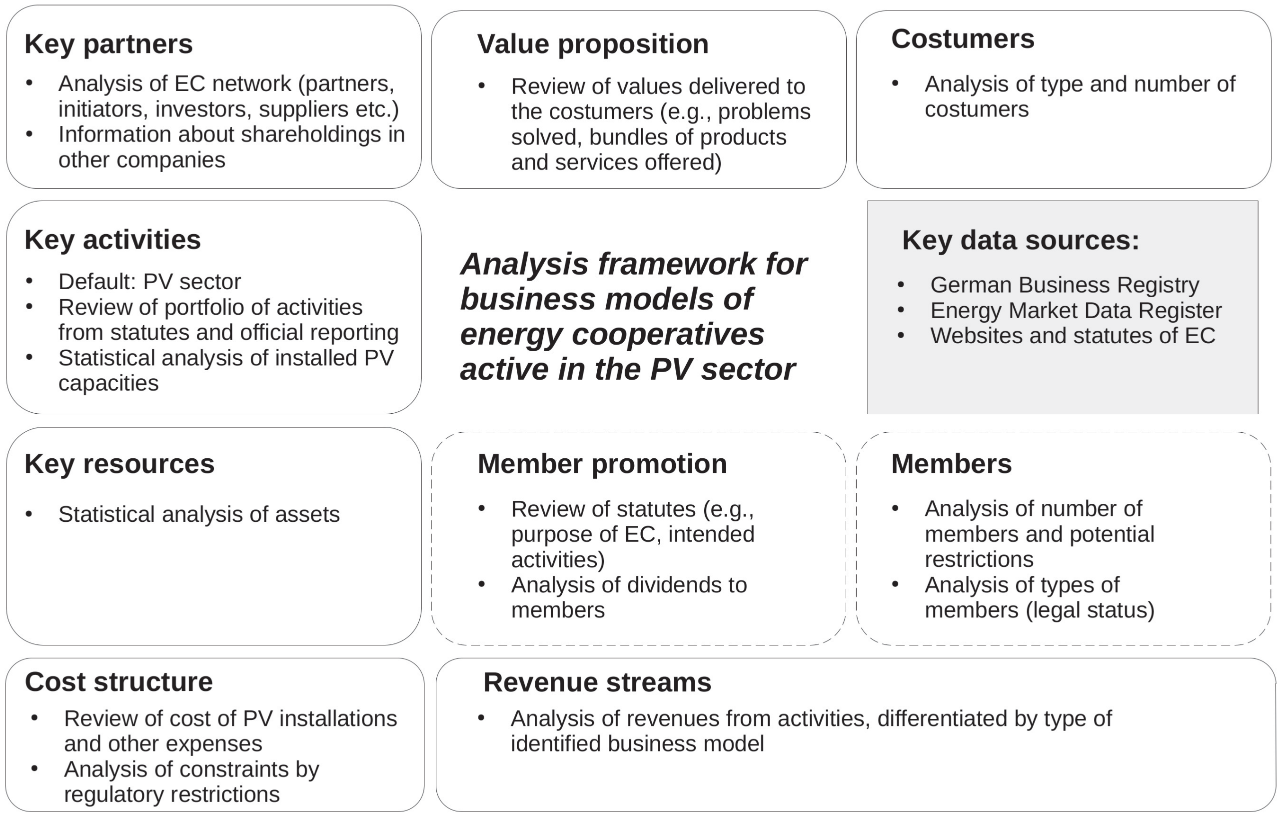

Fig 1. Methodological framework for the analysis of business models of German PV energy coops with examples of statistical information analyzed. Based on the business model canvas developed in Osterwalder and Pigneur [7] (categories in boxes with solid lines) and Dilger, Konter and Voigt [5] (boxes with dashed lines).

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last two are not sharply distinguished from each other. Dilger, Konter and Voigt [5] argue that this depends on the level of market vs. community orientation of an EC. As a consequence of extending the original BMC for EC, the value proposition is further complemented by 'member promotion' and channels for the member segment and member interactions. We build on the work of Dilger, Konter and Voigt [5], but bring the BMC again closer to its original structure as a one-page tool. This better serves the purposes of our analysis in deriving and assessing generic types of EC business models with the help of the compiled database. Fig 1 shows the resulting BMC used in this paper together with the types of analysis to be performed for each component. The next section, together with additional material collected in the Appendix, provides the details of the data analysis and the description of data material compiled.

Data compilation

The analysis presented in the manuscript draws from data collected for the ENBP Inventory "Energy by people"—First Europe-wide inventory on energy communities. The data have been compiled by the authors and are published open access with dataverse.no, see doi.org/10.18710/2CPQHQ.

The compilation of data used in this manuscript draws from various websites, portals, and databases for the German term 'Energiegenossenschaften', abbreviated 'e.G.'. Data on German energy cooperatives deployed in this paper are limited to cooperatives owning PV installations and having a primary business activity related to the energy sector. This excludes, for example, agricultural cooperatives, local credit cooperatives, or housing cooperatives which still may own and/or operate PV installations.

Data were sourced from official registries, such as the Energy Market Data Register [21], Federal Gazette [22], Common Register Portal of the German Federal States [23] and the Commercial Online-Register [24], as well as individual websites of energy cooperatives. We chose 2016 as the base year for the statistical analysis, which is a compromise. In that year, the German Renewable Resources Act went through major changes. At the same time, later years offer less data, because EC are only required to report on a yearly basis but delays are common.

In addition to the quantitative analysis, we conduct a systematic text analysis of EC statutes, focusing on statements regarding membership requirements, purpose (stating the main goal of an EC), and lines of business (specifying activities to achieve the goal). Statutes were sourced from EC websites and/or from Bundesanzeiger Verlag [22]. It is important to note that EC are not obliged to publish their full statutes. The publication of the lines of business on EC creation and updates are required. The purpose statement of EC outlines its general goal. The lines of business provide information on the areas of activity. Complete statutes were obtained for 342 out of 584 EC; purposes for 374 EC, lines of business for 562, and membership requirements for 286 EC. Additional information on data collection and methods of analysis is available in the Appendix and as metadata to the ENBP inventory at dataverse.no.

Results

Key partners

EC networks include a diverse range of partners and suppliers, including communal institutions (who are relevant for approval processes, as providers of potential roof-top spaces etc.), citizens (as providers of space for PV installations, as potential members and customers), other EC (for sharing experience, expanding activities), umbrella organizations such as the Cooperative Federation (supporting the formation process, serving as an auditing body), and financial institutions (providing loans and credits), utilities (handling grid connections), electricity service providers, and building companies and other enterprises (carrying out installations, monitoring, and maintenance; serving as a vehicle to reduce administrative and/or approval efforts).

Data allowing us to systematically quantify EC network parameters are scarce, because the data are largely voluntary in nature. Fig 2 illustrates a typical example of an EC network. The EC 'Bürger-Energie Unterhaching e.G' is of average size, with 2.5 MWp of installed capacities and 550 members. The figure shows that its network is connected to private as well as public sector institutions. The EC has merged with another EC. All network nodes are located within a 20 km radius. However, this particular EC also has a share in a greenfield installation located 400 km away. Close collaboration with energy businesses becomes evident from the shared address. Indeed, we find many cases where an EC address coincides with the address of a partner institution, or where EC websites are administered by them. The typical EC shown in Fig 2 was initiated by a spokesperson of the Agenda 21 and by the municipality of Unterhaching. Anecdotal evidence in our data sample shows that partners often continue to support the activities of the cooperative after their founding in various ways, e.g., by providing office services, with accounting services, or by employees being active members in the cooperative—in the case of the example, they participate in the Supervisory Board.

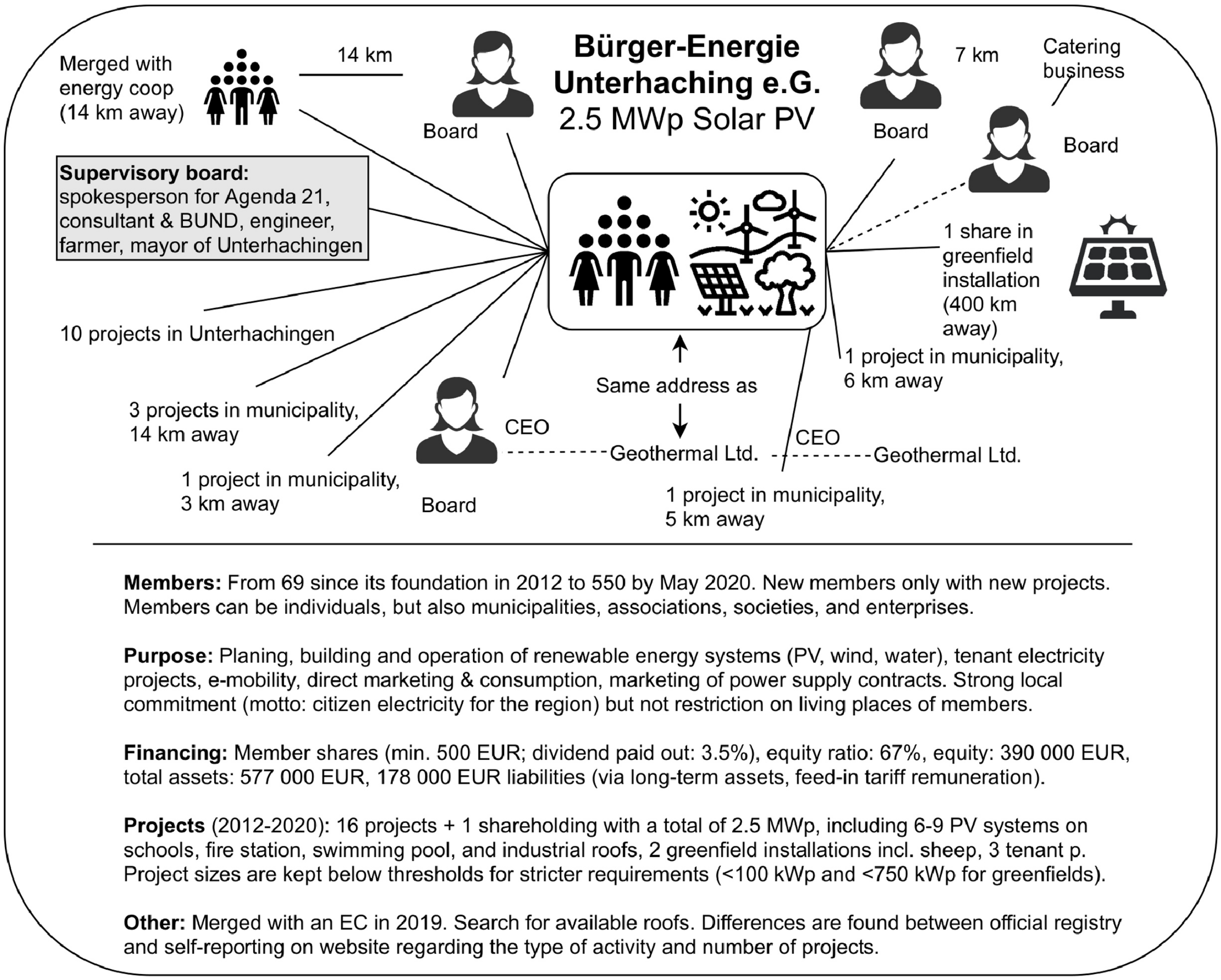

Fig 2. Example for an energy cooperative. Network and background of EC 'Bürger-Energie Unterhaching e.G'. Source of data: Bundesnetzagentur [21], Bundesanzeiger Verlag [22], North Data GmbH [25], and the EC's website, https://beu-unterhaching.de/. Abbr. BUND: Federation on Nature Protection and Environment of Germany.

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For 255 out of the 584 cooperatives information about the initiators of an EC could be collected. Fig 3 shows which groups dominate among them, i.e. citizens & citizen initiatives, municipalities (incl. municipal networks), and financial institutions. Note that shares do not add to 100% as multiple answers are possible. This figure, as all other following figures, have been generated with the help of the statistical software tool "R". Our findings agree with earlier results that emphasize the importance of private citizens [26, 27], financial institutions [27–29] and municipalities [30]. Interestingly, energy and municipal utilities are mentioned significantly less often. An example of the category 'other' are churches and agricultural cooperatives. A notable case is the collaboration of municipalities and financial institutions as initiators of EC. Typically, the financial institutions are also organized as cooperative banks or local savings banks. We did not find an example in our database where a large, nationally active bank was among these financial institutions. Similar to the exemplary case presented in Fig 2, we find

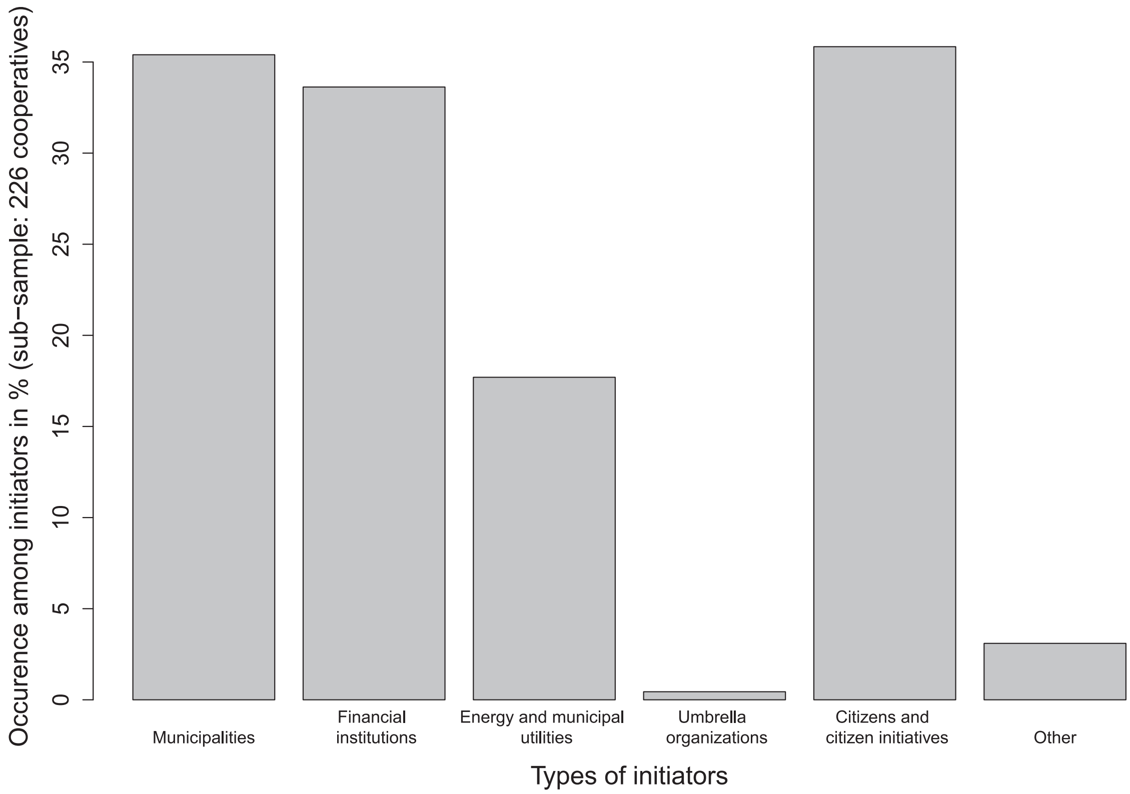

Fig 3. Share of different types of initiators of EC active in the PV sector (in %). Based on available information from 255 out of 584 cooperatives. Source: own data.

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that municipal engagement often started in connection with Agenda 21 activities and the development of local climate action plans.

A large number of EC explicitly state in their lines of business an intention to collaborate with other business entities (stated in 212 out of 562 cases), and 158 of them specify that the goal of the intended collaboration is to jointly create energy production facilities. Also explicitly mentioned are intentions for shared investment projects with partners connected to energy distribution systems (22), energy storage facilities (12), energy efficiency services (8), ICT infrastructure (2), and natural gas systems (1). A noteworthy explicit statement in the line of businesses is the goal to collaborate with businesses and research institutions to develop new technologies and concepts for the energy transition (7).

Finally, we also find 5 cases where the types of key partners envisaged for joint investments are explicitly restricted. The EC 'Bassumer Energiegenossenschaft' only allows the purchasing of shares in municipal utilities (Stadtwerke), the EC 'BürgerEnergie HaPeVi' limits the purchase of shares to the same region, the EC 'EnergieGenossenschaft KaufungerWald' forbids engagement with the nuclear sector, and the EC 'Zukunftsenergie Grevesmühlen eG' and 'Mittelbadische Energiegenossenschaft' only allow the purchase of shares in entities producing energy.

Members and customers

In an EC's business model, members and customers are both targeted, but these groups may overlap. Fig 4 displays a trend in the number of members and customers for EC. Note that

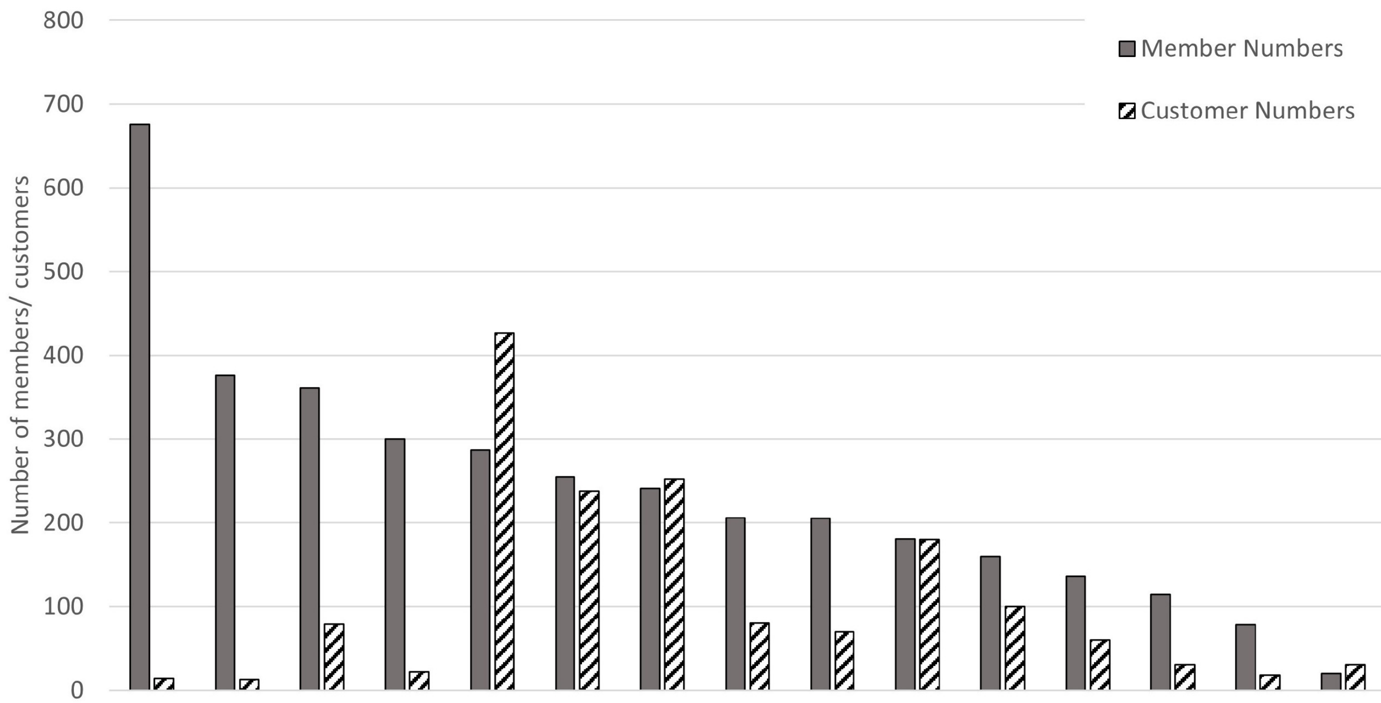

Fig 4. Comparison of the number of members and customers for 15 EC engaging in direct marketing of electricity. Source: own data.

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these data are limited and often not available for the same year. The figure, drawing from EC engaging in direct marketing of electricity with the help of the retailers 'Bürgerwerke' and 'Bavariastrom', still confirms the strong member orientation of EC, since the number of members typically exceeds the number of customers. Interestingly, medium-size and smaller EC tend to have higher shares of customers. Both the member and the customer segments alike are part of the local community or at least have strong local ties. It is noteworthy, that 4 EC specifically forbid any activities with non-members, and two EC require the permission of the board of directors for also targeting non-members.

Who can become a member of an EC is a matter regulated in an EC's statutes. Most EC use a template from an umbrella organization, which typically refers to three potential groups of members, i.e. natural persons, entities under private or public law, and private limited companies (Personengesellschaften). 74% of the EC whose statutes were available did not change the template in this regard. However, we found that 269 of 342 analyzed statutes specify allowed legal forms of their members, whereas 286 state at least a legal or regional requirement.

An exceptional case is the EC Windfang eG, which restricts membership to females. The EC Isarwatt eG requires their members to be connected to the housing sector, whereas the EC Energievision eG asks for compliance with the basic principles of the Christian church. 138 EC state geographic requirements, which has been specified further for 111 EC. 37% of these restrict membership to the municipal level and 30% to the county level. Exceptions are the EC BürgerEnergie Abtsgmünd e.G. who define a radius around their office and the EC Energievision eG who refer to the historical administrative unit of a diocese. Our findings confirm previous survey-based studies, which have shown that individuals, municipal institutions and local cooperative banks commonly form an EC's member base [26, 27]. Note that the representatives of the latter tend to serve on the steering committees of EC [27]. We report that the median number of members in EC active in the PV sector is 122.

The statistical analysis of purpose statements in EC statutes reveals a strong preference towards primarily addressing the needs of members over customers. Out of 374 EC with available purpose statements, 92% focus exclusively on members, expressed by the standard statement of promotion of their members. This is in line with German cooperative law [9] prescribing the main purpose of cooperatives as the financial, cultural, or social support of its members. A cooperative may conduct activities with other parties in pursuit of its main purpose, and 8% of the EC explicitly mention groups other than members. Exceptionally, three EC deviate from the standard statement in the following way. The EC Sonnenkraftwerk Henstedt-Ulzburg e.G. and EC Sonnenkraftwerk Bad Bramstedt—Auenland eG define their sole purposes as '*fostering environmental and climate protection through joint purchasing and operation of renewable energy installations*'. The EC Bürger Energie Markt Schwaben e.G. adds, furthermore, the purpose of energy saving, as well as to '*adhere to the principles of sustainability through joint business operation, also allowing non-members to run businesses*'.

Value proposition and member promotion

The overall value proposition of an EC active in the PV sector is the provision of related energy services to their members and, depending on the business model, additional customers. This includes, first and foremost, access to locally produced and distributed renewable-based electricity or consulting services about the same. On the one hand, an EC thereby offers economic benefits, including cost savings from joint purchasing of electricity and equipment, or dividends from selling electricity. On the other hand, an EC also contributes to solving environmental problems, as perceived by its members and customers alike. As already pointed out in the previous section, for both member and customer segments, the local ties are important. This adds a political dimension to the value proposition.

The analysis of statutes reveals the following statistical evidence. As a general finding, we observe that purposes are overwhelmingly focused on members, whereas the lines of businesses often broaden an EC's perspective towards other target groups and activities.

While economic benefits for customers and members depend on the different business models and related revenue streams, almost all EC state in their purposes an intent to tend to their member's financial needs (364 out of 374). Deviations from this standard are observed for less than 20%, including in purposes supporting the members' social, cultural, and environmental needs, e.g., addressing topics like regional energy independence, energy provision to members, climate and environmental protection, supporting the local economy, or citizen/member representation in the energy transition.

As regards the value proposition to customers and the promotion of members, EC mention in their lines of businesses the provision of 'consulting services in regard to production and use of renewable energy, energy efficiency and energy saving' (369), 'collective purchasing services' (192), 'energy supply to members' (25), and the 'marketing of energy produced by members' (5). Note that the distribution of economic benefits to members in the form of dividends depends on the actual shares held by a member, a matter that is regulated in the statutes and decided by vote each year in the general assembly. The overall picture of economic value propositions to members is accompanied by those proposed to customers. 281 EC provide information on value propositions for non-members and/or specify information on intended additional target groups in their lines of business. The two most important categories named are energy consulting (91%) and collective purchasing of energy production equipment (46%). Occasionally, facility management and marketing of energy produced by third parties was mentioned.

Table 1. Number and percentage of EC specifying intended activities in lines of business. Percentages are shown relative to the sample of 562 EC with available lines of business. Due to EC potentially engaging in several activities, aggregate categories are not the sum of all sub-categories. See text for additional explanation and numbers. Abbrev.: t.s. —total sample. Source: own data.

Activity category	Instances	% of t.s.
I—Energy infrastructure development	536	95%
By activity	535	95%
Construction & operation	421	75%
Financing	246	44%
Trade of energy infrastructure	252	45%
Fixed-term contracts	30	5%
Facilitation	117	21%
By position in supply chain	526	94%
Production	488	87%
Distribution	76	14%
Storage	65	12%
Demand reduction	53	9%
By technology	175	31%
PV	146	26%
Wind	26	5%
Other primary energy	28	5%
Heating	24	4%
Cogeneration	32	6%
II Combining PV with mobility	44	8%
III Energy trade	422	75%
Selling of own electricity	330	59%
Trading	106	19%
Resource trade	3	1%
Collective purchasing of energy	52	9%
Member/customer supply	27	5%
IV Consulting & services	423	75%
Efficiency consulting	66	12%
Savings consulting	57	10%
Energy efficiency services	81	14%
Energy savings services	27	5%
Administrative and other services	58	10%
Marketing and brokering	25	4%
V Public relations	267	48%
Education and awareness	22	4%
Public relations	255	45%
VI Beyond energy sector	48	9%
Agricultural & water sector	20	4%
ICT sector	12	2%
Real estate	8	1%
Financial inter-mediation	6	1%
Intern. development assistance	4	1%
Trade (e.g., local products)	5	1%

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189 EC specifically elaborate on the wider societal benefits they seek to provide in their lines of business. Most often, this is to conduct climate adaptation and mitigation projects (113 EC), support the local economy (22), public education and awareness raising (18), environmental protection (14), supporting social projects and institutions (13), urban and regional development (12), citizen involvement and representation (12), saving resources (11), supporting cultural projects and institutions (8), public services (6), international aid (4), and achieving energy independence (2). The above statements already indicate a strong intention of EC to contribute to value creation for the benefit of the local community. This can also be inferred from the definitions of the geographical scopes of activities, which are specified by 196 EC. 184 of them underline the importance of being locally and/or regionally active. Only 12 express striving for an engagement on the national and/or international level. For those who had stated their intent to create wider societal benefits (189), 149 also plan to achieve them at a local or regional level.

Key activities

As of 12/2020, 584 EC reported activities in the PV sector. The portfolios of activities cover a broad range beyond the construction and operation of PV installations to produce electricity for self-consumption or sale to the market. Altogether, these EC were managing a total of 4430 PV installation. The aggregate capacity of these PV installations adds up to 689–763 MWp, with a median unit size of about 30 kWp, with the range of the estimate depending on assumptions about the share an EC holds. For those where this information is unknown we assumed 0% for the lower range and 100% for the upper range.

Table 1 details these activities, sourcing from intended activities specified by the sample of 562 EC with available lines of business in their statutes. We categorize along activities related to energy infrastructure development (95% of EC from the sample), energy trade (75%), consulting and services (75%), public relations (48%), combining PV with mobility (8%), and activities beyond the energy sector (9%). The category 'Consulting and services' includes conducting and/or financing of building refurbishments, facility and project management, climate adaptation and mitigation services, creating an electricity brand and other marketing. Activities targeting public relations furthermore expand the focus of an EC from its members and customers to the general public in raising awareness for renewable energies. Only 14 EC exclusively refer to PV (combined with wind energy technology in 3 cases), while 10 EC expanded their activities to the PV sector even though their lines of business only refer to the provision of heat. Our statistical analysis of activities underlines the need and trend for EC to diversify their portfolio of activities and business models.

This finding can be exemplary illustrated when looking at the EC Unterhaching which we have presented already in the previous section. Starting in 2012, the EC currently manages 16 different projects in the PV sector. All of them are located within a 20 km radius. While the two first projects were small-scale (<50 kWp) and entirely based on the feed-in tariff business model, the EC extended in the following years in two ways—increasing in scale and switching to partial feed-in models with the majority of generated electricity being directly consumed at the point of generation. Recently, they also added projects to provide electricity to tenants.

Next, we turn to the evolution of activities. Fig 5 shows the year of installation for all the units in our sample. We focus here on development after the year 2000, i.e. not showing units which were installed earlier. We observe a pronounced peak around 2011 in the number of installations with a rapid decline and stagnation thereafter (2014–2017). Developments increase only in the years 2018–2020. Following these findings, we tag the years 2009–2013 as a boom phase, 2014–2017 as a stagnation phase, and the period 2018–2020 as a recent revival.

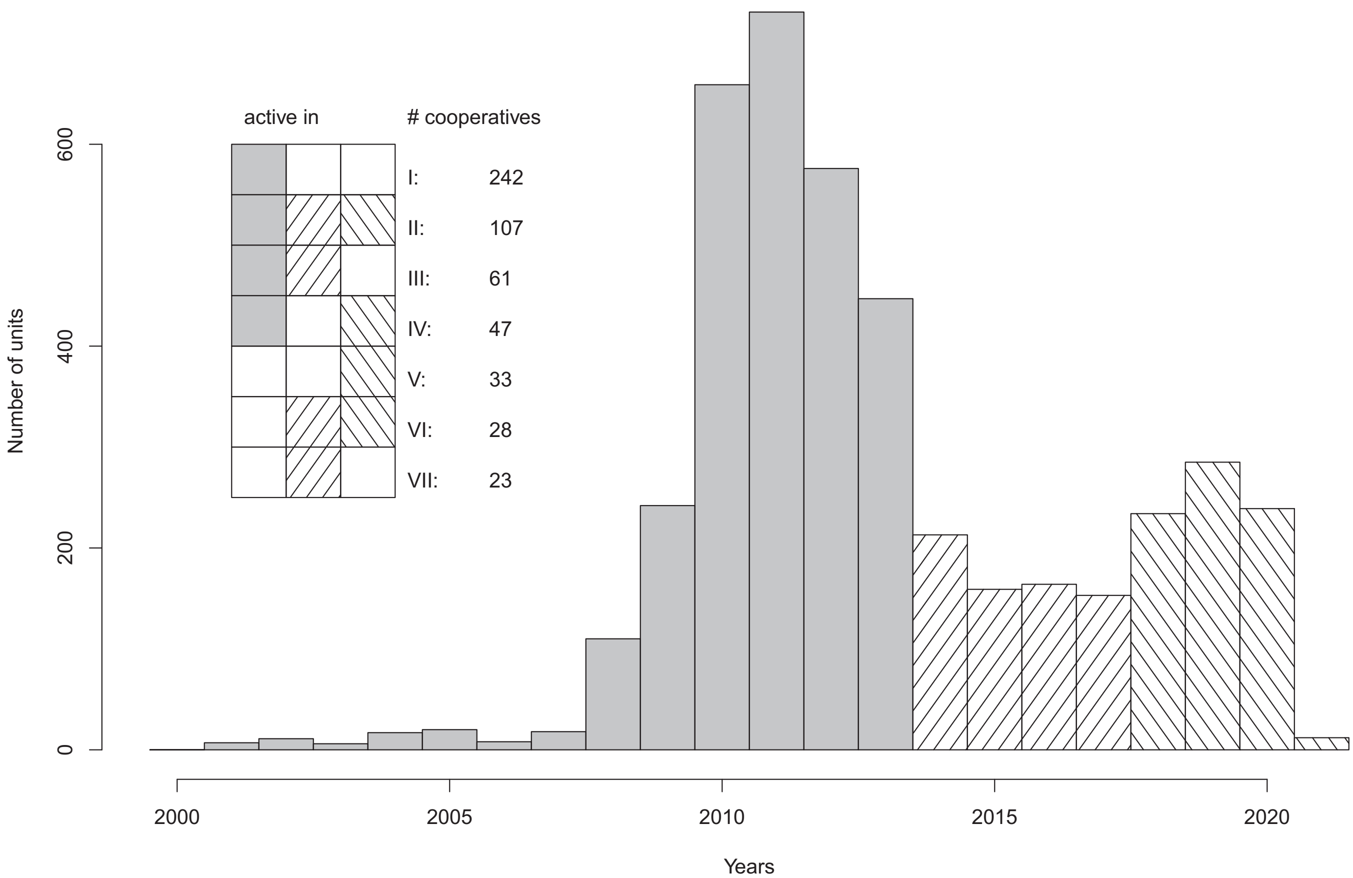

Fig 5. EC activities in the PV sector during the boom phase (grey), stagnation phase (hatched), and recent (hatched). The small inlay shows in detail how many EC were active or founded new in these periods. Source: Own data compilation based on Bundesnetzagentur [21].

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Similar behavior has been observed by other authors studying the age structure of energy cooperatives (e.g., [6, 14, 26]) or prosumer activities [31]. The dynamics in the age structure of energy cooperatives in Germany has been linked to major legislative changes reducing feed-in tariffs and increasing regulatory requirements such as direct marketing or mandatory auctioning. The recent revival is connected to the continued decrease in module prices as well as the adaptation of business models to the new policy framework. While Fig 5 presents aggregated numbers for existing energy cooperatives in a given year, it is also interesting to understand investment strategies of single energy cooperatives. In order to obtain stylized information for the overall sample and to abstract from the up-scaling pathway of a particular EC, we record whether an EC is active in a particular period of time. Insights obtained in this way are shown in the inset in Fig 5. 242 EC installed PV modules during the boom phase, stopping all installation activities after 2014, and only 107 of them make installations in all three periods. It is noteworthy to point out that those active during the stagnation phase are partly just about to finalize their installations. 47 EC paused during the stagnation phase, but have been active recently. Summarizing, the majority of EC scaled up their activities in the boom phase or the early stagnation phase, showing no activity thereafter. The results can be refined by cluster analysis of timelines of installation activities. Such an analysis, in part due to its mathematical complexity, is however beyond the scope of this publication.

The dynamics of these observed activities are mirrored in changes of statutes. Both underline the high pressure on EC to adapt to changing market conditions. While the majority stops their activities, some find new business models beyond the feed-in tariff BM. 77 of 584 EC have updated their lines of business between 2009–2020, indicating a shift in their business activities and an expansion of their portfolio. Updates commonly include shifting from the sole focus on the production of energy to also embrace energy storage, energy distribution, and demand reduction. Investment activities, energy trade, and an engagement in mobility services (e.g car-sharing, operating charging stations) are other examples of how EC develop and deploy new types of business models. The results coincide with the findings in Klagge and Meister [26], who observe a trend towards the diversification of activities as a reaction to legislative changes.

Key resources

Resources of EC include physical resources (e.g., space for installations on buildings and property, PV and other installed capacities together with their equipment), financial resources (e.g., cash, credits, lines of credits), intellectual resources (e.g., local knowledge and access to networks, brands, potential copyrights and patents), and human resources (e.g. employees of an EC, although less common).

The pivotal source for an increase in any resource is the member base of an EC. Most importantly, members finance activities through their shares and/or subordinated loans. Therefore, it is in the interest of an EC to secure their shares and maintain their operational basis. The matter is regulated in statutes. We find that 339 of 342 statutes regulated termination periods, which range between 3 to 60 months. 44% foresee 24 months for mandatory shares, 18% 12 months, 16% max. 60 months, and 9% less then 12 months. In 2016, data about shares are available for 458 EC. The median size of a single share was 250 EUR, but we observe two peaks in the distribution, located at 100 EUR and 500 EUR. Shares scatter between 1 EUR and 5,500 EUR and a member holds on average 9 shares. Looking at the capital available for a single EC, we find a median of 300,000 EUR, resulting from a median number of shares of 1,340.

In addition to financial resources contributed by the members, EC also regularly act as credit takers towards financial institutions (bank loans) and their members (subordinate loans). Unfortunately, data detailing these categories are scarce. A main source for financial information are balance sheets, which are published in Bundesanzeiger Verlag [22]. Since some EC are late in filing their reports, the optimal compromise between a large data set on the one hand and most up to date information on the other is the year 2016. Different financial metrics are reported depending on the legislative requirements as well as standards set by the regional cooperative associations, which act as certifying authorities. We focus here on the metrics 'total balance sheet sum' (as a proxy for the size of a cooperative), the equity ratio (as a metric for leverage between equity and loans), and the split between tangible fixed assets and financial assets to investigate whether a preference to invest into physical value exits. It should be kept in mind that the sample contains all EC active in PV, but that this might be only one activity among others. Therefore, not all of the capital recorded in the balance sheets is necessarily invested into PV. An example is the EC PROKON, which has the highest value of the total balance sums, but their main activities lie in the field of wind energy installations. Unfortunately, most of the EC do not publish a detailed overview of their assets which would allow discrimination between investment purposes. Hence, we can only use the total assets as an indication for the size of the EC, the complexity of businesses being run, and an EC's ability to allocate projects resources.

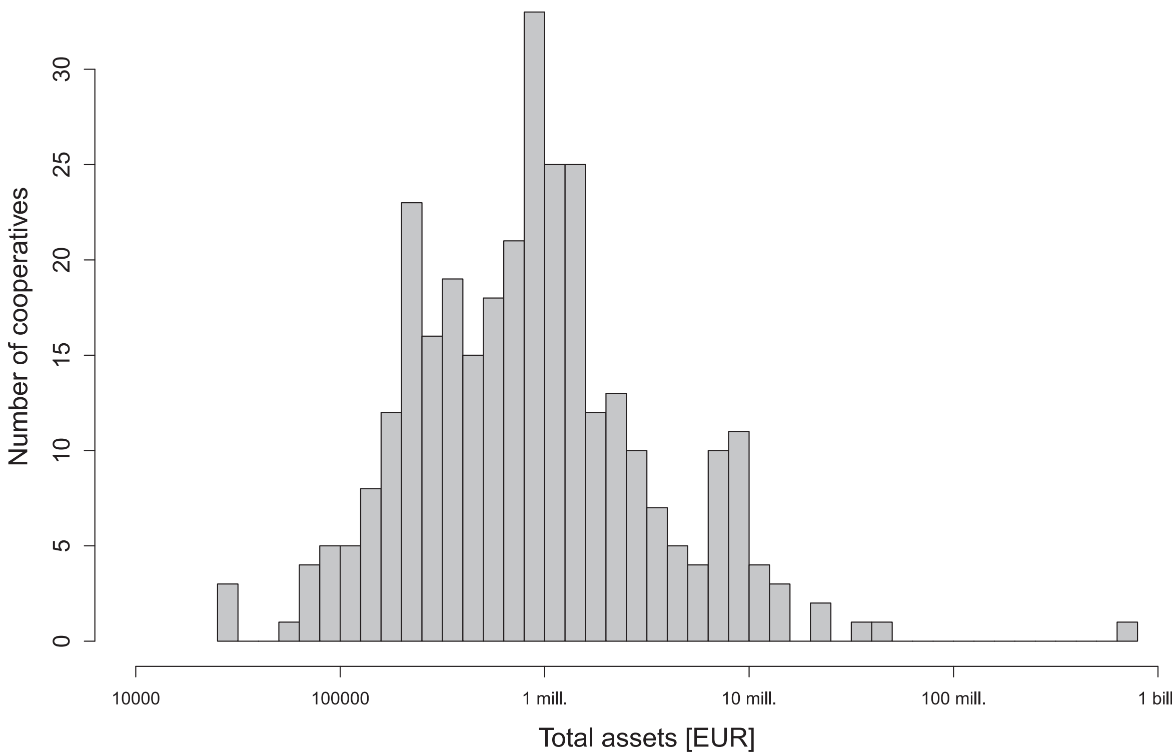

Fig 6. Histogram of the total balance sum. Sample size: 317 EC out of 584 EC. Source: Own data compilation based on Bundesnetzagentur [21].

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The distribution of the total balance sum across all EC is shown in Fig 6. As in the case of aggregated capacities, the horizontal axis is logarithmic, ranging from 10.000 EUR to 1 bill. EUR. The distribution is roughly bell-shaped with three peaks at around 300.000 EUR, just below 1 mill. EUR, and below 10 mill. EUR. Note that the linear, un-scaled distribution would be strongly skewed with a mean of 4.4 mill. EUR and a median of 0.9 mill. EUR.

The equity ratio is another important financial metric measuring the amount of leverage an EC has. This metric is calculated as the ratio of equity to the total balance sum. Fig 7 shows the histogram of the sample in this study (in grey), as well as findings on a smaller sample by Volz [27], and data for 300 municipal utilities [32]. We obtain a mean value of 49% and a median of 55% for the equity ratio. The result is well in line with Kahla et al. [33], who study citizen-led initiatives (Bürgerenergiegemeinschaften) in general for the year 2014. Fig 7 also shows that a quarter of all EC have an equity ratio larger than 90%, i.e. they finance their projects entirely from member shares. The finding confirms results from Volz [27]. The author and Herbes, Brummer, Rognli, Blazejewski and Gericke [4] discuss the tendency among EC to avoid loans. However, for the majority of EC (75%), equity ratios are spread rather evenly, which is a striking difference from Volz [27] who finds a bimodal distribution with a second peak around 30%. The author argues that this demonstrates rational behavior, as commonly observed in the commercial sector. Indeed, the sample for municipal utilities from PwC [32] also shows a median peak at 35%. We reckon, however, that the even distribution found in our larger sample originates from the high degree of diversity of EC in our sample as regards experience as well as business models and financing strategies deployed.

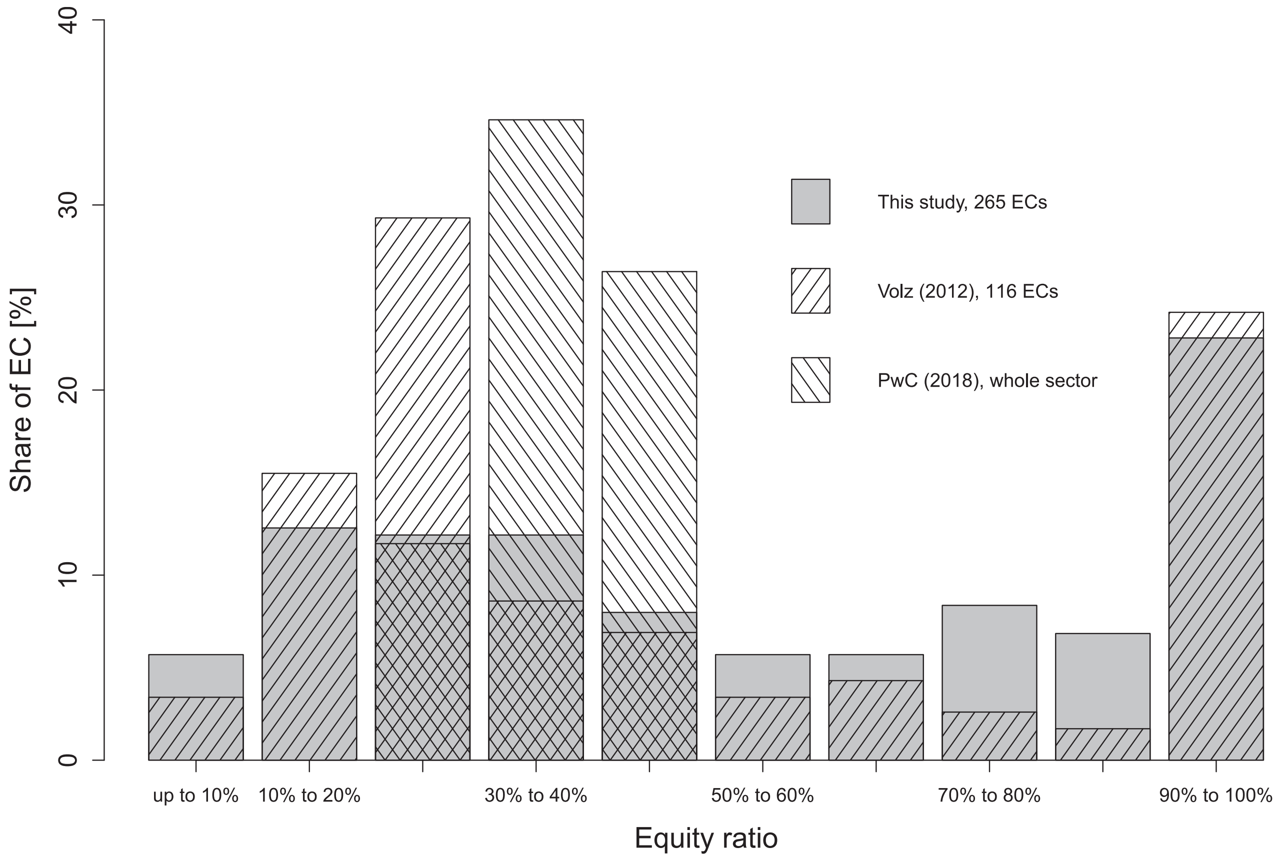

Fig 7. Histogram of the equity ratio. Source: Own data collection, compilation based on Bundesanzeiger Verlag [22].

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The analysis of yearly audits shows that EC overwhelmingly invest into tangible assets, rather than being financially active. Out of the 191 EC with information on the split of assets, we find 132 EC (69%) whose tangible fixed assets make up more than 95% of all their assets. On the other hand, 5 of the EC have less than 5% in the form of tangible fixed assets. The other 54 EC scatter evenly between these two extremes. For 278 of the 326 EC in the sample with available balance sheets, we can also obtain information on current assets. The median of 78.300 EUR and the mean of 936.300 EUR show once more a strongly skewed distribution with many EC having rather low current assets. For them, financing of activities from current assets is a challenge since 78.300 EUR is not sufficient to cover the costs for a typical size of a PV project. As a result, an EC would need to enlarge the number of members, of shares, or to take out loans in order to expand activities.

As regards the physical capital, the access to mounting spaces for PV installations is crucial. We find that the PV modules are overwhelmingly mounted on buildings (3228), as opposed to ground-mounted installations (146). Specifications for the types of buildings are also available, breaking down into households, public buildings, commercial sector buildings, agricultural buildings, industrial buildings, and others. We find that more than 54% of the PV installations of an EC are set up on public buildings, and that households are rather uncommon. Commercial buildings are in the second position with 18%. Least common are industrial buildings with just 2%. Our summary of the results is two-fold. First, the numbers mirror the requirements for the typical size of PV installations, which require roof spaces larger than those of residential

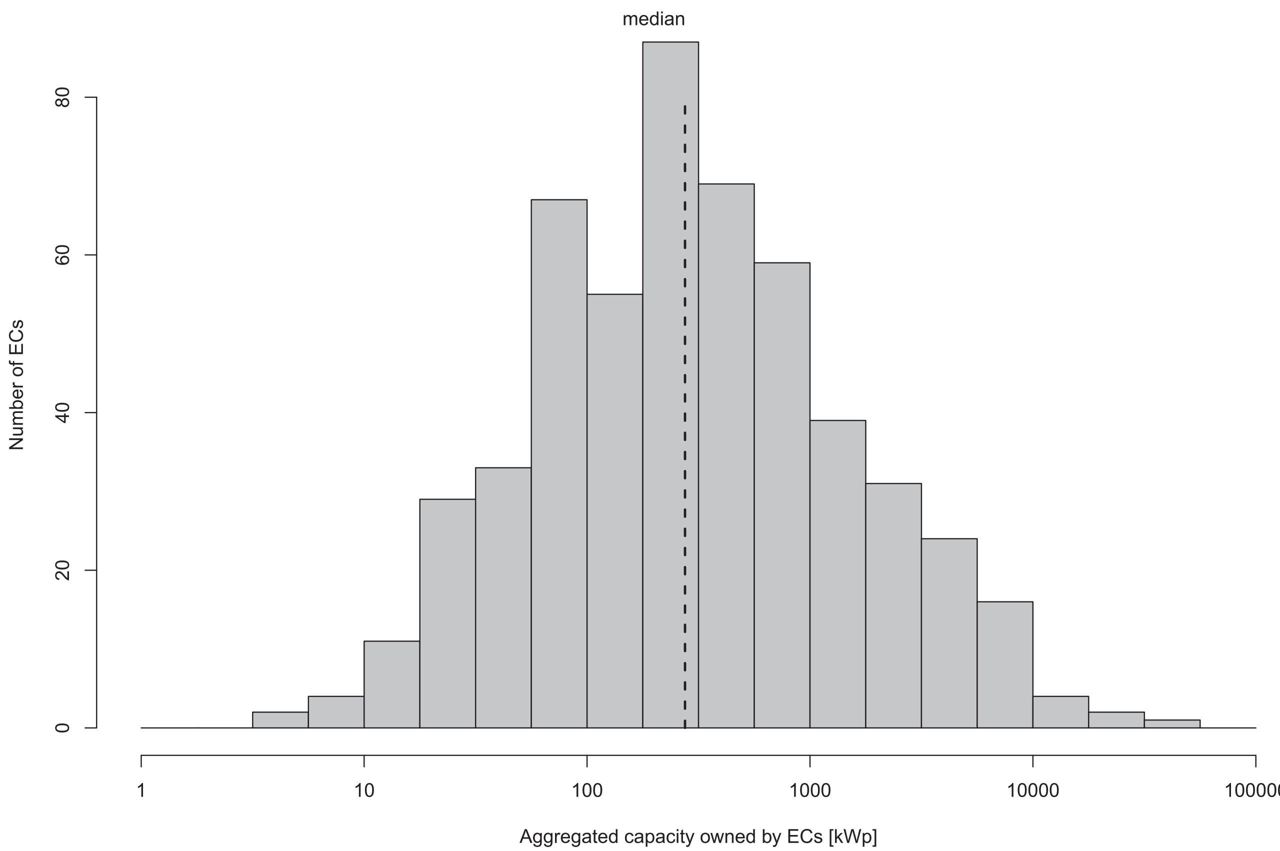

Fig 8. Histogram of the installed capacity per EC. Source: Own data compilation based on Bundesnetzagentur [21].

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buildings. Second, EC activities coincide strongly with having access to public spaces. In consequence, when public spaces are occupied EC will face additional pressure to change their business models. Anecdotal evidence from websites indeed underlines that many EC are currently searching for available roof space and have frozen their member base (to prevent lower dividends per member if activity cannot be sustained).

The aggregate capacity owned by a single EC can be obtained by grouping all 4360 entries in our database with information on capacities and ownership shares in units. The results are illustrated in Fig 8. Note the logarithmic scaling for the horizontal axis. The shape of the distribution resembles a log-normal distribution with a median of 285 kWp. According to the central limit theorem, the log-normal distribution is obtained for a stochastic variable being the product of a large number of positive independent random variables. Therefore, the result may indicate that the accumulated capacity depends on several factors, such as the numbers of members, the size and distribution of single shares, risk aversion in financing options, and the variation in up-scaling pathways. As presented in Fig 8, few EC have an aggregated capacity below 10 kWp, which basically implies one small-scale project. Similarly, there are only a few EC who own more than 10000 kWp. The distribution in Fig 8 clearly shows that the vast majority of EC manage between 10 kWp and 10 MWp, covering a large range in installed capacity as well as corresponding financial commitments. The corresponding coefficient of variation is 3.6, see Koopmans, et al. [34] for the definition. The result may again reflect the considerable spread in member numbers, the size of single shares, the risk aversion in

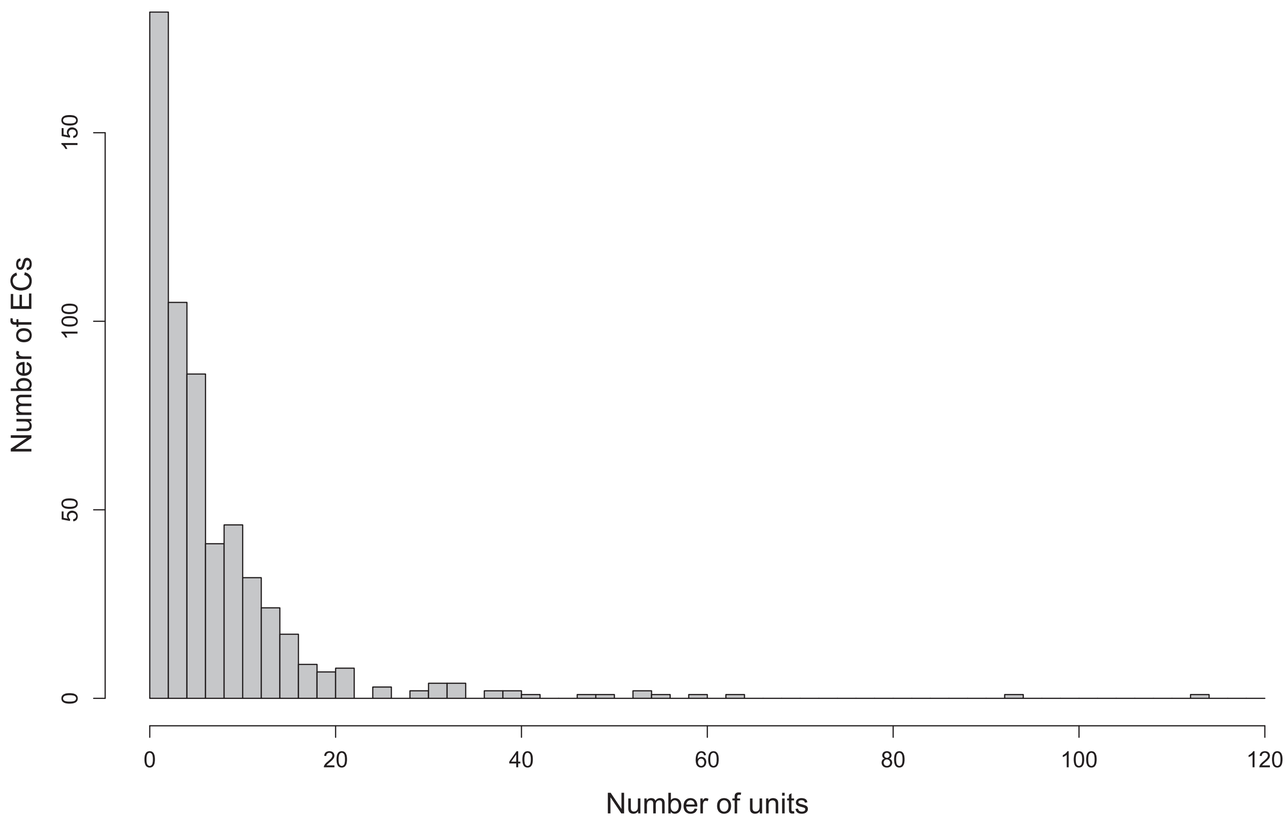

Fig 9. Histogram of the number of PV units managed by an EC. Source: Own data compilation based on Bundesnetzagentur [21].

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financing options, and the variation in up-scaling pathways among EC. Finally, note that inflation effects do not alter the picture significantly, as the time horizon is only 10 years.

Cost structure

Depending on the type and scope of activities, EC face different cost structures. Fig 9 presents the number of separate PV units managed by an EC. We are not aware of other publications systematically studying this information at a large scale. A histogram for 4375 units across all EC is shown. Out of the 584 EC, 9 have more than 40 separate units, one managing even as many as 116 units. On the other hand, 106 EC have just a single project to oversee, and another 76 have 2 projects. Accordingly, the histogram is strongly skewed to the left.

The installation costs for PV units are an important part of total costs. The historic development of these costs has been analyzed in Strupeit and Neij [1] and Wirth [35], who find a considerable decline in installation costs thanks to technological learning and economies of scale. Recently, this analysis has been redone for EC projects in Wierling et al. [36]. It has been found that EC do not pay higher prices for the installation of PV units compared to market averages. Fig 13 shows the evolution of prices for PV installations that EC have faced. As of today, PV modules are cheaper by a factor of 2.5 when compared with prices from a decade ago—which is a situation favoring the engagement of EC in the PV market. The figure contrasts these costs with remuneration possibilities through the feed-in tariffs, which distinguish between different size-classes of installation. Strikingly, both developments align very well, underlining the high responsiveness of policy adjustments to market changes.

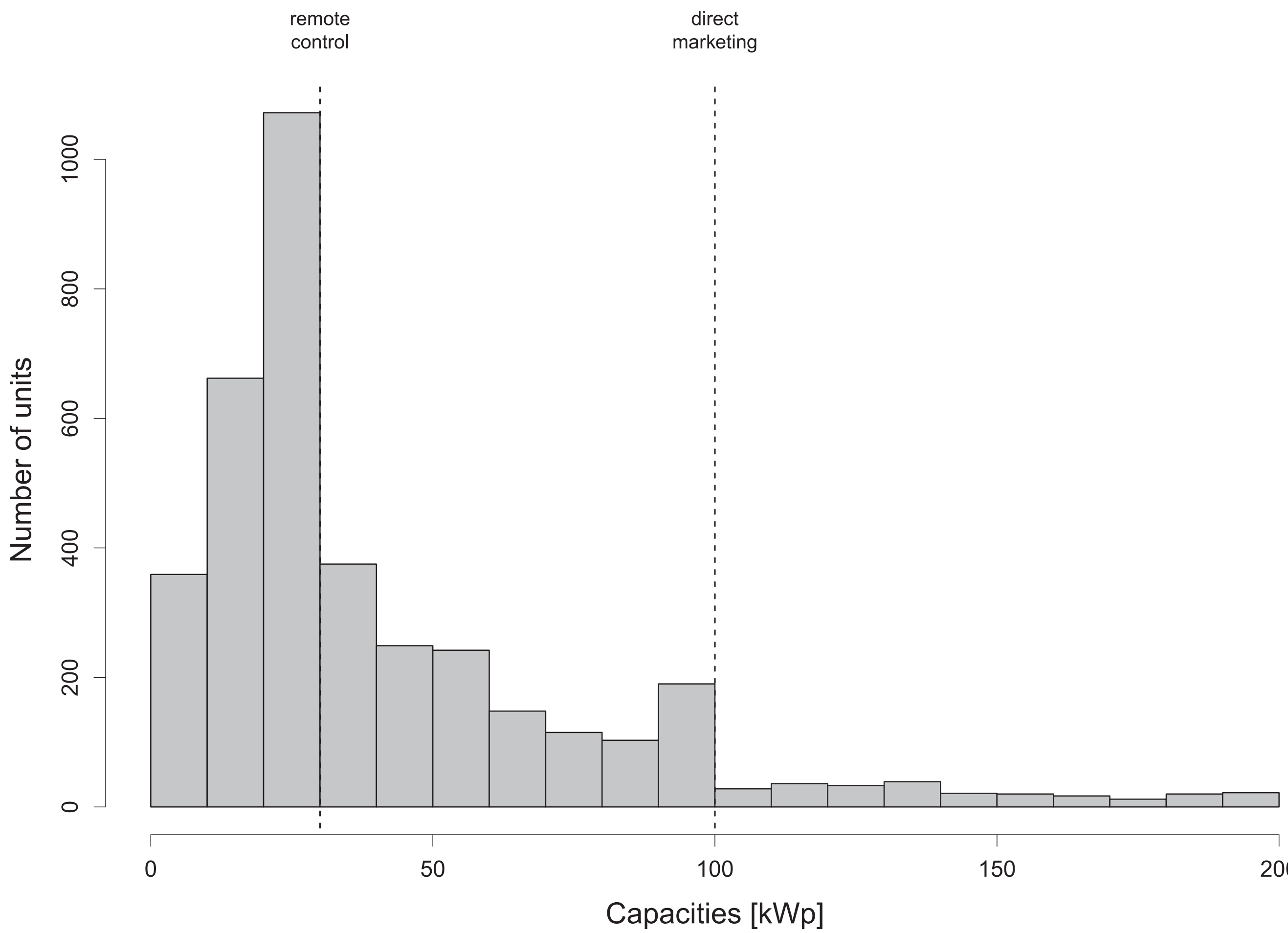

Fig 10. Histogram of the number of PV units by capacity for capacity size below 200 kWp. Source: Own data compilation based on Bundesnetzagentur [21].

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Regulatory constraints are connected with costs, also limiting opportunities for the up-scaling of businesses. The effect of regulatory constraints for EC is clearly visible when analyzing the number of installed units at thresholds defined in the EEG. A key technical requirement set by the EEG is the remote controllability of units above 30 kWp, which adds cost and complexity to projects. The 2014 revision of the EEG furthermore introduced mandatory direct marketing to settle the market premium through a competitive tender. Only units below 100 kWp are exempted from the requirement and can still benefit from feed-in tariffs, which are, however, progressively reduced. The participation in tendering schemes increases coordination and management needs for EC considerably. Indeed, keeping in mind the typical case of an EC which does not employ regular staff, this is a large burden. Similarly, mandatory auctioning for units larger than 750 kWp affects EC activities negatively. As a consequence of these constraints, installation operators tend to stay exactly below these thresholds to continue to maximize economies of scale. The effect is evident in Quaschning, et al. [37], who study PV units in the entire economic sector, irrespective of the type of owner. We repeat the analysis here for the 4375 EC-owned units (see Figs 10 and 11), showing histograms of capacities by installed units. Similar to Quaschning, et al. [37], peaks in the number of installations are found for values below 30 kWp, 100 kWp, and 750 kWp. Note that Quaschning, et al. [37] also

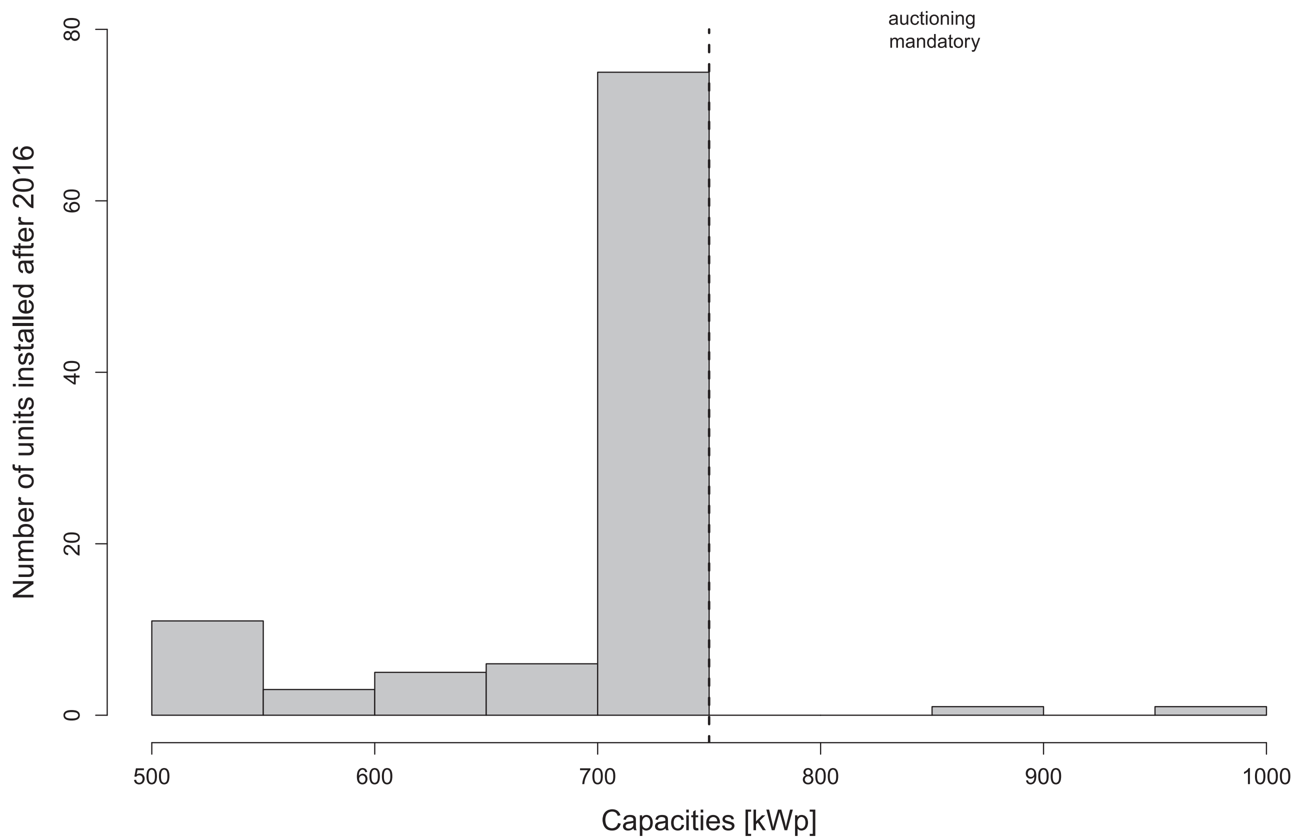

Fig 11. Histogram of the number of PV units by capacity for capacity size between 500 kWp and 1000 kWp. Source: Own data compilation based on Bundesnetzagentur [21].

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found a peak at a threshold of 10 kWp which is connected to the exemption from paying the EEG levy, which is not revealed in Fig 10 due to the choice of bins. However, our data also contain this feature though less pronounced, the number of installations in this lower segment is considerably smaller as households are not included.

Revenue streams

Generally, revenues can be generated from electricity produced and from offering expertise on local networks and PV markets. If EC operate PV installations, the electricity produced per year typically ranges from 900 to 1100 kWh/kWp, depending on geographic location, technical equipment installed, orientation of PV units, as well as weather conditions. In the boom phase between 2009–2013, all generated electricity was typically fed into the grid and remunerated by guaranteed tariffs over a time horizon of 20 years (Fig 12). As can be seen in Fig 13, guaranteed feed-in tariffs were later reduced from about 0.30 EUR/kWh to less than 0.10 EUR/kWh (note slight variations depending on the size of a PV unit). As a result, EC explored direct marketing as an alternative (i.e., the sale of electricity at the market EEX or direct sale to customers through the electricity grid). In case of electricity consumption by the customer at the point of generation (self-consumption), the electricity is not fed into the grid at a rate of 100% (see the increase in partial feed-in in Fig 12 after 2012). After legislative changes in 2014, direct marketing became mandatory for units larger than 100 kWp. The revenue from direct marketing

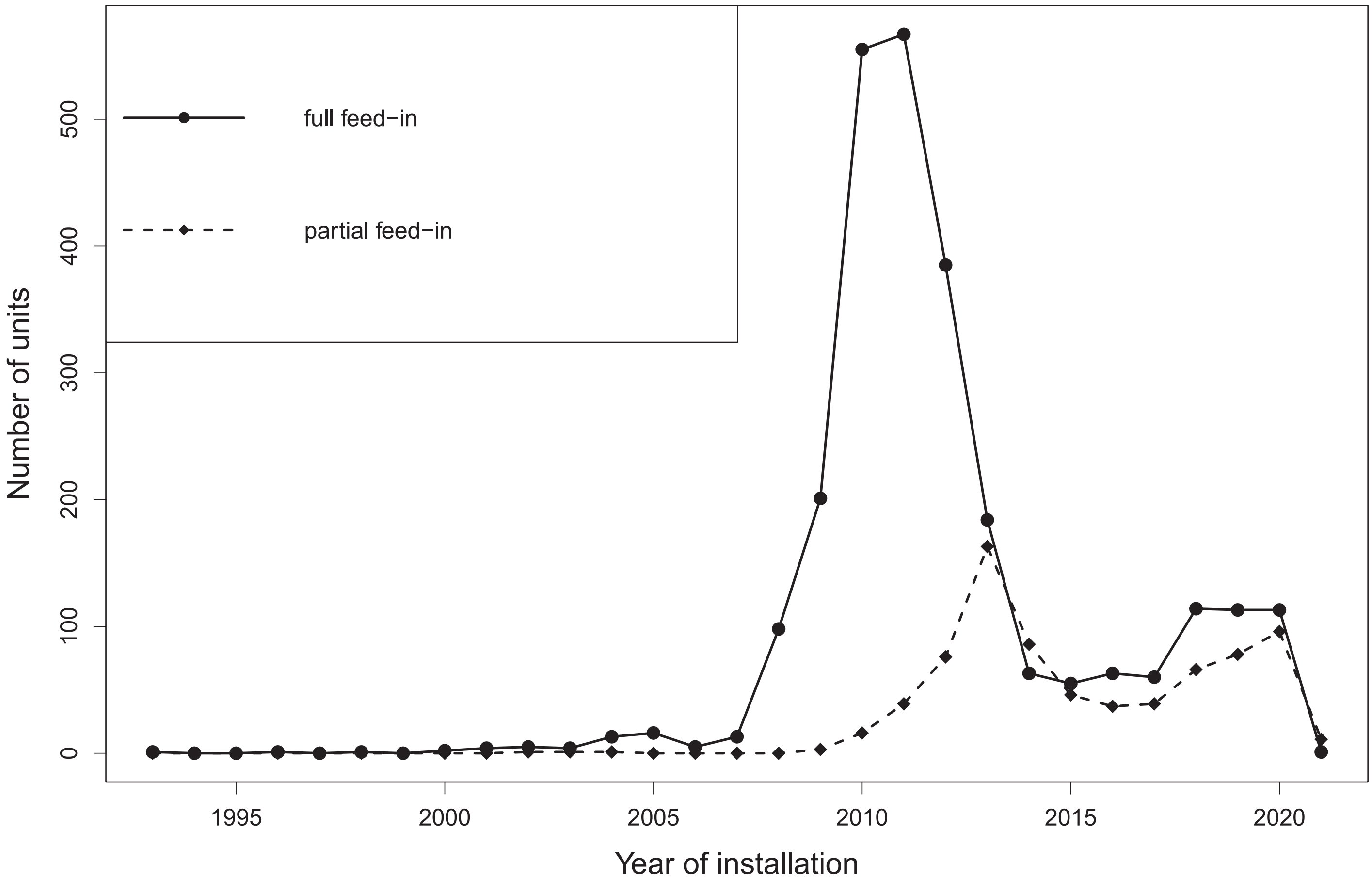

Fig 12. Number of yearly installed PV units with full (full line with circles for the yearly data points) or partial (dashed line with diamonds for the yearly data) feed-in to the grid. Source: Own data compilation based on Bundesnetzagentur [21].

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arises either from the market price for electricity plus a market and management premium, or from the price paid by customers. The latter, the end-user price for electricity, is typically higher than the market price (Fig 13). The EEG offers the possibility of mixing self-consumption with partial feed-in, opening up to a variety of business models. Among the more recent examples are investments into EV charging points.

Revenues connected with offering expertise are diverse. They include revenues from leasing PV installations and/or PV equipment, re-sale of PV equipment (typically small-scale installations mounted on balconies), and contracting (incl. energy-efficiency retrofitting, training, and consulting). Finally, an EC can generate revenues from holding shares in projects of other market actors and from receiving public funding. As we have reported in the Section 'Key Resources', EC often show conservative investment behavior, having a preference to invest in fixed tangible assets. However, some EC opt to invest in financial products to generate additional revenues.

Summarizing discussion

The analysis of intended activities of EC (sourced from statutes) and observed activities (as officially reported) allows us to answer our first two questions, namely 'What business models are deployed by energy cooperatives in Germany investing in the PV sector?' and 'What is

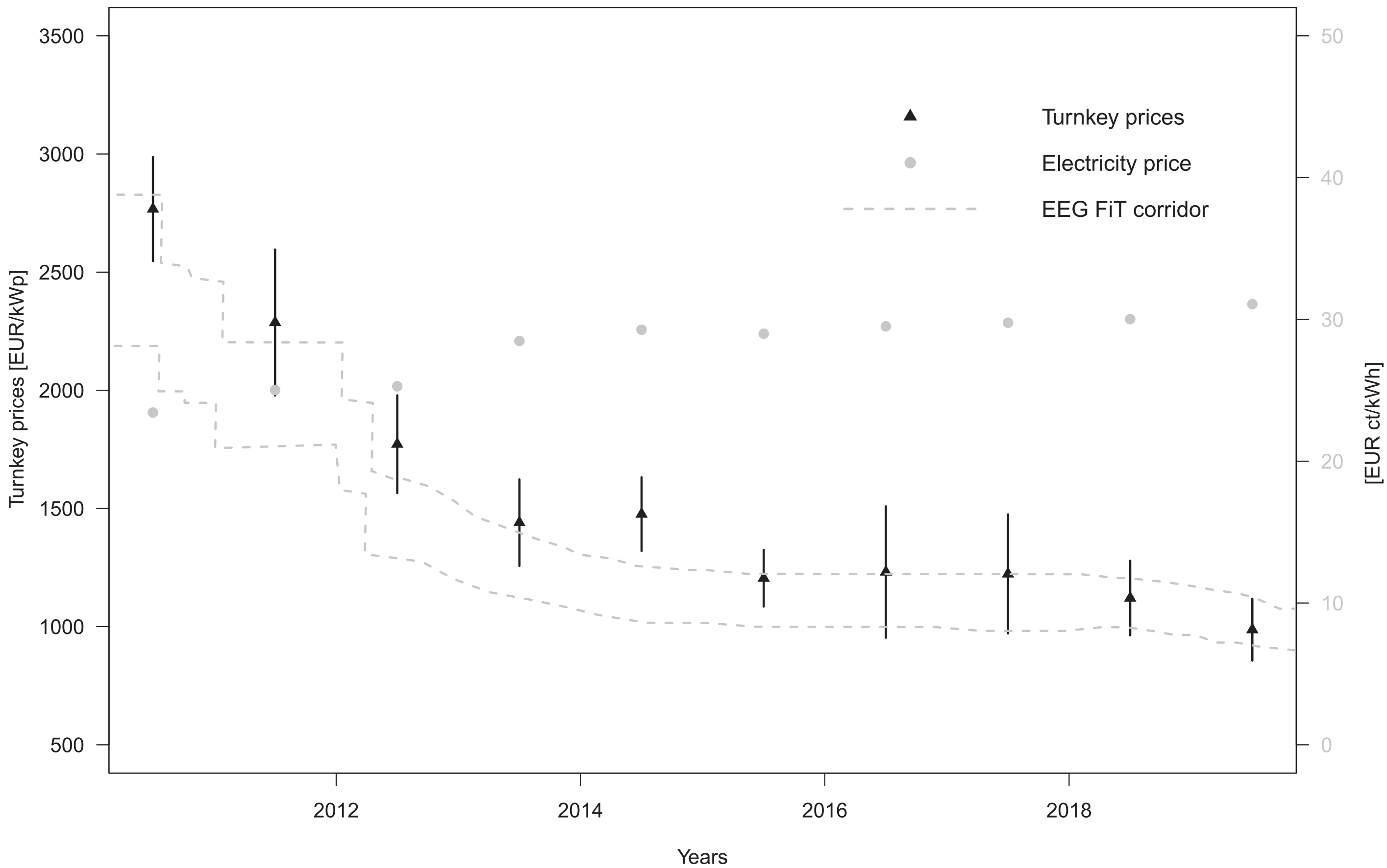

Fig 13. Historic development of turnkey prices for PV modules, corridor of feed-in tariffs (FiT), and household electricity prices. Source of data: [35, 36, 38, 39].

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characteristic for the business models and which one prevails?' The aggregated BMC for all 9 identified business models is presented in Fig 14. In all of them, the public sector is a key partner for EC to engage in a range of activities from the installation and operation of PV units to the provision of consulting & information services in the same domain. The local ties of an EC are crucial for all activities, helping not only to recruit members and customers but also to secure important resources such as finances and roof-top spaces. As the high equity ratios show, EC tend to be risk averse and invest with caution. This also underlines the generally high responsibility of EC towards their members and towards objectives other than short-term financial profits. However, these tendencies also limit the possibility for EC to experiment. Nevertheless, EC are responsive to changing policy and market conditions. As EC engage in different activities, a variety of business models are being deployed. The statistical analysis allows us to rank the following nine business models (BM) according to their relevance:

1. **Feed-in tariff BM**: focuses on the construction, purchase and operation of PV facilities. Relies on public sector partners for the provision of roof-tops or other spaces and on funding partners, such as local banks. Revenues depend on guaranteed feed-in tariffs (FiT). Members mainly benefit from dividends arising from FiT. Prevailing BM but starkly in decline due to progressive reduction of FiT and eligibility for new projects.
2. **Electricity sales BM**: based on the direct trade and/or sale of self-produced electricity at markets or to end-users. Requires either partnering with a stock market institution or

needs customer management. Revenues are generated from selling profits. Member benefit occurs through dividends from electricity sales.

3. **Leasing BM**: provides equipment to end-users on a leasing basis to generate electricity on the customer's roof-space. Revenues are created from leasing receipts.
4. **Tenant contracts BM**: are about the construction and operation of PV facilities on the roofs of apartment buildings, together with the provision of generated electricity to tenants. Revenues come from two options. The first operates under a free-pricing setup, fixed by the EC. The second falls under the regulation of the EEG, clause 23 ('Mieterstromgesetz') and has the advantage of a premium. The model is limited to the operation of < 100 kWp installations, has a price cap, and includes additional obligations for the EC to handle the provision of electricity to the tenant.
5. **Contracting BM** focuses on energy performance contracting, where the EC finances and installs either PV facilities or energy efficiency refurbishments (e.g., street-lighting). This is a typical BM to engage with public actors as customers. Revenue is based on customer payments in relation to cost savings resulting from energy performance upgrades. Members benefit through dividends.
6. **Coordinated purchasing BM** builds on the provision of affordable access to energy and energy equipment for members and customers through bulk-purchasing. Relies on private sector as retailers of the desired products. Revenues are generated from resales.
7. **Purchase of shares BM** focuses on investment into other (renewable) energy market participants, e.g., municipal utilities. Revenues stem from investment returns and members receive dividends.
8. **Energy system management BM** is organized around the provision of services such as consulting, facility management, and brokering activities offered to a wide variety of customers (incl. members). Revenue is based on service fees, from which members profit through dividends.
9. **E-mobility combined with PV BM** connects the purchasing and/or operation of charging points and the provision of e-mobility (sharing) services with the use of excess electricity. Revenues are generated from service fees. Members benefit through services provided and/or dividends.

Next, we turn to the evolution of business models to answer the third research question 'What is the evolution of investments undertaken by EC and how sustainable are the BM?' Our statistical analysis shows that business models deployed by EC are in major transition. Since 2013, the previously dominant business model based on guaranteed feed-in tariffs is increasingly being replaced due to declining governmental remuneration. In fact, 45% of the EC in our database of 584 EC chose to not develop new projects, only continuing to operate their existing PV installations under the generous and guaranteed feed-in tariffs that are now being phased out. However, we also find that the majority are exploring new business opportunities. Increasingly, this implies the combination of self-consumption with direct marketing of generated electricity through the grid. Thereby, EC diversify their portfolio of business models, also expanding towards consulting & information services and contracting. Similarly, different business models are deployed in an EC depending on the size and location of PV installations and/or equipment. We also find cases where different business models are utilized for a single unit. As a general trend, we find that the complexity of projects undertaken by EC has been

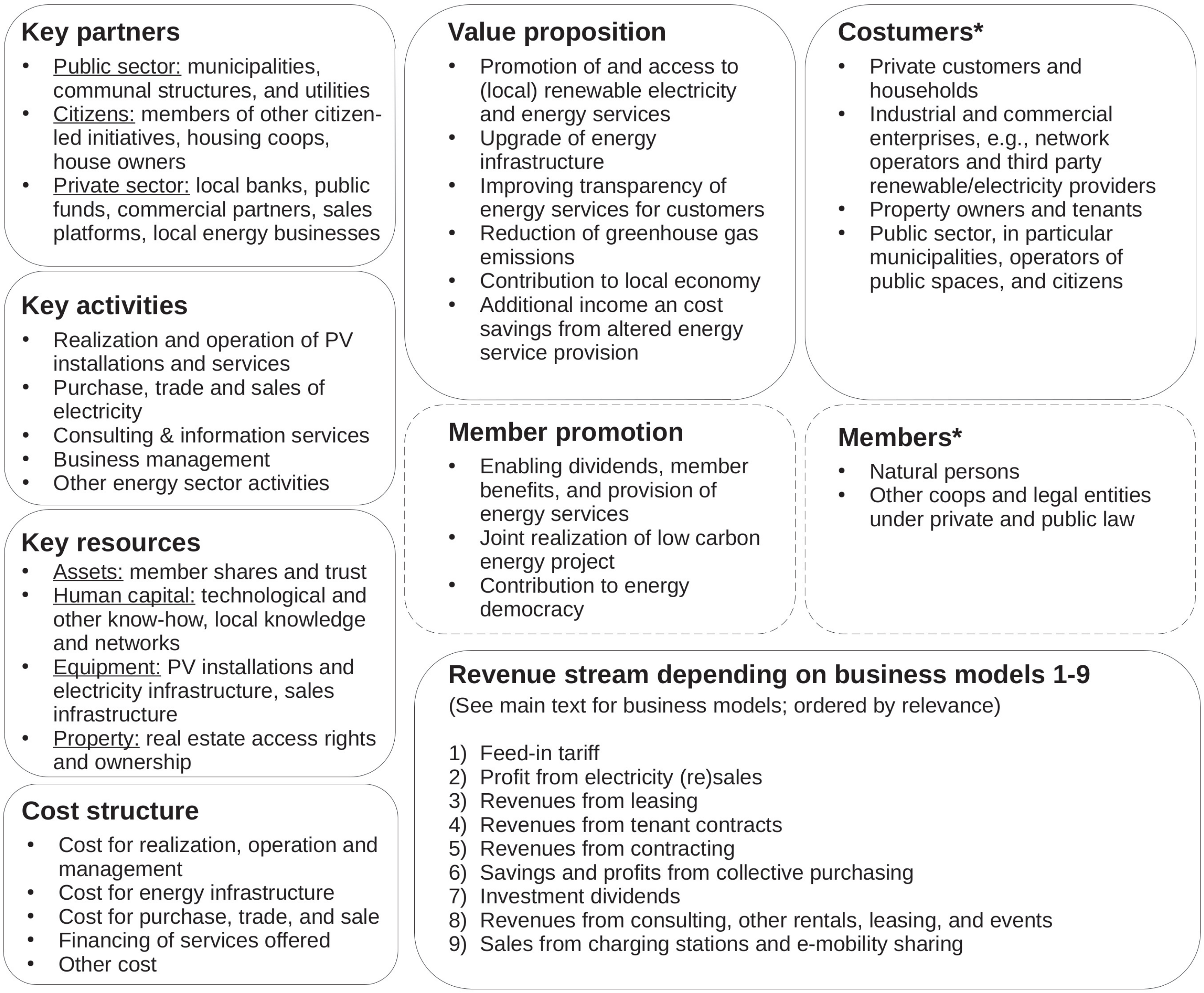

Fig 14. Aggregated business model canvas for German EC active in the PV sector. Segments marked with * are potentially overlapping.

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increasing. On the one hand, this reflects an accumulation of managerial and technical expertise within an EC over the years. On the other hand, it underlines the need to find new market niches due to more stringent policy conditions.

Conclusion and limitations

The statistical analysis of German EC active in the PV sector reveals that EC are engaging in a broad range of activities to exploit a variety of business models. We have identified 9 different types which are aggregated in a business model canvas shown in Fig 14. EC are successfully recruiting members and customers, finding their niche in the market and are able to compete with incumbent actors from the private sector. Nevertheless, evidence also shows that 45% of EC in the sample rely exclusively on a business model based on generous and guaranteed feed-in tariffs offered by the government. Since the phasing out of these support schemes, those EC did not expand their activities. The other 55% who chose to continue developing their activities are increasingly exploring new business models connected to self-consumption (e.g., entering the mobility sector), storage solutions (e.g., vehicle-to-grid, power-to-gas), operation of service platforms, and peer-to-peer trading. Here, opportunities arise for future research to study how EC are able to ignite local, sustainable energy transitions. Also, our data compiled in the ENBP Inventory allow to create scenarios that estimate the contribution of energy communities to the energy transition in European countries. The exercise could be replicated in other countries provided available statistical information.

Our results show that EC have a strong focus on the provision of economic benefits for their members, which is in contrast to the findings of Klagge and Meister [26] where social and cultural goals rank equally with financial ones. Rather, our findings support the idea that EC active in the PV sector predominantly fall into the third type of cooperative business model framework suggested by Dilger, Konter and Voigt [5]. This third type, called the investor-type, has a stronger market orientation than hybrid- and prosumer-types, which are more community-oriented. The result also hints at a discrepancy between the formal goals stated by EC in official documents and observed business models (incl. different ways to promote members). However, the reporting of 'soft' benefits is less standardized and thus likely less visible.

One aspect exceeding the scope of this investigation concerns the implications for European EC activities in general. While recent requirements to register PV sector activities in Germany offer a unique possibility to statistically analyse EC business models, the potential for generalization beyond this country is limited, as results also depend on specific legislative and market conditions. However, it is expected that other countries will set up similar reporting schemes connected with the implementation of Directive EU-2018/2001 [40] and Directive EU-2019/944 [41].

Supporting information

S1 Text. Supporting information to the manuscript. Details on data sources and data quality.
(DOCX)

Author Contributions

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Funding acquisition: August Wierling, Valeria Jana Schwanitz.

Investigation: August Wierling, Jan Pedro Zeiss, Constantin von Beck, Valeria Jana Schwanitz.

Methodology: August Wierling, Jan Pedro Zeiss, Constantin von Beck, Valeria Jana Schwanitz.

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Writing – original draft: August Wierling, Jan Pedro Zeiss, Constantin von Beck, Valeria Jana Schwanitz.

Writing – review & editing: August Wierling, Jan Pedro Zeiss, Constantin von Beck, Valeria Jana Schwanitz.

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PAPER VII: EVALUATING QUALITY OF IMPACT INDICATORS FOR COMMUNITY ENERGY INITIATIVES.

Evaluating Quality of Impact Indicators for Community Energy Initiatives

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Declaration of interests

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Jan Pedro Zeiss: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **August Wierling:** Writing – review & editing, Conceptualization. **Valeria Jana Schwanitz:** Writing – review & editing, Conceptualization. **Timothy Peter Marcroft:** Writing – review & editing

Abstract

For two decades new types of Community Energy Initiatives (CEIs) have been on the rise in Europe. Their unifying characteristics are democratic citizen control, citizen ownership and an engagement in the renewable energy transition. Across Europe, thousands of initiatives exist. The portfolio of engagement is broad, potentially manifesting value through the realisation of environmental, social and economic benefits. However, most evidence is based on qualitative case studies, lacking a critical debate on the quality of indicators employed to assess their impacts.

Synthesising the literature streams on impact assessment and indicator quality criteria, this paper develops a workflow to guide the evaluation of the accuracy, usability, interpretability and understandability of future impact indicators for CEIs. The workflow is then employed to compare exemplary efforts in impact assessment conducted by the scientific community, governmental actors, CEI umbrella organizations, and initiatives themselves.

The study identifies several flaws among currently employed CEI impact indicators. Assessment efforts by both the scientific community and governmental actors tend to focus on identifying instead of quantifying impacts. Indicators also lack clear communication and linking to associated impacts. Furthermore, a strong reliance on subjective opinions of change can be observed. Finally, expected impacts and objectives are occasionally misinterpreted as materialized impacts. CEIs and CEI umbrella organizations show more systematic and well documented impact assessment approaches, also attempting to rely as little as possible on subjective opinions. However, this leads to a more frequent use of proxy indicators that only measure the drivers for an impact, not the impact itself.

1. Introduction

Over the past two decades, Community Energy Initiatives (CEIs) have been on the rise in Europe. While CEI have been conceptualized in various ways (Bauwens et al., 2022), they can be broadly defined as citizen-owned and democratically controlled initiatives aiming to contribute to the sustainable energy transition. Schwanitz et al. (2023) estimate that, across Europe, two million people have collectively invested at least 11 billion Euros in more than 10,000 CEIs. In this way, about 10 GW of renewable energy capacity have been added. Over the years, a variety of claims regarding the beneficial nature of such CEIs have been made, both in the academic literature (c.f. Berka & Creamer, 2018; Bielig et al., 2022; Brummer, 2018) as well as by practitioners (e.g. REScoop, n.d.) and policymakers (e.g. European Parliament, 2018, 2019). These claims range from increasing acceptance for renewable energy technologies, strengthening economic value creation, and combatting energy poverty, to increasing community spirit or capacity building.

At the same time, however, various authors have pointed out limitations with the evidence base for the benefits generated by CEIs. In their review of the CEI literature, Bielig et al. (2022) find that the evidence is mostly based on qualitative studies of individual or small samples of CEIs. Similarly, Schwanitz et al. (2023) and Wierling et al. (2023) point out the lack of systematic tracking of CEI-related data. With the recent official legal recognition of 'Renewable Energy Communities' (RECs) (European Parliament, 2018) and 'Citizen Energy Communities' (CECs) (European Parliament, 2019) by the European Union, demands for more systematic monitoring of the economic, environmental and social impacts of CEIs have also been growing among policymakers (e.g. European Commission, Directorate-General for Energy, 2024). This has led to a number of recent attempts on the part of European governmental actors to map and assess the impacts generated by CEIs, for instance the Energy Communities Repository under the European Directorate-General for Energy (European Commission, 2024) or a report compiled by the European Joint Research Centre (Caramizaru & Uihlein, 2020). In the meantime, CEIs or CEI umbrella organizations themselves have for a long time had an interest in mapping and communicating their own impacts or those of their member organizations (c.f. Énergie Partagée, n.d.-b, 2019; Proka et al., 2021). While the above examples demonstrate a general awareness for the need of better CEI impact monitoring, the attempts remain fragmented and a systematic reflection on the quality of the employed indicators, as is common in other domains such as SDG indicators (e.g. Gebara et al., 2024) or environmental indicators (e.g. Niemeijer & De Groot, 2008), is missing.

Therefore, this paper sets out to develop and apply a frame of reference to facilitate more systematic reflection on the approaches to measuring CEI impacts. After a brief overview over the impacts associated with CEIs (Section 2.1), we review existing definitions of impacts (Section 2.2), as well as quality criteria for indicators employed in other disciplines (e.g. Gebara et al., 2024; Joumard & Gudmundsson, 2010) and in practical guidelines by statistical offices and governmental agencies (e.g. European Commission, 2021; Eurostat, 2014) (Section 2.3). Using the above as theoretical foundation, we develop a workflow to guide the selection and evaluation of high-quality indicators for CEI impact assessment, which is presented in Section 3. Using the workflow as frame of reference, Section 4 investigates exemplary cases of CEI impact assessments from the scientific literature, governmental efforts, as well as efforts conducted by CEI or CEI umbrella organizations themselves. Thereby we can shed light on several avenues for improving future assessment efforts.

2. Literature review

2.1. Mapping community energy impacts

A significant corpus of scientific literature focusses on investigating the benefits generated by CEIs, representing positive impacts thereof. Negative impacts of CEIs are often disregarded (Van Der Waal, 2020). This paper therefore uses the two terms interchangeably. Berka and Creamer (2018), Brummer (2018) and Bielig et al. (2022) have reviewed the literature on CEI benefits, with the latter focussing exclusively on social benefits, while the former two also include economic and environmental benefits. Table 1 lists the overarching benefit categories identified by the three literature reviews.

Table 1: Overarching categories of CEI benefits identified in CEI literature

Berka and Creamer (2018)	Brummer (2018)	Bielig et al. (2022)
(1) Socio-economic regeneration (2) Access to affordable energy (3) Knowledge and skills (4) Social capital (5) Empowerment (6) Increased local acceptance of RE (7) Energy literacy & environmentally benign lifestyles	(1) Economic benefits (2) Education and acceptance (3) Climate protection and sustainability (4) Community building and self-realisation (5) RE generation targets (6) Innovation	(1) Energy justice (2) Energy democracy (3) Social capital (4) Community empowerment

Similar benefits generated by CEIs have also been emphasized by policymakers and practitioners. The EU officially recognizes CEIs, stating that they "…facilitate the uptake of new technologies and consumption patterns, [...] advance energy efficiency at household level and help fight energy poverty through reduced consumption and lower supply tariffs.'(European Parliament, 2019, number 43). The European Federation of Energy Cooperatives lists local economic value creation, acceptance for renewable energy, affordability of renewable energy investments, local community development and energy efficiency improvements as potential benefits (REScoop, n.d.). The International Renewable Energy Agency mentions social (e.g. public acceptance, social cohesion, gender equality), economic (e.g. energy access, local development, energy security) and environmental (e.g. climate adaptation, biodiversity) benefits of CEIs. On the national level, CEI umbrella organizations such as Community Energy England emphasize benefits related to energy awareness and behavioural change, resource efficiency, reducing energy bills (for vulnerable customers), and local value creation and community development (Community Energy England, n.d.). In France, the organisation Énergie Partagée finds that CEI reinvest a significantly larger proportion of their profits into the local community compared to private renewable energy developers (Énergie Partagée, 2019) as well as contributing to awareness raising and capacity building, local networking and collaboration of different actors, and alleviating anxiety in face of challenges of climate change (Énergie Partagée, n.d.-b).

2.2. Defining impact

Various streams of literature provide definitions for impact. The International Association for Impact Assessment defines impacts as 'future consequences of a current or proposed action.' (IAIA, 2009, p. 1). Following a similar notion, within the social impact assessment domain, Vanclay (2002) conceptualizes impact as the result or consequence of an intervention or project. The pressure-state-response framework commonly used in environmental impact assessment conceptualizes impact as a change in a system state that results from an applied pressure to the system (Niemeijer & De Groot, 2008). Finally, the logical framework commonly used in project planning and assessment defines impacts as the long-term effects of a project on specific communities, populations, or ecosystems (Bodem-Schrötgens & Becker, 2020; Ebrahim & Rangan, 2014). From a linguistic perspective, the Brittanica and Cambridge dictionaries define impact as an effect/influence of someone/something on someone/something (Britannica Dictionary, n.d.; Cambridge Dictionary, n.d.).

Three distinct themes can be identified in these definitions. First, an impact always includes a change of some sort over time. Second, an impact is always the result of a specific event or action of an entity. Third, an impact is always considered in relation to the affected entity. The third theme is evident for instance in Ebrahim and Rangan (2014), as well as the definition by the Brittanica and Cambridge dictionaries, who specifically point out that impacts are effects on 'something/someone', i.e. a defined entity, such as a community, population or ecosystem. The narrative around 'consequences' found in Vanclay (2002) or the International Association for Impact Assessment (2009) also raises the question of 'consequences for whom?'. Meanwhile environmental impact assessment requires a definition the boundaries of the system of investigation, for example the region or specific species that is considered in the assessment of a certain environmental impact.

A precise description of an impact therefore consists of three components (Table 2). Firstly, a change in an observable over time. Second, an entity or event that, intentionally or unintentionally, generates the change in the observable. This second component will be referred to in the following as 'impact actor'. And third, a defined target (geographical region, social group, ecosystem, species, …) that is affected by the change in the observable, referred to in the following as 'impact recipient'.

Table 2: Overview over and examples of impact components

Impact components		
Impact actor Defined entity (e.g. actor, event, policy, project, intervention) causing a change in an observable	Change in observable The change over time in the observable, measured either qualitatively (positive/ negative) or quantitatively	Impact recipient Defined entity (e.g. region, social group, institution, ecological system) that is affected by the change in the observable
Examples from CEI context		
- CEI - Group of CEIs	- change in energy literacy - change in installed renewable capacities - change in energy prices	- among the municipality's inhabitants - within a given country - for members of the CEI

2.3. Indicator quality criteria

Developing criteria to ensure high quality of indicators has been a topic of concern within academia as well as among practitioners such as statistical offices and governmental and non-governmental accounting institutions. This has resulted in several frameworks with criteria to evaluate the quality of an indicator, which will be briefly reviewed in the following. Refer to the Supplementary Material 1 for an overview of the various criteria and their definition.

On the broadest level, the accuracy of an indicator is determined by its reliability and validity, where reliability describes the degree to which two similar instances of measurement produce the same result, and validity describes the degree to which two methodologically different instances of measurement produce the same result (Campbell & Fiske, 1959; Sullivan & Feldman, 1979). Reliability can thus be understood as the methodological robustness of the indicator, for instance in terms of data collection and aggregation approach, reproducibility and susceptibility to manipulation or interference. Validity, on the other hand, refers to the degree to which the indicator truly represents the aspect of interest.

Joumard and Gudmundsson (2010) review existing indicator quality criteria from different disciplines such as environmental impact assessment and public health. They derive three categories of indicator quality criteria, being (I) Representativity, with the criteria of Validity, Reliability and Sensitivity, (II) Operation, with the criteria Measurability, Data Availability and Ethical Concerns, and (III) Policy application, with the criteria Transparency, Interpretability, Target relevance, and Actionability. Eurostat (2014) summarises quality criteria from various institutions such as the OECD and the former UN MDG task team. They classify quality criteria into Relevance and utility for users, Methodological soundness, Measurability, and Criteria for the indicator set (e.g. indicator complementarity). A framework used by the EU to evaluate the quality of policy indicators is the RACER framework (European Commission, 2021; see also: Eisenmenger et al., 2016). The acronym stands for the 5 quality criteria of Relevance, Acceptability, Credibility, Ease of monitoring, and Robustness. The EU Better Regulation Toolbox (European Commission, 2023) extends the RACER criteria with Attributability, Data access and quality, Timeliness, Baseline and Target, Metadata, and finally Data protection. The European Statistics Code of Practice (Eurostat, 2017) proposes 9 principles for the process and output of statistical accounting, being Sound methodology, Appropriate statistical procedures, Non-excessive burden on respondents, Cost effectiveness, Relevance, Accuracy and reliability, Timeliness and punctuality, Coherence and comparability, and Accessibility and clarity1 . Finally, Gebara et al. (2024) synthesize a set of 5 quality categories with several subcategories for SDG indicators and provide a framework to test the degree to which an indicator fulfils each criteria. The criteria cover relevance, general quality (e.g. comparability, scientific robustness), data, acceptability, and applicability. In addition, they also

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[1] Note that the European Statistics Code of Practice contains 6 additional principles relating to the institutional environment of European statistical offices. These principles have been excluded here, as they do not relate to indicator quality.

point out two categories of criteria to evaluate the quality of whole indicator sets, being Mutual exclusiveness and Collective exhaustiveness.

The identified criteria were merged based on conceptual similarity, resulting in 11 indicator quality criteria for CEI impact assessment presented in Table 3. Note that the criteria in the reviewed literature do not necessarily relate to impact indicators. Table 3 therefore provides descriptions for each criterion that are adapted to the case of impact indicators. The 11 criteria were categorised into criteria for indicator accuracy, usability and interpretability. Following the conceptualization of impact presented in Section 2.2, impact accuracy criteria evaluate if the indicator is able to adequately capture a change in an observable, establish causality between observed change and CEI activities and whether the indicator is representative for the given impact recipient. As such, special emphasis was put on the criteria of Attributability and Representativeness. While these were only rarely named in the reviewed criteria, they are of special importance for impact indicators as they evaluate the degree to which the indicator establishes a causal link between the change in the observable and CEI actions (Attributability), as well as whether the indicator measures the change in the observable with respect to the impact recipient (Representativeness). Usability refers to aspects such as the availability of data, proper documentation, or the communicability of the indicator, for example, using unambiguous definitions and language that is understandable by all relevant actors. Finally, Interpretability refers to the contextualization of the indicator in terms of normative and relative reference values (Acosta-Alba & Van Der Werf, 2011). Normative references put the indicator into context with general goals that are agreed upon in society (e.g. sustainable development goals). Relative references are used as benchmark comparisons to similar cases that generate the same impact. These allow for the evaluation of the societal desirability of the impact as well as how the CEI performs at generating (avoiding) the desired (undesired) impact compared to other entities.

Table 3: Overview of quality criteria for indicator accuracy, usability, and interpretability for CEI impact indicators.

Indicator Accuracy		**Indicator Usability**	
Criteria	**Guiding question**	**Criteria**	**Guiding Question**
Validity	*Does the indicator measure the associated impact or simply a potential driver for the impact?*	Relevance	*Is the Indicator accepted by and relevant for all involved users and stakeholders?*
Sensitivity to change	*Does the indicator measure the change in the observable in reference to a temporal baseline or general average? Does the indicator capture the change in the observable at the appropriate temporal resolution?*	Appropriateness	*Can the data/information required for the measurement of the indicator be collected at the appropriate frequency and detail? Is the required data collection and analysis effort/ burden on the respondents proportionate to the relevance of the indicator?*
Reliability	*Does the indicator measurement methodology follow established scientific procedures and is it resistant to unwanted influences? Is the data trustworthy and of sufficient quality?*	Ethical concerns	*Does the indicator require data that may be subject to any official data protection regulations or violate any social norms?*
Representative-ness	*Does the indicator correctly reflect the effect of the change in the observable on the impact recipient?*	Understandability	*Is the indicator well documented, easy to understand and communicable?*
		Indicator Interpretability	
		Criteria	***Description***
Attributability	*Is the indicator able to establish a direct causal relationship between CEI activity and the change in the observable?*	Normative reference	*Is the indicator put into context with normative goals to allow the interpretation of the societal desirability of the impact?*
		Benchmark	*Is the indicator compared to a benchmark, allowing for a judgement of the performance of the CEI in generating the impact, compared to other actors?*

Note that the two quality criteria for the consistency of sets of indicators that are proposed by Gebara et al. (2024) and Eurostat (2014) were not included in the final list of indicator quality criteria presented in Table 3. The first states that, within a defined set of indicators, individual indicators must not overlap in terms of what they measure. While this is crucial when developing composite indicators where several sub-indicators are combined into a final score, to avoid double counting of individual components leading to a bias in the final indicator score (Genovese et al., 2017), such composite indicators are rarely used for CEI impact assessments. Exceptions are Bauwens and Defourny (2017) and the indicator framework developed for the Ashton Hayes Community Energy Initiative (NEF, 2012). In cases where individual indicators are not combined into a final composite score, using several indicators to measure the same impact may even be beneficial as the alignment (or misalignment) of the individual indicators provides a measure for the validity of the respective indicator.

The second criterion states that indicator sets should measure as many facets of the entire phenomenon as possible. Indicator (sets) are, however, always simplified representations of reality (Heink & Kowarik, 2010; Merry, 2011), and as such never fully represent a phenomenon in its entirety. In fact, the issues associated with the reductionist character of indicators have been pointed out by various authors (e.g. Bell & Morse, 2008; Gasparatos et al., 2009; Mair et al., 2018). As such, we argue, that it is more important to clearly communicate which aspects of a phenomenon are represented with the chosen indicators, instead of aiming for the – likely unattainable – goal of capturing the entire phenomenon. The question, whether an indicator captures a crucial aspect of a specific impact and the degree to which this is transparently communicated is already covered in the criteria of Validity and Understandability.

Finally, we excluded the criterion put forth by Joumard and Gudmundsson (2010), stating that indicators should measure a parameter that can be influenced directly by management or policy action. CEI impacts are inherently influenceable by the CEI itself, being the entity generating the impact. As such, this criterion is irrelevant for the study of CEI impacts.

3. Workflow for quality assurance of CEI impact indicators

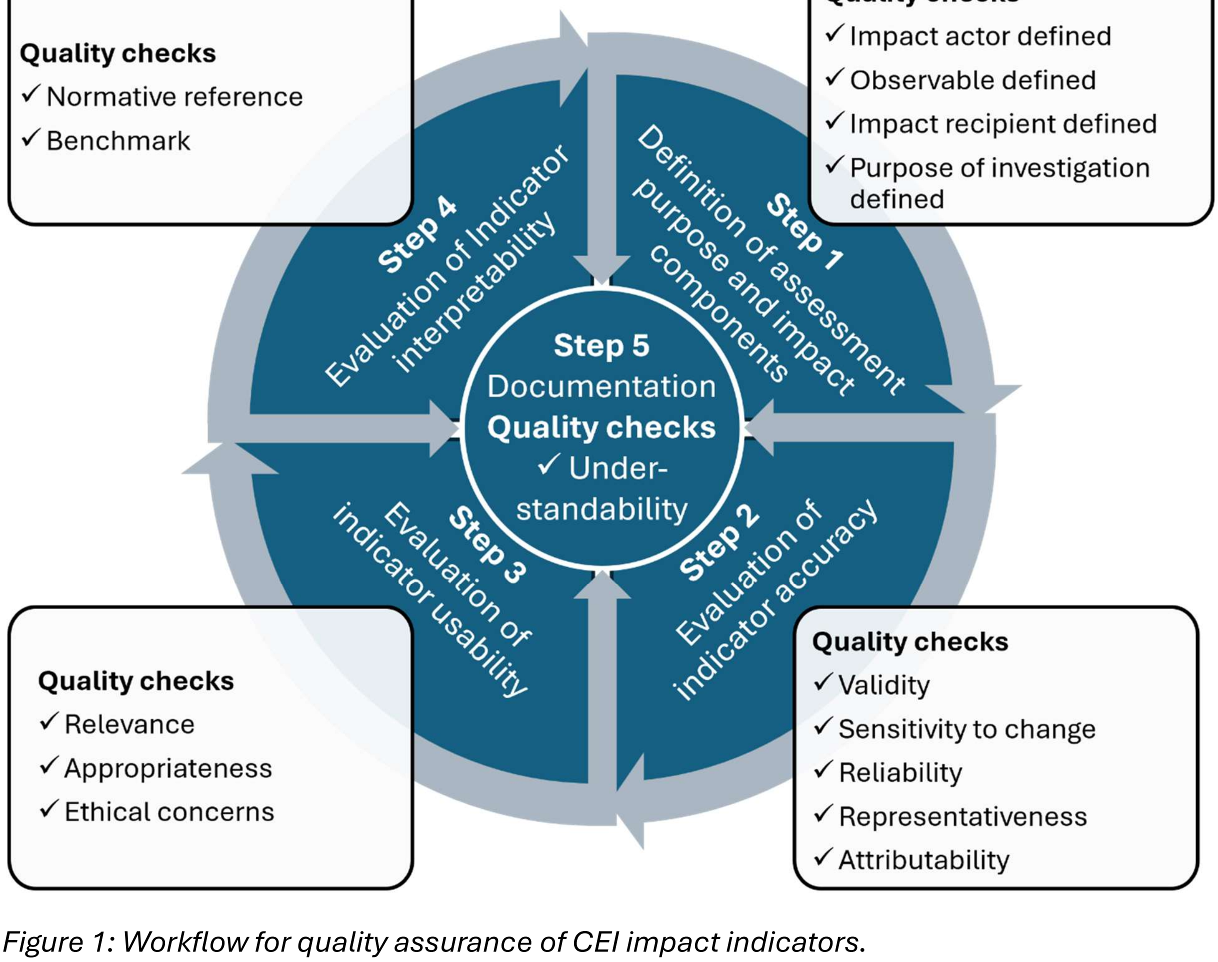

Figure 1: Workflow for quality assurance of CEI impact indicators.

Figure 1 depicts the process of selecting/designing high quality indicators for CEI impacts along 5 steps. As others have pointed out (e.g. Eurostat, 2014; Gebara et al., 2024; Van Der Waal, 2020), indicator accuracy is always dependent on the context of its application. Along the conceptualization of impact, that was developed in Section 2.2, the context can be defined as a specific configuration of the impact components, being (I) the change in the observable, (II) the impact actor generating the change and (III) the impact recipient affected by the change. In addition, the context is also dependent on the purpose of the specific impact assessment. Is the goal, for instance, to simply generate a one-time snapshot or conduct regular and continuous monitoring? As such, the definition of the context in step 1 represents a prerequisite step, without which it is impossible to judge the quality of the potential indicators.

After completing step 1 and fulfilling the associated quality checks, potential indicator candidates are evaluated for their accuracy, usability and interpretability. Indicator accuracy is dependent on 5 criteria (see also Table 3):

- Validity – The degree to which the indicator measures the actual impact
- Sensitivity – The ability of the indicator to show that a change in the observable has occurred
- Reliability – The methodological robustness and quality of the data used to measure the indicator
- Representativeness – The degree to which the indicator correctly represents the effect of the change in the observable on the relevant impact recipient
- Attributability – The ability of the indicator to prove that the change in the observable is a result of the actions of the impact actor (=CEI)

Once the accuracy of the indicator is ensured, step 3 evaluates the usability of the indicator. The first criteria judges whether the indicator is accepted by all relevant users and stakeholders. The second criteria evaluates whether the necessary data to measure the indicator can be obtained at the appropriate frequency and detail. Furthermore, this criteria judges whether the required data collection and analysis effort is in proportion to the relevance of the indicator for the users and stakeholders. Especially the indicators for the social impact of CEIs often require data collection through surveys or interviews. As such it is important to balance the burden on the respondents with the usefulness of the indicator. Thirdly, the usability of an indicator is dependent on its reliance on data that may fall under data protection regulation as well as the indicator adhering to general moral codes and practices.

Step 4 evaluates the interpretability of an indicator. The possibility of linking an indicator to a defined normative reference allows for an unambiguous interpretation of the societal desirability of the associated impact, beyond subjective intuition. Furthermore, an indicator should allow for comparison with other entities generating similar impacts, to assess the performance of the impact actor in generating (avoiding) the desirable (undesirable) impact in relation to others.

It is important to note, that the first 4 steps of the indicator quality assurance process are represented as an iterative cycle in Figure 1. When selecting potential indicators for a CEI impact assessment, an insufficient adherence of an indicator to the quality criteria in a specific evaluation step may require one to modify the initial indicator candidate or even find completely new indicators. Perhaps an indicator may fulfil all necessary accuracy criteria, but result in insufficient usability, for instance because of too extensive data collection requirements. Here, it may be necessary to make minor compromises in terms of accuracy for the benefit of increased usability. Similarly, should it turn out to be impossible to find indicators that adequately fulfil all the criteria, then it may be necessary to reconfigure the impact context (step 1). For instance, one may choose to assess the impact on a more narrowly defined impact recipient, or measure only a specific aspect of the total impact (= measure a different change in an observable). As a result, it is also problematic to provide absolute values indicating when a criterion in fulfilled. Defining the level of adherence to a criterion that is deemed sufficient, as well as the willingness to make compromises between inversely related criteria (e.g. usability vs accuracy), will always depend on the specific context of the assessment effort. As such, the presented tool aims to guide a more systematic reflection on the quality of indicators, instead of presenting universally applicable definitions on when a criterion is fulfilled.

Finally, once indicators of sufficient quality have been found based on steps 1 – 4, step 5 involves the documentation of the impact assessment effort. The associated quality criteria of Understandability can be seen as fulfilled, if sufficient documentation is provided to allow third parties to retrospectively evaluate all the previously named indicator quality criteria. As such, this step is represented as the central node in Figure 1, relating to all previous steps.

4. Examining CEI impact indicators

4.1. Corpus of examination

Table 4: Overview on investigated exemplary cases of CEI impact assessments from the scientific community, government actors and CEIs and CEI umbrella organizations.

Scientific Studies (efforts to assess CEI impacts by the scientific community, published in conference papers and journal articles)	- 48 publications identified based on reviews of CEI impacts/benefits by (Berka & Creamer, 2018; Bielig et al., 2022; Brummer, 2018)
Governmental Efforts (efforts by European governmental actors to assess CEI impacts, or on their behalf)	- **JRC:** Report on CEI benefits by the European Joint Research Centre (Caramizaru & Uihlein, 2020) - **ECR:** European Energy Communities Repository (European Commission, 2024)
Community Efforts (Efforts to assess CEI impacts, conducted either by CEI themselves or by CEI umbrella organizations)	- **AHEC:** Framework for CEI impact assessment developed on behalf of the Ashton Hayes Energy Community - **EP:** Énergie Partagée - Initial one-time assessment of economic impact of French CEI and self-assessment tool for wider social impact (including economic impact)

In the following, we apply the workflow developed above to retrospectively evaluate the quality of the chosen indicators and the measurement methodology in selected CEI impact assessment efforts (see Tab. 4). We separate into three overarching categories, being (I) scientific studies – including 46 journal articles and 2 conference papers/reports published by universities and other research institutions (2001-2021), (II) governmental efforts conducted by public institutions or by third parties on behalf of such institutions – for which we investigate two main cases, and (III) community efforts conducted by individual CEI or CEI umbrella organizations – for which we examine an interesting case for each.

For the investigation of the scientific literature on positive CEI impacts (benefits), we build on the corpus of 93 studies used from three major literature reviews (Berka & Creamer, 2018; Bielig et al., 2022; Brummer, 2018). Excluded from this initial corpus were all studies that were not conducted by scientific research institutions, are no longer accessible, or do not present own results, as well as those listed by Brummer (2018) that exclusively discuss barriers for CEI development.

Note that in our choice of the literature corpus, we neglect studies on indicators for renewable energy communities that take an engineering perspective only, such as those reviewed in Giannuzzo et al. (2025). The reason is that we are interested in indicators that measure broader societal impacts, and not, as Bauwens et al. (2022, p. 3) also point out, indicators for CEI that place emphasis on 'the material connection between actors as embodied by an infrastructure, such as a microgrid or a network, and much less on the social dimension of the community'. Furthermore, this engineering-oriented literature stream has only recently begun to adopt the definition of 'Renewable Energy Communities', as put forth by the EU (European Parliament, 2018). The difference to our paper (and in line with the social-science oriented literature stream) is the requirement that relevant initiatives comprise a form of citizen leadership, whereas the engineering-oriented literature stream broadens the concept of Renewable Energy Communities, mainly investigating local conglomerations of actors (public actors, households, SMEs,..) that engage in self-consumption, with citizen-leadership playing a subordinate role. However, we will reflect our findings in view of this research in Section 4.3.

For the investigation of governmental efforts on measuring positive CEI impacts (benefits), we examine two main cases. First, we use the highly cited report by the Joint Research Centre (JRC) of the European Commission that maps various CEI benefits (Caramizaru & Uihlein, 2020). Second, we analyse indicator choices by the European Energy Communities Repository (ECR) (European Commission, 2024), a project funded by the European Union from 2022 – 2024, with one of its initial goals being the development of an extensive list of indicators for future monitoring of CEI impacts. The project began collecting data on these indicators for 107 CEI, with the goal expand the number of CEIs over time. Up until mid-2024, these indicators, as well as the associated measurement methodology was documented on the website of the ECR. However, for unknown reasons, the European Directorate-General for Energy decided thereafter to remove nearly all the results and documentation of this impact assessment. The only remaining aggregated impact indicators published on the most recent webpage of the project are the capacities installed, finances invested, and greenhouse gas emissions saved by the investigated CEIs (c.f. European Commission, 2024). Evidence for the originally much more extensive impact assessment effort can still be found on previous versions of the webpage, archived by the Internet Archive (Internet Archive, 2023, 2024a, 2024b). Some disaggregated information about CEI impacts can, however, still be found in the profiles of the individual CEIs shown on the map of the Energy Communities Repository. While the now lacking documentation no longer allows for an in-depth evaluation of the employed indicators, this effort still represents so far the only government-led effort aiming to systematically map a wide range of impacts on the European level.

For the investigation of CEIs and CEI umbrella organizations that track positive CEI impacts (benefits), we examine the Ashton Hayes Energy Community (AHEC) and the French organization Énergie Partagée (EP). The first is a project of the village Ashton Hayes, United Kingdom, to become carbon neutral, initiated by a group of engaged local citizens (Ashton Hayes Going Carbon Neutral, 2010). Our choice is motivated by the fact that the Ashton Hayes Energy Community commissioned the development of a framework to evaluate the impacts of their project (NEF, 2012). Secondly, we chose to review Énergie Partagée, a French umbrella organization for CEIs. The organisation conducted an initial study on the economic impact of citizen energy projects and later developed a self-assessment tool for French citizen energy projects to evaluate their social and economic impacts (Énergie Partagée, n.d.-b).

4.2. Examination

In the following, the above mentioned CEI impact assessment efforts are evaluated using the workflow presented in Section 3. The most noteworthy positive and negative practices relating to the 11 indicator quality criteria (c.f. Tab. 3) are summarized for the three groups of impact assessments in the Appendix (Tab. A.1).

4.2.1. Step 1: Definition of assessment purpose and impact components

Prerequisite for the evaluation of the quality of employed impact indicators is the definition of impact components and assessment purpose. In terms of the study Purpose, only 19 out of the 48 scientific papers specifically endeavour to investigate CEI impacts or benefits. The remaining 29 papers focus on other main research questions but mention benefits of CEIs as a sidenote. Furthermore, all the scientific papers represent retrospective assessments of past impacts of CEIs. The same is true for the investigation conducted by the JRC as well as the economic impact assessment conducted by EP. In contrast, the cases of the ECR, AHEC, and the self-assessment tool by EP represent endeavours to develop indicator frameworks for future CEI impact assessments. While this is not specifically stated, these three examples may also be intended to be used in continuous monitoring efforts.

In terms of defining CEIs in their role as Impact actors, the governmental efforts (ECR, JRC) use the official definition of CEIs as RECs and CECs (European Parliament, 2018, 2019). EP also clearly defines CEIs along their own conceptualization (Énergie Partagée, n.d.-a). The definition used by the AHEC is less precise, as it is unclear whether the framework is intended to exclusively measure the impacts of the CEI or the larger project by the village of Ashton Hayes. Similarly, the scientific papers occasionally blur the lines between 'community energy' referring to citizen-led or municipal-led initiatives (e,g, Hoppe et al., 2015; Schweizer-Ries, 2008).

The range of Observables that are being investigated varies greatly. Among the scientific literature, we find papers focusing on a single observable (e.g. Devine-Wright, 2005; Fraune, 2015; Musall & Kuik, 2011), while others investigate the change among a wide range of observables (e.g. Callaghan & Williams, 2014; Wüste & Schmuck, 2012). Brummer (2018), Bielig et al. (2022), and Berka & Creamer (2018) discuss the specific benefits (i.e. changes in observables) that have been investigated in the literature. A summary can be found in Table 1. Governmental and community efforts generally endeavor to cover a large spectrum of observables relating to environmental, economic and social benefits.

Among the three impact components, the definition of the Impact Recipient is the most problematic. In some cases, this component is not discussed at all (e.g. ECR) or simply referred to as 'citizens' or 'local community' (scientific literature, JRC, AHEC). Some notable exceptions are studies investigating the economic impact of community wind projects, for example at the municipal, county, or federal state level (e.g. Okkonen & Lehtonen, 2016; Phimister & Roberts, 2012). Others assess CEI effects on families (Süsser & Kannen, 2017), farmers (Hicks & Ison, 2011; Mundaca et al., 2018), women (Fraune, 2015) or low-income households, minorities and other vulnerable groups (e.g. Forman, 2017; Hanke et al., 2021; Lacey-Barnacle, 2020). A best practice example can be found in Ruggiero et al. (2014, table 3), where all impacts are associated with a specific impact recipient. Similarly, Énergie Partagée clearly describes the impact recipient as the administrative region (Département) within which the citizen energy project is located, as well as the neighbouring regions.

4.2.2. Step 2: Evaluation of indicator accuracy

The initial question regarding the accuracy of an indicator is whether the chosen indicator truly measures the impact of interest (Validity). First and foremost, a considerable number of scientific publications discuss objectives and intentions of CEIs or expectations of the stakeholders regarding the CEI impacts, instead of actually measuring materialized impacts (e.g. Becker & Kunze, 2014; Li et al., 2013; Rogers et al., 2008; Seyfang et al., 2013). While this is not inherently problematic, instead simply representing a different research goal, it may become a Validity concern if misinterpreted as indicating materialized impact. Statements such as the following exemplify the risk of misinterpretation: 'Benefits from the wind farm will be gained locally. [...] residents have outlined key ideas that will support local businesses, community groups and individuals of all ages' (Hinshelwood, 2001, p. 98). The fact that these papers discussing intended and assumed impacts have consistently been mentioned by three literature reviews on the topic of CEI benefits (Berka & Creamer, 2018; Bielig et al., 2022; Brummer, 2018), provides further evidence of the risk of misinterpretation. Similarly, the economic impact study conducted by EP is largely based on assumptions made in the financing plans at the start of the citizen energy projects, instead of real economic performance. This choice was made due to the investigated projects having been established recently, and no data covering their full lifetime being available yet. A second Validity issue is related to measuring potential drivers for an impact instead of the impact itself (c.f. Gebara et al., 2024). For instance, EP and ECR use the number of training and educational activities conducted by a CEI as a proxy indicator for increased awareness and competences regarding energy issues. A CEI having conducted such activities does not prove that the impact truly materialized. EP, in fact, uses several such indicators that simply measure activities conducted by CEIs.

In terms of the Sensitivity criteria, several scientific publications as well as the JRC report focus mainly on qualitatively identifying impacts, based on responses from interviews or surveys, instead of quantifying change over time in the observable (e.g. Burchell et al., 2014; Callaghan & Williams, 2014; Hicks & Ison, 2011; Middlemiss & Parrish, 2010). This is especially common among the aforementioned studies that do not investigate CEI impacts as their main research goal (see Section 4.2.1). In these cases, the question of how, at what frequency, and in relation to which baseline the change is measured becomes obsolete. Those efforts that (intend to) measure change over time, provide varying degrees of information on the measurement process. EP, for instance, states that the economic impact assessment captured the lifetime of a renewable energy project, defined as 20 years. The AHEC, in fact, specifies over which timeframe each respective impact will materialize, but does not go into detail regarding the implication thereof for the measurements process. However, there is rarely a clearly defined baseline against which change is measured. Devine-Wright (2005) and Schweizer-Ries (2008), are some of the few examples that establish a baseline by conducting an initial assessment prior to the start of the CEI/project.

The main Reliability challenge relates to the fact that a large number of impacts of CEIs are highly subjective, such as changes in community spirit and trust, or acceptance for renewable energy technologies. In such cases, it proves difficult to find objectively verifiable indicators not ultimately based on subjective experiences of individuals. More problematic, however, is the use of subjective opinions to measure objective impacts. Some studies discuss objective impacts such as increased renewable energy capacities, increased income or reduction in greenhouse gas emissions simply based on subjective responses from interviewees (e.g. Ruggiero et al., 2014; Wüste & Schmuck, 2012). The little remaining information available on the ECR suggests similar practices, for instance with statements on environmental benefits being based simply on the opinions of the surveyed CEI members. However, even in cases where purely subjective impacts are measured, it is possible to reduce variability due to subjective interpretations to some degree. Some rare cases, such as the AHEC or Bauwens & Defourny (2017) measure social cohesion and trust using standardized and field-tested indicators or measurement methodologies, such as the Buckner Neighborhood Cohesion scale or using survey questions developed by the World Values Survey. In fact, it is surprising that the awareness of this issue is greatest among the community efforts, and not, as one may expect, among the scientific literature. Both the AHEC and EP, representing the community efforts, refer to this challenge and aim to provide both subjective-qualitative and objective-quantitative indicators for each impact, whenever possible.

While the often-ambiguous definition of the impact recipient leads to challenges in evaluating the Representativeness of some of the employed indicators, some instances among the scientific literature could be identified, where the indicators do not represent the impact recipient. For instance, Radtke (2014, p. 241) surveys whether members of a CEI '[…] felt that the local community would perceive their energy facilities positively', concluding that 'Community energy clearly increases faith and trust in local community action as well as in the use of renewable energies.' Exclusively surveying the opinions of the CEI members in this matter is likely not representative of the local community. Similarly, Becker and Kunze (2014, p. 185) find that a CEI has led to 'behaviour change and consumption reduction among the town's population', based on the response of one interviewee. Without additional information, it proves challenging to judge the degree to which said interviewee has the necessary insight to justify such a statement. The same issue is present among the governmental efforts. The ECR exclusively surveyed CEI members but assessed impacts on the wider community. Among the community efforts, in contrast, the AHEC intends to use data from a survey of the inhabitants of the village. EP, on the rother hand, ensures that indicators for economic impact are measured at the correct geographic scale, for instance by instructing which types of taxes are paid to the regional government and should therefore be included in the assessment.

In terms of Attributability, in some cases a change in an observable can be directly attributed towards a CEI. Van Der Waal (2020), for instance, finds that the investigated CEI has significantly improved local public transport by using profits from a wind turbine to finance additional bus and boat routes. Okkonen & Lehtonen (2016) or the assessment by EP model the economic value and number of jobs created by the construction and operation of a community renewable energy installation. Similarly, the social impact tool developed by EP uses direct outcomes of the CEI (e.g. number of conducted activities of a certain kind) as indicators. However, while this last example ensures Attributability, it may lead to reduced Validity, as the indicator does not truly measure the impact of interest (see discussion on Validity). In other cases, establishing causality between CEI activity and impact requires additional steps, which are not always sufficiently done. Romero-Rubio & De Andrés Díaz (2015), for example, use the share of renewable capacities installed, and finances invested into renewable energy technologies by German citizens as an indicator for CEI contribution to RE deployment. While this indicator correctly describes the change in observable, it does not establish that this development is a result of CEI activities, as it also includes installations by private citizens. Süsser and Kannen (2017) investigate people's attitudes towards RE technologies by measuring the share of respondents with positive attitudes. Again, it is not immediately clear how they prove that the measured level of acceptance is indeed a result of the CEI's engagement. Similarly, it is not immediately clear how the AHEC framework intends to establish Attributability for all investigated impacts. A comparison to a control group can be used to establish Attributability in such cases. Such a control group can be the same case prior to the establishment of the CEI or a spatially removed case without a CEI but otherwise similar conditions. Devine-Wright (2005) and Schweizer-Ries (2008), are examples for the former, while Musall and Kuik (2011), and Warren and McFadyen (2010) are examples for the latter approach.

4.2.3. Step 3: Evaluation of Indicator Usability

The Relevance criterion states that an indicator should be relevant for and accepted by all involved users and stakeholders. For the scientific literature, the criterion is largely dependent on the relevance of a study and the chosen indicators for the scientific community, which is typically discussed in the introduction of the respective paper. In terms of the governmental efforts, the high citation count of the JRC report may indicate its relevance to academics and policymakers, while the abandonment of the ECR effort and subsequent removal of existing results may indicate that no relevant findings were produced. The AHEC framework, however, stands out as positive example. Here, relevant impacts and indicators were selected in a co-design event with participants from the whole village.

The Appropriateness criterion evaluates the effort required to collect and process all necessary data. Given that the gathering and processing of CEI data in general is limited and unsystematic (Schwanitz et al., 2023; Wierling et al., 2023), most CEI impact assessment efforts rely on new data, largely collected through surveys or interviews. Beyond a few exceptions (e.g. Fraune, 2015; Hanke et al., 2021; Radtke, 2014), most scientific studies as well as the JRC report collect such data for only very small numbers of case studies. This may indicate that collecting data on larger samples requires too much effort. Similarly, the low return rate on the impact survey distributed by the ECR may be the result of the survey being too extensive. The same is likely the case for the AHEC framework. While this framework deserves praise for its attempt to systematically capture a large spectrum of indicators, there is no evidence that it has ever been fully applied. In fact, the framework itself states that the reliance on regular surveys of the inhabitants of the village may be a challenge. EP on the other hand tries to solve this issue in several ways. In their economic impact assessment EP extrapolates the impact identified in a representative sample to the total population of citizen energy projects. In the social impact self-assessment tool, EP mainly uses indicators that can be measured by the CEI themselves, based on internal data. As mentioned before, however, such indicators based on activities conducted by a CEI may not truly capture the impact of interest (see discussion on Validity).

Regarding the Ethical Concerns criterion, no major issues were observed. However, fulfilment of this criterion may occasionally be inversely related to other criteria. Specifically, where impacts are identified as a result of interview or survey responses, it is important to understand whether the respondents are representative of the impact recipient and have the necessary insight into the issue at hand, to be able to make a qualified judgement regarding the impact. This, however, would require information on the identity of the respondent, which often cannot be provided due to data protection requirements. Becker and Kunze (2014, p. 185), who point out that one interviewee stated that a CEI has led to 'behaviour change and consumption reduction among the town's population', is such an example, where additional information on the interviewee would help to judge the Representativeness and Reliability of such a statement.

4.2.4. Step 4: Evaluation of Indicator Interpretability

In terms of the Normative Reference, most of the investigated examples, both from the scientific literature, as well as governmental and community efforts, generally discuss benefits of CEI, instead of impacts. Where an impact may be either desirable or undesirable depending on the direction of the change, benefits are implicitly desirable. Commonly, references to concepts such as 'Energy justice'(c.f. Stephens, 2019) or 'Energy democracy' (c.f. Van Bommel & Höffken, 2021) are made. However, as also pointed out by Van Der Waal (2020), the general disregarding of potential negative impacts of CEI may result in a biased perspective thereon.

In order to judge the performance of a CEI in generating (avoiding) a desirable (undesirable) impact, the assessment results should be compared to other actors or general averages (Benchmark). As an illustration, a commonly used indicator to assess economic impact/benefit is tax returns to the municipality (e.g. Li et al., 2013; Süsser & Kannen, 2017; Wüste & Schmuck, 2012). However, simply measuring taxes paid by CEI will always result in a positive impact. Only in comparison with other actors (e.g. taxes paid by private renewable energy developers) is it possible to truly judge the performance of the CEI. Similarly, the JRC report measures CEI contribution to renewable energy deployment in terms of rooftops covered in solar panels, or number of panels installed. These non-standardized units do not allow for comparison with other actors. Good practice examples related to this criterion are Hanke, Guyet and Feenstra (2021), who compare prices of CEI-produced electricity to general national prices, or Allan, Mcgregor and Swales (2011) who model economic impact of community owned wind turbines in relation to a reference scenario of a privately owned installation. Musall and Kuik (2011) and Warren and McFadyen (2010) compare renewable energy acceptance levels for a community owned wind installation with a privately owned one. EP also provides a comparison to private renewable energy developers for their economic impact assessment. For the social impact assessment, EP provides a compass that ranks the impact of each respective project along several impact levels. While this does not allow for a comparison with other actors outside of the community energy domain, it provides an easy way to compare one's performance with that of other projects having undertaken this impact assessment.

4.2.5. Step 5: Documentation of impact assessment

Among the scientific literature, several of the previously discussed issues also relate to the Understandability criterion. For instance, the ambiguous definitions of the impact recipient and various conceptualizations of CEIs (see Section 4.2.1) occasionally lead to challenges in evaluating the Representativeness criterion or whether a study truly investigates impacts of CEIs or other entities. Moreover, the common focus on discussing objectives and intended impacts may risk misinterpretation. Furthermore, indicators are often not clearly stated and associated to their respective impact. Instead, indicators need to be inferred from the text. Only very few cases were found that systematically describe indicators used to measure the impact or outcome of CEI activities (e.g. Hanke et al., 2021; Mundaca et al., 2018). This issue is also present in the JRC report, were the discussion of the same impacts and indicators is spread out over various sections and subsection. The ECR, as already mentioned (see Section 4.1), previously provided documentation. However, this was removed after the project ended. By far the most systematic and detailed documentation is provided by the community efforts (AHEC and EP), both of which clearly describe investigated impact, associated indicators and data sources. In the case of EP, most of this documentation is available on their website, in particular concerning economic impact. Being intended for member use, the methodological details of the social impact self-assessment tool are only accessible by members. While EP did not hesitate to share this documentation upon request by the researchers, publishing it generally online could be an opportunity for greater transparency with non-members who wish to better understand these assessments.

4.3. Engineering perspective on indicator evaluation

As pointed out in the beginning of this section, a separate literature stream exists, that is dominated by engineering scholars and focusses on REC, understood as configurations of local energy producers and consumers focussing on self-consumption. As shown by Gianuzzo et al. (2025) this literature stream is characterized by a far more systematic discussion around indicators and measurement approaches for REC performance. Such studies often precisely describe indicators using mathematical expressions and use advanced energy system simulation software and econometrics to assess, for instance, the RECs' effects on the energy grid, greenhouse gas emissions saved, levelized costs of energy consumed, revenues generated, or energy poverty reductions. Unsurprisingly, this literature stream only shows a very limited focus on the social impacts of REC. While Gianuzzo et al. (2025) list several social performance indicators, a closer inspection of their findings reveals that this list is deceptive. The authors' findings regarding the frequency at which these indicators are mentioned, as well as the references provided for each indicator suggest that most of the social performance indicators were identified from a single source, being Couraud et al. (2023). Furthermore, a considerable share of the social performance indicators listed by Gianuzzo et al. (2025) relate to aspects such as data accessibility, GDPR compliance, or cybersecurity. This differs greatly from the social science-oriented community energy literature, which emphasizes social impacts such as increasing social capital, energy justice, community empowerment, or capacity building (see Section 2.1).

5. Conclusion

In the past two decades, community energy initiatives have increased in prominence in Europe, often being seen as key actors in a sustainable and socially just transition of the European energy system, due to the large spectrum of potential economic, environmental and social benefits they may generate (Caramizaru & Uihlein, 2020; European Parliament, 2018, 2019; Schwanitz et al., 2023). However, previous reviews (e.g. Berka & Creamer, 2018; Bielig et al., 2022) of the literature on CEI benefits have questioned the evidence base for such claims. We expand upon these previous findings by investigating in more detail the indicators that have been employed in the scientific literature, governmental efforts and by CEIs themselves to measure benefits and impacts generated by CEIs. Using the indicator quality evaluation workflow developed in this study, we are able to identify key areas of improvement regarding the assessment of CEI impacts.

First and foremost, we find a tendency among the scientific literature and governmental efforts to simply identify impacts instead of their quantification. While an initial emphasis on identifying impacts is valuable—laying the groundwork for more targeted and detailed assessments in subsequent studies—the focus has to change to a more quantified approach. Indeed, the recently enacted EU definitions for CEI specifically emphasising the generation on such benefits, as well as new CEI support schemes being tied to the adherence to these definitions (e.g. BMWE, 2025; European Energy Communities Facility, 2025), requires a stronger focus on the quantification of CEI impacts, allowing for evidence based policy-making. Furthermore, both among the scientific literature as well as governmental efforts, there is a need for improved documentation of the impact assessment methodology, including the clear communication of the impact to be investigated, defining the recipient upon which the effect of the impact is to be measured, as well as systematically linking indicators to the associated impacts. An improved documentation of the assessment methodology will also address the current issue of confusion of intentions and objectives with materialized impacts. Furthermore, there is a need to address the high reliance on subjective opinions obtained through interviews or surveys. While it may not be possible to find objective indicators for all impacts of interest, an unambiguous documentation of the impact recipient as well as the interview or survey respondents allows, at minimum, for a better judging of the representativeness of the obtained subjective opinions.

In comparison to the above, the investigated impact assessment efforts by CEI and CEI umbrella organizations, are characterized by a far more systematic approach. Each impact to be assessed is clearly linked to a set of indicators, which are accompanied by detailed documentation regarding measurement methodology. Furthermore, these efforts address the issue of relying too heavily on subjective opinions by attempting to employ both subjective-qualitative and objective-quantitative indicators wherever possible. Especially the French umbrella organization Énergie Partagée has also put an emphasis on developing indicators that are easy to understand and require minimal data collection effort to operationalize. The main area of improvement lies in the use of proxy indicators that measure, for instance, activities that may generate the intended impact, instead of measuring the actual impact.

While this study has shown the need for more systematic monitoring, pointing out several areas of improvement, there is a general agreement among the CEI literature that bureaucracy and formalities required to administer a CEI are a key barrier for their success (e.g. Allen et al., 2012; Brummer, 2018; Seyfang et al., 2013). As such, there is a need to balance the need for further monitoring with the additional burden put on CEIs in terms of data collection and reporting (see Appropriateness criterion in Tab. 3). We see each actor (governmental institutions, scientific community & CEI umbrella organizations) fulfilling a specific role in this endeavour. From a governmental perspective of evidence based policy making, there is a need to further specify the impacts – and resulting contributions to policy goals - that CEI are expected to generate, beyond the current vaguely defined 'environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates' (European Parliament, 2019, Article 2.11). This will allow for a more targeted monitoring of the most policy-relevant impacts, avoiding an excessive reporting burden on CEIs due to overly ambitious assessment frameworks. The ECR and AHEC assessment efforts indicate that attempting to cover too large of a spectrum of impacts may result in the efforts being unsuccessful. Clearly linking expected impacts to policy goals will also allow for a better interpretation of the performance of CEIs in generating the respective impact (c.f. Normative reference and Benchmark criteria in Tab. 3). The role of the scientific community lies, in turn, in the development of a palette of methodologically robust indicators to measure the key CEI impacts. To this end, a closer collaboration between the traditional social-science-oriented CEI research domain and the recent engineering-oriented domain is advised. Thereby, the existing expertise of the former on the social characteristics and dynamics of CEIs can be supplemented with the expertise of the latter on quantitative, statistical and model-based methodological approaches to CEI impact assessment. The workflow developed in this paper may also serve as guidance for the development of high-quality indicators. Finally, the role of the CEI umbrella organizations lies in ensuring that potential indicators can be operationalized in the context of the respective CEIs, in terms of data and reporting requirements, sufficient documentation that is understandable by non-experts, establishing appropriate reporting procedures that consider the resource limitations of CEIs as well as support CEIs during the reporting process. Examples such as the self-assessment tool developed by Énergie Partagée suggest that CEI umbrella organizations have significant expertise in developing templates and tools for CEI impact reporting that are adapted to the specific context of CEIs.

In summary, we recommend (I) a stronger focus on developing methodologically robust indicators among the scientific community, (II) further specification by governmental actors regarding the impact that CEIs are expected to generate, and (III) a closer collaboration with CEI umbrella organization to ensure that future CEI impact monitoring is conducted in a manner that is appropriate to the resources and expertise available to the reporting CEIs.

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Appendix A

Table A.1: Summary of findings from the application of the indicator evaluation tool to CEI impact assessment efforts conducted by the scientific community, governmental actors and CEI and CEI umbrella organization themselves. Bullet points indicated with '-' denote negative features, '•' denote neutral features or those that could not be evaluated, '+' indicate positive features. Abbreviations: AHEC – Ashton Hayes Energy Community, ECR – European Energy Communities Repository, EP – Énergie Partagée, JRC – Joint Research Centre.

	Scientific Literature	Governmental Efforts	Community Efforts
Purpose	• Majority of studies do not focus on CEI impact assessment as primary research goal • Exclusively retrospective exploration of materialized CEI impacts	• ECR: Initially, systematic monitoring of EU CEI. Goal later abandoned • JRC: Mainly retrospective exploration of materialized CEI impacts. One case of estimation of future CEI impacts	• AHEC: Not specifically stated, but design of assessment framework hints towards being intended for regular monitoring • EP: One time study of economic impact of French citizen-owned wind and PV projects; development of self-evaluation tool for social impacts of citizen energy projects
Impact Actor	- Various conceptualizations of CEI - Occasionally unprecise delineation of CEI from other entities such as municipalities, decentralized biomass projects	+ European REC and CEC as defined by EU Directives	- AHEC: CEI/ village. Framework developed on behalf of CEI, but likely intended to measure impacts of project by the whole village to become carbon neutral. Unclear boundary + EP: French citizen renewable energy projects as defined by EP

Observables	• Large spectrum of CEI observables investigated, as summarized by Brummer (2018), Berka & Creamer (2018), Bielig et al. (2022)	• ECR: environmental benefits/ impacts, social benefits, economic impact (not further specied), acceptance of renewable energy • JRC: social and energy justice impacts, contribution to renewable energy expansion, effects on distribution networks and impacts on system costs.	• AHEC: Large spectrum of economic, environmental and social impacts. • EP: Economic impact: taxes, rents, dividends & interests paid, jobs created; Social Impact: 5 main categories (Citizenship, Resilient territory, Local economic impacts, Cooperation, Reapropriating local energy)
Impact Recipient	- Varying degree of specificity. Often simply defined as 'local community'. Only in rare cases defined in more detail (e.g. defined geographic area, farmers, women, vulnerable groups,...)	- ECR: not defined - JRC: Varying degree of specificity, ranging from specific focus on members to ambiguous statements such as 'citizens'	- AHEC: vaguely ddescribed as 'community', likely referring to the village + EP: defined as department of project and neighboring departments
Validity	- Misinterpretation of intentions and objectives as materialized impacts	- ECR: In some cases, activities conducted by CEI that may generate an impact are used as proxy indicator for the actual impact - JRC: Several instances where CEI intentions or activities that may generate an impact are used to indicate actual impact	+ AHEC: no significant issues identified - EP: economic impact measured based on assumptions from financing plan instead of materialized impact; Use of social impact indicators that measure drivers for impacts, not stated impact itself

Sensitivity	- Often only focus on identifying impacts instead of measuring change over time. + In some cases, several instances of data collection, and comparison of change between instances	- ECR: Repeated surveys may have been planned initially, but were never completed - JRC: Often only focus on identifying impacts instead of measuring change over time	• AHEC: Classification of impacts along short-, medium-, and long-term. No evident discussion of baseline for measuring change • EP: Economic impact over lifetime of citizen energy project (=20 years); No information provided for social impact. Likely since start of the respective project
Reliability	- Often reliance on subjective feelings of change of interview and survey respondents	- ECR: Often reliance on subjective feelings of change of interview and survey respondents - JRC: assessment based on 24 case studies. Very limited information on methodology of data collection	+ AHEC: proposed framework uses objectively verifiable indicators as much as possible. In cases where subjective impacts are measured (e.g. Mental health, social cohesion), uses established & field tested indicators + EP: For nearly every impact, both quantitative-objective and qualitative-subjective indicators provided
Representativeness	- Occasionally, CEI members surveyed about impact on wider community. CEI members are likely not representative of impact recipient - Difficulty of judging whether interview respondents have the necessary insight into the local context to make statements on specific impacts	- ECR: Only CEI members surveyed. Not representative of impact recipient - JRC: no information available	+ AHEC: Most data collected from Ashton Hayes Annual Survey, which aims to cover as many local inhabitants as possible + EP: No significant issues identified. EP also provides instructions on how to only measure components of economic impact that materialize at the correct geographic scale

Attributability	• Some studies fail to sufficiently establish that a change in an observable is the direct result of CEI activities, while others use comparisons to control groups to establish causality	- ECR: not enough information available to evaluate this criterion + JRC: no significant issues observed	- AHEC: not enough information available to evaluate this criterion + EP: indicators represent direct outcomes of CEI
Relevance	+ Relevance to scientific community generally established in the introduction	- ECR: Abandonment of impact assessment effort may indicate irrelevant findings + JRC: High citation count may indicate relevance of the investigation.	+ AHEC: Co-design event with local stakeholders to map most relevant impacts and potential indicators + EP: EP as CEI umbrella organization has an interest to document and communicate the benefits produced by its members
Appropriateness	• Generally impact assessments are limited to few case studies. May indicate challenges in collecting data for larger samples	- ECR: Low return rate for survey and abandoning of the impact assessment effort may indicate that survey was too time-consuming for CEI to complete • JRC: Impact assessments limited to few case studies. May indicate challenges in collecting data for larger samples	- AHEC: Unclear, whether developed framework has ever been applied by AHEC. Framework relies heavily on surveys of local inhabitants. Potentially, excessive burden on respondents + EP: Attempts to reduce the effort required by extrapolation from smaller sample to total population. Self-assessment tool relies on easy to measure indicators largely only requiring internal data that CEI already have

Ethical Concerns	• While unavoidable, anonymization of interview respondents due to data protection requirements may increase difficulty of evaluating e.g. whether interview subjects have necessary insights to make statements on impacts (see also representativeness)	• no significant issues observed	• no significant issues observed
Normative Reference	• Discussion of 'benefits' implies societal desirability. Common references to Energy democracy, energy justice, etc. - Lack of attention towards negative impacts of CEI	• Discussion of 'benefits' implies societal desirability. Common references to Energy democracy, energy justice, etc. - Lack of attention towards negative impacts of CEI	• Discussion of 'benefits' implies societal desirability. Common references to Energy democracy, energy justice, etc. - Lack of attention towards negative impacts of CEI
Benchmark	- Results are not always put into context. E.g. Some studies assess taxes paid by CEI, without comparison to taxes paid by other renewable energy actors. + Other studies compare to national averages, control groups, or other actors.	- ECR: no comparisons made - JRC: no comparisons made. Additionally, choice of some units (e.g. number of rooftops covered in solar panels) allow for little comparability.	- AHEC: No reference cases are suggested for the proposed indicators. + EP: economic impact compared to privately owned renewable energy installations; Social impact compass, showing degree to which individual CEI fulfills each indicator, allows for easy comparison with other CEI.

Understandability	- Issues related to understandability due to ambiguous definition of impact recipient, risk of misinterpretation of intentions and materialized impacts and variety of employed conceptualizations of CEI. - No clear communication of indicators and associated impacts.	- ECR: Documentation available until mid-2024. Then removed for unknown reasons - JRC: inconsistent linking of impacts and indicators.	+ AHEC: Detailed list of impacts with associated indicators. • EP: Detailed documentation exists, but not publicly available

PAPER VIII: COMMUNITY ENERGY INITIATIVES AS DRIVERS FOR DEGROWTH? AN EMPIRICAL INVESTIGATION OF THEIR ALIGNMENT WITH FIVE IMPERATIVES OF DEGROWTH.

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Community energy initiatives as drivers for degrowth? An empirical investigation of their alignment with five imperatives of degrowth

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ABSTRACT

In view of the emerging social, environmental and economic crises, the degrowth movement questions the current growth paradigm. The fundamental criticism put forth by degrowth is that unlimited growth cannot be sustained within the planetary boundaries.

Citizen-owned and democratically controlled Community Energy Initiatives (CEI) engage since many years in the sustainable energy transition. This paper investigates to what extent they align with the degrowth movement. Drawing from an inventory of over 10000 European Community Energy Initiatives, we go beyond the few case studies and theoretical think-pieces. We test potential alignment by empirically investigating indicators for the following degrowth imperatives: (1) Reduce environmental impact, (2) Re-orient economic priorities, (3) Reduce inequality (4) Foster democratic decision making, and (5) Re-localize production and consumption. The results suggest a strong alignment with the environmental impact reduction, democratic decision making, and re-localized production and consumption imperatives, while the alignment with the economic re-orientation and inequality reduction imperatives varies considerably across countries and types of initiatives.

1. Introduction

Humanity faces serious climate change impacts and biodiversity loss (IPBES, 2019; Lee et al., 2023). The earth's planetary boundaries approach, developed by Steffen et al. (2015), signalled that 6 out of 9 boundaries have been crossed in 2023 (Stockholm Resilience Centre, 2023). Along Kate Raworth's (2017) donut theory, this situation, generally referred to as overshoot, requires us to review our production and consumption patterns. At the same time, the donut theory suggests the need to define a social floor: society must be able to meet its basic needs, without generating inequalities. A paradigm shift is generally put forward by advocates of degrowth, which mainly involves challenging the predominant economic growth model (Kallis and March 2015; Latouche, 2009; Schmelzer et al., 2022).

Initially degrowth built upon the criticism of the ecological destructiveness of sustained economic growth. This criticism was strongly influenced by the works of Daly (1972, 1991) on Steady-State-Economics, Georgescu-Roegen (1977) on Bio-economy, and Meadows et al. (1974) on Limits to Growth. These authors argued that continued growth of the physical, quantitative throughput of the economy cannot be sustained in earth's closed system. Following the argument that economic growth cannot be fully decoupled from material and energy consumption, the core idea of degrowth is that an ecologically sustainable society is irreconcilable with continued economic growth (Hickel and Kallis, 2020; Parrique, 2019; Polewsky et al., 2024; Schneider et al., 2010; Vadén et al., 2020).

Over time, the degrowth concept has moved beyond its original environmental perspective, also criticising the growth paradigm as a driver for sustainability issues such as rising inequality and decline in democratic governance (Ariès, 2005; Asara et al., 2015; Cosme et al., 2017; Demaria et al., 2013; Latouche, 2009; Schneider et al., 2010). At the same time degrowth acknowledges that past economic contractions have often led to negative societal consequences such as increasing unemployment and inequality (c.f. Hickel, 2020). To avoid such negative consequences, degrowth argues for a fundamental value shift away from materialism and consumerism towards a society that associates

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quality of life with non-material well-being related to, for instance, leisure, creativity, conviviality, and cooperation (Associazione per la Descrecita, n.d.; Demaria et al., 2013; Kallis, 2018; Latouche, 2009; Research & Degrowth, 2010; Schneider et al., 2010). This value shift, so it is argued, cannot be enforced top-down, instead requiring a voluntary bottom-up process. As such, social enterprises, non-profit organisations and collective action initiatives are seen as ideal examples of degrowth in practice, as they are generally democratic, voluntary, open, and transparent structures through which average people are able to involve themselves in social and economic changes directly (Demaria et al., 2013; Petridis et al., 2015; Sekulova et al., 2013).

Community Energy Initiatives (CEI) - broadly defined as initiatives engaging in the energy transition and being democratically controlled and directly owned by citizens - are often claimed to provide a wide variety of benefits in alignment with the ideas of degrowth. Such benefits include increasing citizen participation in the energy sector, local value creation, community development, fighting energy poverty, and advancing renewable energy deployment and energy saving (Berka and Creamer, 2018; Bielig et al., 2022; Brummer, 2018; European Commission, n.d.; REScoop, n.d.). Coincidentally, CEI are often associated with increasing energy democracy (Stephens, 2019) and energy justice (Van Bommel and Höffken, 2021). These notions are also reflected in the two definitions of CEI by the European Union, stating that the *'primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits'* (European Parliament, 2018, art. 2, 2019, art. 2).

However, even though the CEI movement has been growing significantly in the last decades, with more than 10000 initiatives existing in Europe today (Schwanitz et al., 2023b), they have mostly been investigated through case studies and systematic accounting of their impact is limited (c.f. Bielig et al., 2022). Studies that specifically address the alignment of CEI with the degrowth ideas are rare, finding conflicting results. Kunze and Becker (2015) find the highest degree of overlap between the CEI and degrowth concepts. They argue that CEI align with degrowth due to their focus on reducing energy consumption as well as ecological business models. However, the authors also point out that the investigated cases have been specifically chosen as they 'illustrate degrowth-related features particularly well' (Kunze and Becker, 2015, p. 428). Gibellato et al. (2022) investigate nine Italian CEI, coming to the conclusion that some forms of CEI adhere more closely to degrowth than others. Similarly, Rommel et al. (2018) provide a theoretical thinkpiece building on previous studies focussed on German CEI. They conclude that German initiatives are at a crossroads between a green growth path (i.e., focussing on technological advancement within the current growth paradigm) and a degrowth path (i.e., transitioning towards localised business models, energy sufficiency, and the provision of services as opposed to pursuing continued materialistic economic growth). Both Gibellato et al. (2022) and Rommel et al. (2018) point out the need to further investigate this topic, especially on the European level beyond individual countries.

This paper aims to address the lack of understanding of the alignment of CEI with the degrowth ideas on an aggregate level, beyond individual case studies of best-practice examples. The empirical investigation sources from a cross-country database recording more than 10000 of such initiatives in Germany, France, and other European countries (Wierling et al., 2023). However, while degrowth can be summarized as "a democratically planned reduction in production and consumption to restore a sustainable ecological footprint, reduce inequalities and improve quality of life" (OPCD, n.d.; Parrique, 2019), it remains a "concept in the making" (Petridis et al., 2015, p. 176) with diverse roots in various scientific disciplines and activist movements (Demaria et al., 2013; Eversberg and Schmelzer, 2018; Institute for degrowth studies, n.d.). As such, it proves difficult to empirically test the alignment of CEI with a singular unified conceptualization of degrowth. Instead, we opted for an approach to investigate the alignment of CEI with a set of imperatives that are commonly associated with the degrowth idea. This allows for a more nuanced understanding of the synergies between CEI and the different interpretations of degrowth.

Section 2 reviews the degrowth literature with the goal to synthesize a set of five degrowth imperatives along which the following investigation of CEI and degrowth alignment will be conducted. Section 3 describes the data compilation process as well as the selection of the alignment indicators for each degrowth imperative. Section 4 presents the results of the empirical exploration of the alignment indicators. Section 5 discusses alignment of CEI with the degrowth imperatives, based on the results of the empirical exploration. Finally, Section 6 concludes the study.

2. Review of degrowth imperatives

Degrowth in not a singular concept, but an amalgamation of diverse scientific and activist ideas (Kallis, 2018; Petridis et al., 2015). The following review synthesizes the predominant perspectives on degrowth into five distinct imperatives. For this purpose, we conducted a search on Scopus for papers containing the term "Degrowth" in title, keywords or abstract. We then mapped all conceptual and review papers, that (I) discuss the meaning of the term degrowth and (II) had more than 50 citations, for their respective definitions of degrowth. In this process, two books, that were commonly cited in the reviewed papers, were also included. Furthermore, as degrowth has strong roots in activist movements (Demaria et al., 2013; Petridis et al., 2015), we also investigated definitional statements of degrowth movements that are a part of the International Degrowth Network (n.d.). Aligning topically similar statements resulted in five common degrowth imperatives (see Table A1): (I) Reduce environmental impact, (II) Re-orient economic priorities, (III) Reduce inequality, (IV) Foster democratic decision making, and (V) Re-localize production and consumption.

The first imperative, representing one of the two original core aspects of degrowth was found in every investigated definitional statement and relates to the goal of reducing humanity's environmental impact to a level that can be sustained within the planetary boundaries (Steffen et al., 2015). While degrowth recognizes the need to shift to more sustainable technologies such as renewable energy (Hickel, 2020; Kallis, 2018), it argues that an overall reduction in material and energy consumption is needed, beyond the simple substitution of one resource with another (Degrowth.info, n.d.; Degrowth Copenhagen, n.d.; OPCD, n.d.; Kallis, 2011; Latouche, 2009; Schneider et al., 2010).

The second original core imperative represents the goal of reorienting our socio-economic priorities from the economic growth paradigm to a value system focussed on non-material well-being. Degrowth argues that the aforementioned reduction in material and energy throughput is only possible through an economic contraction. For this process to find support within society, a fundamental value change needs to occur, from a society that values materialism and consumerism to one with a higher emphasis on non-material well-being related to, for instance, leisure, creativity, conviviality, and cooperation (Associazione per la Descrecita, n.d.; Degrowth Central Victoria, n.d.; Demaria et al., 2013; Degrowth.info, n.d.; Hickel, 2020; Kallis, 2018; Latouche, 2009; Research & Degrowth, 2010; Rede para o decrescimento, n.d.; Schneider et al., 2010). This process also includes the decommodification of goods and services (Hickel, 2020; Kallis, 2018; Trainer, 2012), a shift towards informal markets based on voluntarism and neighbourhood help (Cosme et al., 2017; Demaria et al., 2013; Trainer, 2012) and a restructuring of the current financial system built on debt and excessive financial speculation (Trainer, 2012).

The increasing scarcity of resources that results from a shrinking of the economic throughput will accentuate existing wealth disparities (Trainer, 2012). Hence the third imperative argues that a degrowth transformation can only succeed if coupled with a more even distribution of wealth, both on a global level as well as within individual countries (Cosme et al., 2017; Degrowth Vienna, n.d.; Degrowth

Switzerland, n.d.; Demaria et al., 2013; Fournier, 2008; Jarvis, 2019; Latouche, 2009; OPCD, n.d.; Schneider et al., 2010).

Degrowth further emphasizes the voluntary nature of the envisioned transformation process, in contrast to unvoluntary economic contractions such as recessions (Hickel, 2020, Jarvis, 2019). As such, degrowth proponents commonly advocate for a strengthening of more participative forms of democracy, such as direct democracies (Degrowth.info, n.d.; Demaria et al., 2013; Kallis, 2018; OPCD, n.d.; Muraca, 2013; Schneider et al., 2010; Trainer, 2012; Weiss and Cattaneo, 2017). This fourth imperative is also grounded in criticisms of current representative democratic systems that are characterised by lobbyism, political elites and power struggles, and are seen as causes for economic inequalities and perceived injustices (c.f. Trainer, 2012).

The fifth imperative is characterised by a criticism of large global value chains, instead advocating for localized economies based on largely self-sufficient communities, where goods and services are produced and managed as a commons by small cooperatives or working bees (Beling et al., 2018; Degrowth.org, n.d.; Degrowth Aotearoa, n.d.; Degrowth California, n.d.; Kallis, 2018; Latouche, 2009; Rede para o decrescimento, n.d.; Schneider et al., 2010; Trainer, 2012).

3. Materials and methods

As outlined in Fig. 1, the investigation of the alignment of CEI with the degrowth imperatives was conducted along a four-step process. Following the identification of five degrowth imperatives from scientific literature and statements by degrowth movements (see section 2), a set of indicators was selected for each imperative, allowing for an investigation of the alignment of CEI with the five respective imperatives. Indicators were selected based on their ability to depict aggregate level alignment of the European CEI sector in general with the degrowth imperatives. The data necessary for the estimation of the indicators is largely sourced from the previously compiled open-access "Energy by People - ENBP" database with over 10000 European initiatives and 16000 CEI-owned renewable energy production units (Wierling et al., 2022a, 2023). However, due to data availability limitations, most indicators are calculated for a subsample of the CEI contained in the ENBP database, with a focus on French and German CEI, as data coverage was higher for these two countries. While basic administrative data such as CEI name, founding date, and address, are available for most entries in the ENBP database, more specific data is often lacking. In some countries, extensive databases on renewable energy installations as well as detailed yearly financial reports of the CEI are available, while in other countries the only source of information are individual CEIs' websites.

Indicator results showing CEI predominantly reflecting the goals of the associated degrowth imperative were classified as 'substantial alignment', while those predominantly contradicting the associated degrowth imperative were classified as 'non-alignment'. Indicator results showing a large variability across countries or types of CEI were marked at 'partial alignment'. Final alignment of CEI with the overarching degrowth imperatives was defined based on the combined alignment of all subordinate indicators. The classification of the alignment of each individual indicator is justified in more detail in Section 5.

3.1. Data compilation

The ENBP database (Wierling et al., 2022a, 2023) of European CEI was compiled over the course of 4 years and published in 2022. The selection of CEI for the ENBP database was guided by three aspects: (I) the initiative is democratically led by citizens instead of private enterprises or public actors, (II) the initiative is striving for social or environmental benefit beyond pure economic interest, and (III) the initiative

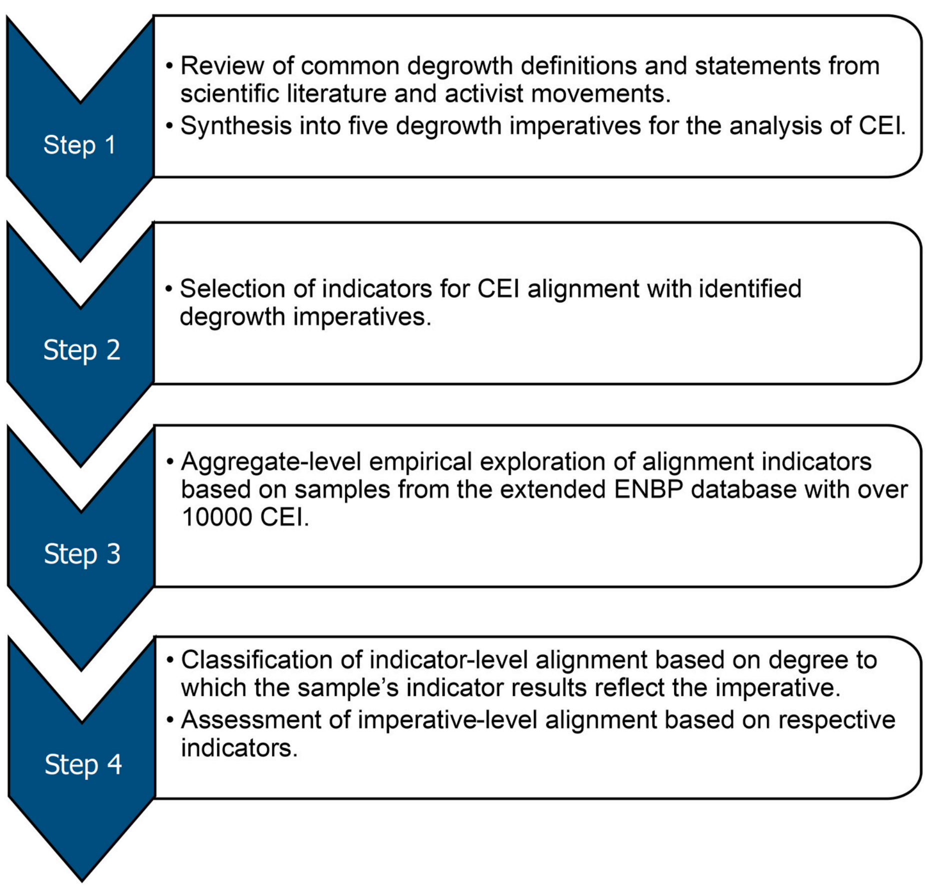

Fig. 1. Methodological process of empirical investigation of aggregate level alignment of CEI with degrowth.

engaging in activities related to the energy transition (Wierling et al., 2023). In contrast to other conceptualizations of CEI (c.f. Bauwens et al., 2022), specific criteria to evaluate the adherence to the three aspects were set to be more inclusive, with the goal to include a large variety of different forms of CEI in the database. This serves the purpose of this paper well, as it avoids selection biases as a result of choosing "best--practice examples", as for instance in Kunze and Becker (2015). Due to practical reasons related to the findability of initiatives, the database mainly includes initiatives officially registered under a legal form, such as cooperatives or associations. However, exceptions to this rule were made, if other initiatives could be identified from previous studies or based on expert knowledge. The database encompasses administrative, financial and demographic data on CEI as well as administrative and technical data on tangible assets owned by CEI (e.g. renewable energy production units). The data was collected primarily from business registers, lists of CEI maintained by CEI umbrella organisations, databases on renewable energy actors and installations, individual initiatives' websites as well as their coverage in media. Detailed information can be found in Wierling et al. (2023).

This paper extends the ENBP database by collecting additional data on the number of employees and more detailed information on the activities conducted by CEI. In a few cases, we also source from related empirical investigations of the same database (Schwanitz et al., 2023b; Wierling et al., 2020, 2021, 2022b). We further make use of data on a smaller sample of 105 CEI across Europe, available on the Energy Communities Repository, which is maintained by the European Commission (European Commission, n.d.).

3.2. Indicators for CEI and degrowth alignment

3.2.1. Imperative 1: reduce environmental impact

We investigate this imperative using two indicators. The total amount of renewable energy installed by CEI represents the aspect of a technological transition, while the share of CEI that engage in energy efficiency and sufficiency activities represents the aspect of reducing material and energy consumption. Estimates for renewable energy capacity installed by CEI are available from Schwanitz et al. (2023b), and estimates for energy consumption reduction activities are available from Schwanitz et al. (2023a) and Wierling et al. (2022b).

3.2.2. Imperative 2: Re-orient economic priorities

We first investigate the degree to which CEI purpose statements reflect the envisioned re-orientation of societal values from profit-maximisation and consumerism to subsistence and non-material well-being. Purpose statements were collected from the statutes of 374 German PV CEI, in connection with a previous study (Wierling et al., 2022b). The collected purposes were scanned for the presence of environmental or social goals beyond the economic support of their members. As additional indicator we use data from a small sample of 44 CEI contained in the Energy Communities Repository (European Commission, n.d.), stating whether profits are reinvested into community projects or distributed as dividends to members.

The aspect of decommodification of goods and services is addressed through an investigation of non-commercial services that CEI provide free of charge. Information was collected from the websites of 366 German and 127 French CEI active in the PV sector. The identified non-commercial services were classified into overarching benefit categories adopted from Bielig et al. (2022). These categories are Energy poverty reduction, Political activism, Community development, Knowledge Sharing and Other activities.

The reliance of CEI on employees was used as an indicator for the alignment with the envisioned shift from formal to volunteer-based markets. Information on employees was gathered for 540 German CEI from the yearly reports published in the national business register (Bundesanzeiger Verlag, 2024). The most recent reports ranged from 2015 to 2022. Employments were converted into full-time-equivalents (FTE) in the following way: Part-time = 0.5 FTE, Apprentices/Dual students = 0.5 FTE, Assistants = 0.25 FTE. CEI were classified based on their number of employees using the size classes of the German Federal Employment Agency (Bundesagentur für Arbeit, 2021).

Finally, financial data of CEI serves as indicator for the alignment with the goal of abolishing the current debt-based financial sector. A previous study (Wierling et al., 2022b) investigates CEI equity ratios as well as whether CEI assets are predominantly composed of fixed tangible or financial assets. Data on equity ratios serves as indicator on CEI reliance of loans for their investments, while the share of fixed tangible and financial assets indicates the degree to which CEI engage in financial trading and speculation.

3.2.3. Imperative 3: reduce inequality

CEI may produce benefits either for their members or external stakeholders (c.f. Bauwens and Defourny, 2017), thereby potentially contributing to alleviating inequalities. We first investigate whether CEI mainly focus on providing benefits for members or external stakeholders, as well as whether CEI offer services specifically targeted towards disadvantaged groups. We then focus on who tends to benefit from being a CEI member by investigating the inclusivity of CEI members and the financial barriers for becoming a member in terms of required membership fees.

The initial investigation builds on the analysis of CEI purpose statements and non-commercial activities (see Imperative 2). Purposes were scanned for the presence of statements indicating that the CEI aims to provide wider community benefits beyond their members. Non-commercial activities were scanned for any references to the provision of special services to disadvantaged groups.

We then explore the inclusivity of the CEI member-base as well as the financial barriers for becoming a member. For the inclusivity aspects, we investigate member demographics, ie. the share of female and vulnerable[1] members as well as those aged under 35, which is provided for 92 CEI in the Energy Communities Repository (European Commission, n.d.). The financial entry barrier is investigated through the cost of membership shares, which members are required to purchase. The ENBP database contains information on share size for 1176 CEI from Belgium, Czech Republic, France, Germany, and Switzerland. Shares have been converted from local currencies to EUR using a ten-year average, resulting in a rate of 1 EUR = 1.08 CHF for Switzerland and 1 EUR = 26 CZK for the Czech Republic.

3.2.4. Imperative 4: foster democratic decision making

We explore this imperative by analysing the degree to which CEI adhere to the one member - one vote principle as indication for democratic decision making. We further investigate to what degree members actively participate in CEI decision making. The share of CEI adhering to the one member - one vote (OMOV) principle serves as a proxy for formal decision-making power, because specific legal forms allow, or dictate, shades of decision-making. Karakas (2019) and Wierling et al. (2023) list the adherence of different legal forms to the OMOV principle. Data about the legal forms are available for 9078 CEI. This paper adds a more detailed investigation of governance principles for 294 French CEI, based on their individual statutes. We also use data from the Energy Communities Repository (European Commission, n.d.) on the share of members that participated in the last general assembly as well as the total number of members to test a previous claim that member participation declines with increasing size of CEI (Rommel et al., 2018).

3.2.5. Imperative 5: Re-localize production and consumption

The fifth imperative advocates for increased self-sufficiency and

[1] Note that the European Energy Communities Repository, from which this data is sourced, does not provide a precise definition of the term 'vulnerable member'.

local production and consumption. CEI are seen as preferable to commercial renewable energy actors in this regard, as the generated benefits (e.g. produced energy, financial profit) tend to remain within the local community (Walker and Devine-Wright, 2008).

We first address the aspect of self-sufficiency in terms of the CEIs' ability to supply their members with energy. Schwanitz et al. (2023b) have investigated this aspect for the CEI contained in the ENBP database. We then investigate whether renewable electricity produced in CEI-owned facilities is consumed locally or fed into the general grid. For 3445 German CEI-owned PV installations, the ENBP database contains information taken from the German Core Energy Market Data Register (Bundesnetzagentur, n.d.), which specifies whether produced electricity is fully or partially fed into the public grid.

For those installations where the produced energy is not consumed directly on-site, the question arises if the CEI members (who benefit from the generated profits) are in fact located in proximity of the production unit. A geographic mismatch of CEI members and energy production units would indicate that the local community at the site of the installation does not significantly benefit from the profits generated by the energy production and feed-in. As such, we compare the geographical spread of CEI members and CEI-owned renewable energy installations. We employ information from Wierling et al. (2022b, 2020) regarding the geographic spread of CEI members as well as the degree to which CEI implement geographic restriction as a prerequisite for becoming a member. Next, the geodesic distance of each renewable energy production unit to the CEI owning the unit is analysed. Prerequisite is the existence of geolocation data for both the unit and the CEI in the ENBP database. This resulted in distance information for 12724 CEI-unit pairs.

Finally, we investigate whether CEI mainly rely on local resources represented by their use of different PV panel brands. The ENBP database contains information on the manufacturers of PV panels used in 1018 German and 366 French CEI-owned PV installations. For each manufacturer the location of its registered headquarter was identified via internet search.

4. Results

4.1. Imperative 1: reduce environmental impact

The main contribution of CEI to this imperative lies in the installation of renewable energy capacities, which Schwanitz et al. (2023b) estimate at 7–10 GW for the European CEI contained in the ENBP database. Solar photovoltaics makes up the largest share thereof. In terms of reducing total material and energy consumption, CEI contribution lies mainly in their engagement in energy efficiency and sufficiency projects. An analysis of the lines of business stated in the statutes of 562 German PV CEI finds references for energy efficiency consulting (12 %), energy saving consulting (10 %), energy efficiency services (14 %), and energy saving services (5 %) (see Wierling et al., 2022b). Furthermore, out of 10546 CEI, 759 have started energy efficiency or energy saving projects, such as information campaigns and renovation and retrofitting projects (see Schwanitz et al., 2023a). Note that CEI may not systematically report energy savings related activities, hence the above values should be interpreted as a potential minimum.

4.2. Imperative 2: re-orient economic priorities

Purpose statements of German PV CEI, representing their intended goals, show that only 50 out of 374 investigated CEI use customised statements referencing goals such as supporting social projects, local community development and sustainability transition initiatives. The remaining 324 adopt a general phrase based on the German cooperative law (GenG, §1), focussing on supporting their members. Thereof, 297 exclusively state the economic support for members, while the remaining 27 extend their focus also to members' social and cultural needs. While the standardised statement based on the cooperative law is often chosen for its legal security and flexibility, the existence of a small number of CEI with customised purpose statements that go beyond economic support for members indicates that some CEI put more emphasis on such non-economic goals than others.

As an indicator for the aspect of decommodifying goods and services, we investigate the share of CEI that offer services to the wider community free of charge. The data show that a considerable number of CEI in our sample do not provide such non-commercial services, however significant variability exists among European countries. For Germany, we find that out of the 366 investigated cases, only 22 mention the provision of such services, related to knowledge sharing in the form of awareness raising campaigns as well as collaborations with schools and running consulting workshops (11 cases), community development such as helping social initiatives and churches and maintaining public infrastructure (8 cases), and international development assistance through supporting renewable energy and social initiatives in developing countries (3 cases). In France, 58 out of 127 initiatives provide free of charge services. Thereof, 36 focus on energy poverty reduction (e.g., helping low-income households with applications to receive subsidies for energy efficiency upgrades). 25 cases are counted that relate to knowledge sharing services. 6 initiatives engage in community development, such as hosting social and cultural events. Note that CEI may engage in more than one activity, hence the sum is not equal to its parts.

In terms of CEI reliance on volunteers or employees, we find that, in a sample of 540 German CEI, the majority relies exclusively on volunteers. Less than 16 % report on regular employees and less than 3 % have more than 10 full-time-equivalent (FTE) positions. Only 3 cases with more than 100 FTE are found. The majority of CEI having employees engage in electricity distribution and the operation of small local grids, which require specialised skills and continuous attention.

Furthermore, a previous publication (Wierling et al., 2022b) has found that CEI often have high equity ratios, with a quarter of the investigated sample having an equity ratio of over 90 %. This indicates a comparably low reliance on loans to finance CEI activities. However, cases with significantly lower equity ratios could also be identified. This study also showed that assets owned by the vast majority of investigated CEI are tangible fixed assets instead of financial assets, hinting towards a low engagement in financial trading activities.

Finally, data from the Energy Community Repository shows that more than half of the 44 CEI in the sample report that profit is exclusively distributed to members, while the remaining report that profits are reinvested in community benefit projects.

4.3. Imperative 3: reduce inequality

The investigation of the purposes of German PV CEI (see Section 4.2) shows that those CEI with customised statements (as opposed to those using the generic purpose statement) commonly mention a goal to support the development and value creation of the local community. While this can be seen as a means to decrease inequality, if targeted towards low-income communities, our previous studies suggest that CEI tend to be more active in regions with higher-than-average incomes (Wierling et al., 2020, 2021). Furthermore, beyond intended goals stated in the purposes, few investigated CEI report concrete activities targeted at addressing inequality. Some examples include "Energiegenossenschaft Starkenburg" (Energiegenossenschaft Starkenburg, n.d.) and "fairPla.net"(fairPla.net, n.d.), who foster international development assistance for countries in the Global South, or the cooperative "Qvinnovindar" (Qvinnovindar, n.d.) that promotes female engagement in the energy sector. We find, however, significant differences in the focus on equality related issues across countries. For instance, out of a sample of 127 French CEI, 36 provide free-of-charge energy consulting services to low-income households, while similar evidence could not be found among German CEI.

Beyond such CEI specifically targeting equality related aspects, the

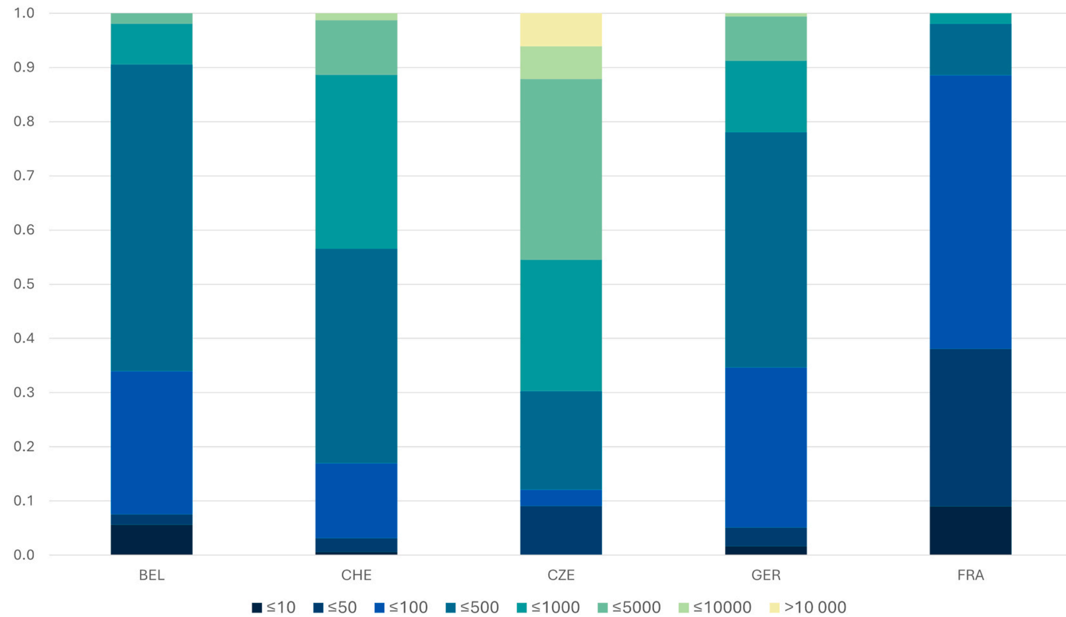

Fig. 2. Distribution of Share sizes in EUR for 53 Belgian, 159 Swiss, 33 Czech, 721 German, and 210 French CEI.

previous investigations of CEI purposes and use of profits, indicate that a significant share is mainly focused on providing (financial) benefits for members. This begs the question of the inclusivity of such CEI and who consequently benefits of being a member therein. We investigate the size of membership shares of CEI as representation for the financial barrier for becoming a member. CEI members are required to purchase at least 1 share. Fig. 2 shows the distribution of member share sizes for CEI of 5 selected countries. As can be seen, significant variability in the share size distribution can be found across countries, with the median class ranging from 50 to 100 EUR in France to 500 to 1000 EUR in the Czech Republic. The reason for the high share sizes in the Czech Republic is likely the result of a majority of Czech CEI being larger agricultural cooperatives that also engage in energy related activities such as biomass or biogas.

The financial entry barriers to CEI membership may then be linked to the lack of inclusivity of the member base. Data from the European Energy Communities Repository shows that about half of the included CEI report a share of female members below 25 %, while ~95 % report a share of vulnerable members below 25 % and ~90 % report that less than 25 % of their members are aged below 35. Other studies have confirmed that CEI members lack in diversity, with CEI members often being "well-off, rural, male sexagenarians" (Wierling et al., 2020, p. 249; see also: Radtke and Ohlhorst, 2021; Sebi and Vernay, 2020).

4.4. Imperative 4: foster democratic decision making

A core aspect of the democratic nature of CEI is the decision-making process based on the One Member - One Vote (OMOV) principle which is independent of a member’s share, in contrast to a voting system dependent on a shareholder’s share, that is common in private shareholding companies. Our data show that 40 % of CEI are registered under the legal form of cooperative, which generally adheres to the OMOV principle (c.f. Karakas, 2019). While other legal forms adopted by CEI are more flexible in terms of governance, the OMOV principle remains a common choice. A detailed investigation of French CEI, which generally prefer other legal forms such as the joint-stock-company (SAS), confirms this point. Over 90 % of the French CEI still adhere to the One Member - One Vote principle voluntarily.

While this principle sets the legal framework for a more egalitarian governance system compared to other companies, it is also interesting to investigate whether it truly translates to a highly participative decision-making within CEI. Rommel et al. (2018) point out a trend where member participation in general assemblies tends to decline with increasing size of the CEI. The yearly general assembly is the main tool through which the entire member-base is able to participate in major decisions (e.g. payout of dividends, electing steering committee, deciding on new projects). Based on the data from the European Energy Communities Repository, we can confirm this trend. As Table 1 shows, the participation rate in the most recent general assembly almost continuously declines with increasing median membership numbers. Data on membership numbers of CEI included in the ENBP database show that close to half of the CEI have above 100 members. Assuming that the trend shown in Table 1 holds true, would indicate that a significant share of CEI have comparably low member participation in decision-making. Similar trends of low participation rates were also identified in other studies (Van Veelen, 2018; Wierling et al., 2020).

4.5. Imperative 5:re-localize production and consumption

In terms of self-sufficiency, CEI theoretically produce sufficient energy to cover the energy needs of all their members (Schwanitz et al., 2023b). The question arises, however, whether this energy is truly used for local self-consumption or simply fed into the national grid. Fig. 3 shows the evolution of the ratio between full and partial feed-in over the last 20 years for a sample of German CEI-owned PV units. A clear trend from almost exclusively full feed-in to increasing partial feed-in installations can be observed. This trend coincides with the gradual reduction of feed-in tariffs over the past two decades (Wirth, 2024). The decreasing profitability of the feed-in tariff business model therefore

Table 1
Comparison of membership participation in last general assembly with median membership number for all CEI with participation rate in given range. Intervals for assembly participation were adopted from the European Energy Communities Repository.

Assembly participation rate (%)	Median membership number
<25	334
26–44	129
45–55	68
56–75	47
76–90	16
>90	27

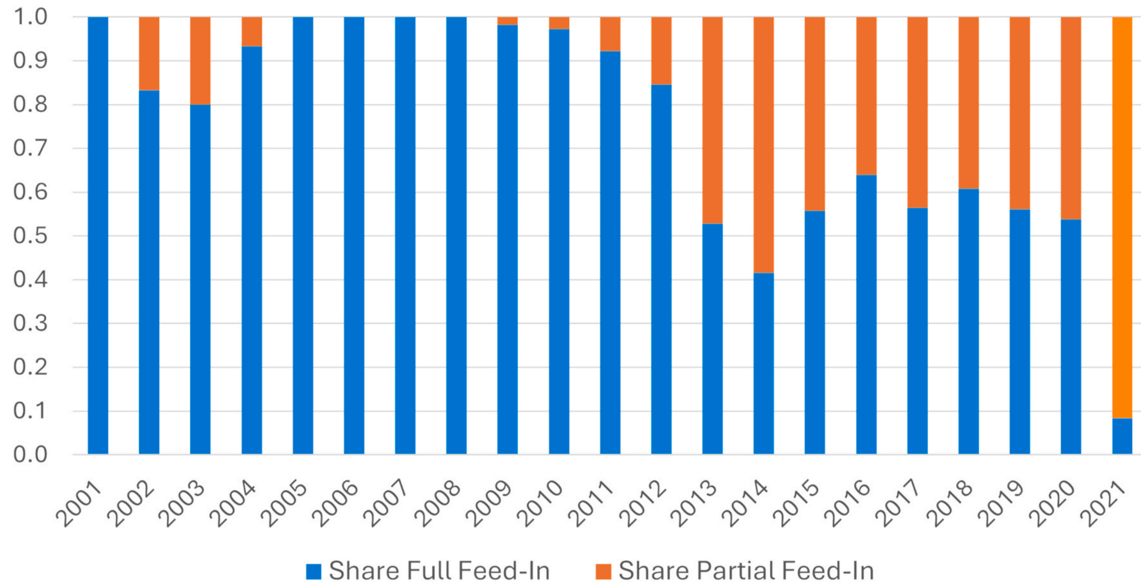

Fig. 3. Share of 3811 newly installed German PV units owned by CEI that fully feed electricity into the national grid or partially use electricity for local self-consumption.

pushed CEI to experiment with new business models, such as local self-consumption (Wierling et al., 2022b).

In such cases where produced energy is fed into the grid, the local (financial) benefits only arise if CEI members are located in close proximity to the production facilities. In terms of the geographic spread of CEI members, Wierling et al. (2020, 2022b) find evidence indicating that CEI members are commonly located closely to the CEI and that some CEI even enforce geographic restrictions on membership.

Next, we investigate the geographical spread of CEI activities. Fig. 4 shows the share of production units located within a certain radius of the CEI for the sample of 12724 CEI across Europe. About a quarter of installations are located directly at the CEI headquarter (<1 km distance). In total, almost two thirds of installations lie within a 10 km radius. However, we do also find occasions where production units are located several hundred or even more than thousand kilometres from the CEI, occasionally even being located in foreign countries. A more detailed breakdown along technology types and countries can be found in appendix Fig. A1. The exception being Swiss and Spanish installations. However, for these two countries, our sample only comprises installations from 2 CEI each, therefore not being representative. Regarding the two most common technologies, wind installations are generally located at greater distance than solar PV installations. Noteworthy is also the low spatial spread of biomass/biogas and heating technologies.[2] These constitute a large share of the samples for Finland and Denmark. The low spatial spread of these technologies is a result of being used in local district heating systems operated by the CEI. The same is true for hydropower installations in Germany, a significant share of which have been installed in the first half of the 20th century by rural electrification cooperatives, with the aim of providing electricity to rural areas de-prioritized by market and state actors. Those that remain active today tend to still operate local electricity distribution grids. These results confirm a previous study on a smaller sample, exclusively investigating CEI owned PV installations in Germany and Italy (Wierling et al., 2021). Interestingly, Rommel et al. (2018) point out that, especially for wind installations, there is a chance that recent changes in

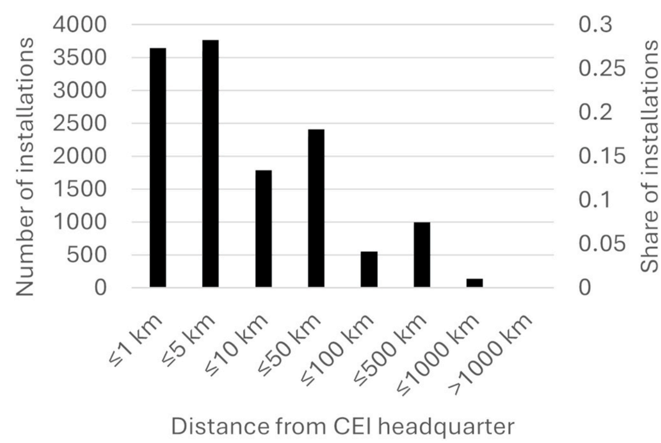

Fig. 4. Share of 12724 CEI production facilities located within specified distance from headquarters for total sample of CEI across Europe.

legislation in Germany as well as technological development may lead to increasingly larger turbines located at greater distances. Our data does not substantiate this claim, neither for Germany nor the EU in total. While turbines have increased in capacity, there is no significant correlation between year of installation and distance from CEI headquarter. The same is also true for other technologies than wind.

These results indicate that both members and energy production facilities are mostly located in close proximity to the CEI headquarter. This suggests that the financial benefits generated from feeding produced electricity into the grid and distributing the revenues as member dividends remain within close proximity to the CEI.

Finally, we investigate the PV panel brands used by German and French CEI as representation of CEIs' use of local resources. Fig. 5 shows the world regions in which the registered headquarter of the PV panel producer is located. German CEI continuously rely strongly on PV panels from East Asian manufacturers, mainly Chinese. The remaining panels are sourced mostly from European and North American manufacturers. French CEI, on the other hand, rely predominantly on European manufacturers (mostly German and French), only showing a significant share of East Asian brands in the years 2017–2020. In 2020, a large percentage of panels were also sourced from North American brands. It is important to note that this is not a perfect representation, as today the

[2] Overlap between the two technologies may exist: Biomass/biogas technologies may be used for either heat or electricity production (or both). The category Heat therefore includes all heating technologies not further specified, or fossil fuel-based heating systems.

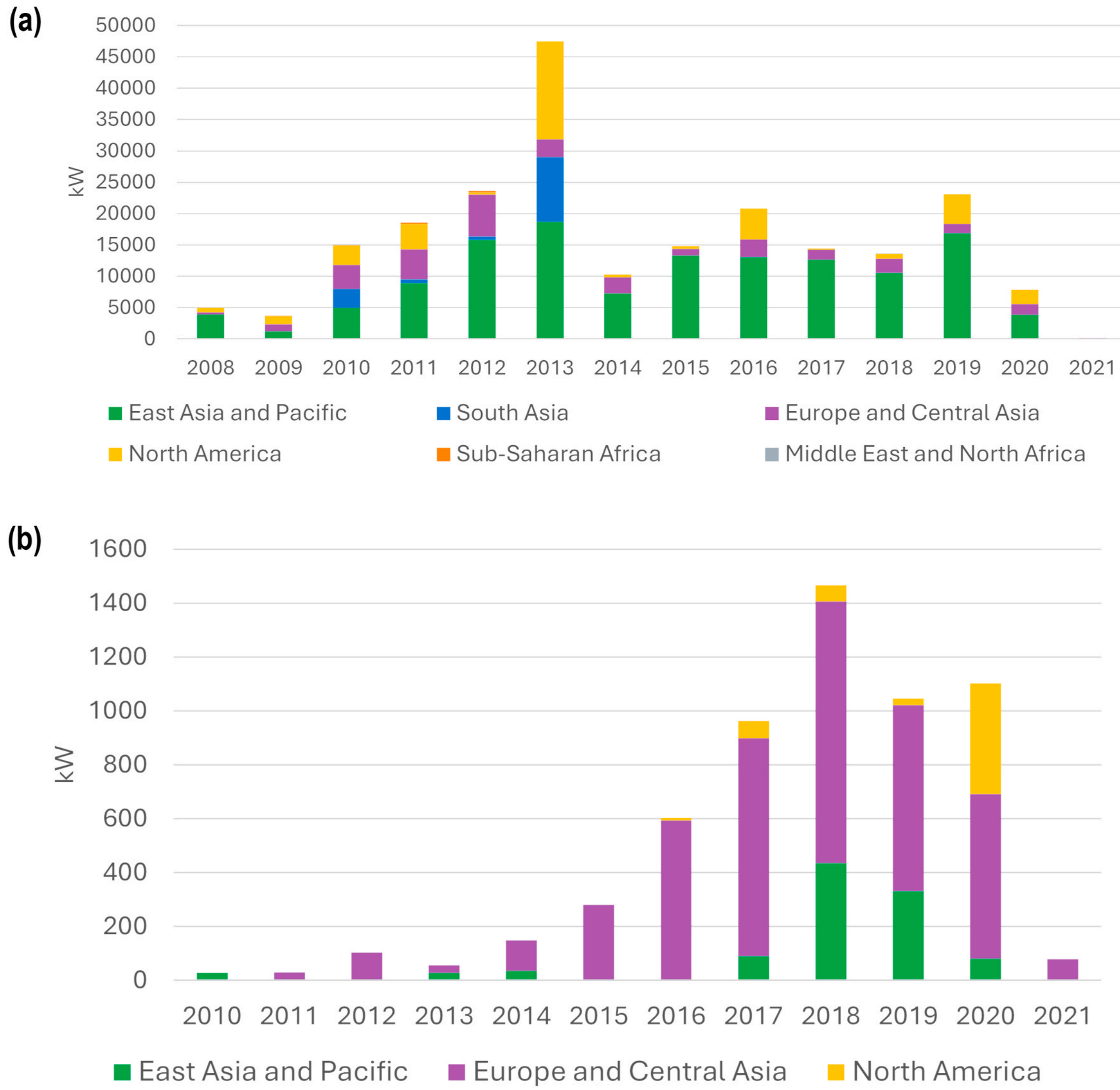

Fig. 5. a and b: Location of registered headquarter of PV panel manufacturer of 1018 German (top) and 366 French (bottom) CEI-owned PV installations, based on share of total newly installed capacity per year in kW. Classified into World regions based on the World Bank.

vast majority of PV panel assembly occurs in China, even for non-Chinese manufacturers (IEA, 2022). However, the considerably greater use of European panel brands among French CEI compared to German ones still hints towards a greater awareness on local sourcing of materials among French CEI. Furthermore, international companies tend to pay taxes in the country of their registered headquarters, and as such the choice of panel brand contributes to the respective country's economy.

5. Discussion

Fig. 6 summarises our findings regarding the alignment of CEI with the five degrowth imperatives. Our investigation indicates that CEI across Europe align strongly with the environmental impact reduction imperative, mainly through their engagement in deploying renewable energy technologies. However, some controversy can be found in the degrowth movement around the use of technology (c.f. Kerschner et al., 2018). While some see technological advancement as necessary for a sustainable transition, others specifically criticise the narrative that technological advancement is the sole solution to current environmental challenges, instead emphasising the need to lower material and energy consumption rather than simply substituting one resource with another. In fact, degrowth specifically criticises other development narratives such as green growth for their assumption that environmental impact can be fully decoupled from material and energy consumption through technological advancement (Hickel and Kallis, 2020; Polewsky et al., 2024; Schneider et al., 2010; Vadén et al., 2020). Only a small share of CEI report activities related to energy consumption reduction, indicating a weaker alignment with this aspect. However, it is likely that not all CEI report such activities hence the true share is expected to be higher. In summary, we interpret the ability of CEI to fulfil the energy needs of their estimated 2 million members across Europe (Schwanitz et al., 2023b), as well as contributions to energy savings, as indication for a strong alignment with the first degrowth imperative.

Regarding the economic re-orientation imperative, our results show large variability within and across countries. On the one hand, CEI reliance on volunteers, and avoidance of loans and financial trading activities indicates a strong alignment with this degrowth imperative. On the other hand, we find that CEI often state primarily economic goals in their purposes and often distribute profits to members. Finally, we see that French CEI report considerably more non-commercial activities compared to German ones. The variability in terms of purposes, profit distribution and non-commercial activities hints towards an only partial alignment of the CEI sector as a whole with the second degrowth imperative. The aspect of voluntarism is also subject to some

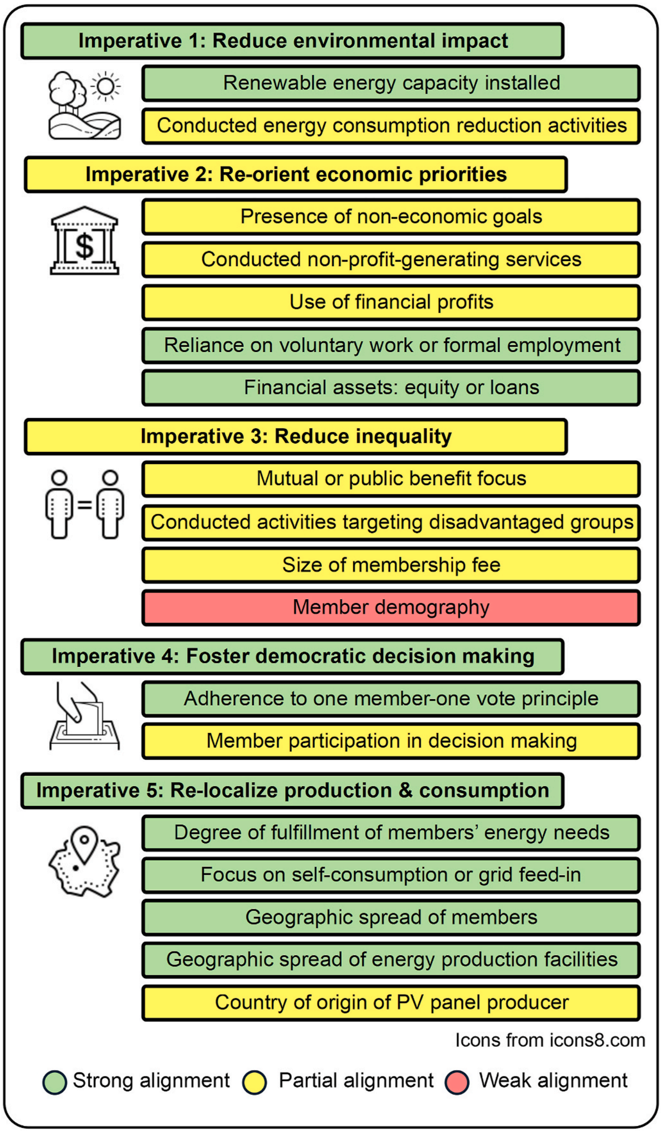

Fig. 6. Summary of degrowth imperatives, associated indicators and CEI alignment with respective degrowth imperative. Icons from icons8.com.

controversy within the literature. While some emphasise the need to move towards a more informal economy based on voluntarism and neighbourhood help (Cosme et al., 2017; Demaria et al., 2013; Trainer, 2012), others argue instead for mechanisms such as a job guarantee (e.g. Hickel, 2020). Depending on the stance taken on this issue, our results on reliance on employees or volunteers can be interpreted differently. Overall, our findings are in line with other studies such as Dilger et al. (2017) that situate CEI on a spectrum ranging from "investor-type" to "prosumer-type" initiatives. The former mainly focus on providing financial returns to members, while the latter emphasise a direct value proposition towards their members' or external stakeholders' needs.

Similar variability can also be found in terms of the alignment of CEI with the equality imperative. Relating our investigation of CEI membership share sizes to a study from 2020, which compiled microdata on household savings from the European Central Bank (Demertzis et al., 2020), indicates that low-income households likely struggle to afford the purchase of such shares. According to this data, the first quartile of French, German and Belgian household savings lie between ca. 1200 and 2200 EUR. This suggests that median membership share sizes of up to 500 EUR in Germany and Belgium represent a significant proportion of the total savings of the poorest 25 % of the population. Note also that CEI occasionally require the purchase of several shares, thereby further exacerbating this issue. The exception being France with only just over 10 % of CEI having a share size above 100 EUR. Demertzis et al. (2020) do not provide data on household savings for the Czech Republic and Switzerland. However, it can be expected that the pattern in the Czech Republic is similar to that of Belgium and Germany, potentially even more pronounced given the far higher membership fees. In Switzerland, the higher membership fees are likely counter-balanced by generally higher household incomes and wealth. CEI members also often lack diversity in terms of female, vulnerable and young members. We furthermore find evidence suggesting that CEI are often focussed on supporting members and only occasionally offer services specifically targeted towards disadvantaged groups. The focus on providing member benefits combined with the lack of inclusivity of the member base indicates a weak alignment of CEI with the core idea of the equality imperative, being a more equal distribution of wealth and resources. On the other hand, the French case indicates a far greater alignment with the imperative, with share sizes being significantly lower compared to other countries as well as a stronger focus on providing services to disadvantaged groups.

In terms of the governance imperative, we find that CEI across Europe adhere to the One Member - One Vote principle, indicating a highly democratic decision-making structure, thereby aligning with this imperative. However, degrowth also argues for a move to more direct democratic decision-making structures instead of representative democracies (Research & Degrowth, 2010; Schneider et al., 2010; Trainer, 2012). The majority of CEI tend to elect a steering committee that runs the day-to-day operations, and only major decisions are made in the yearly general assembly. Especially among larger CEI, member participation in general assemblies seems to decline, leaving the decisions in the hands of a small group of representatives. However, even though this indicates that CEI members do not regularly make use of their right to participate in the decision-making, the formal governance structure of CEI still guarantees every member the possibility to equally influence the decision-making if they so wish. As such, we argue that CEI nonetheless align strongly with the fourth imperative. Especially small CEI seem to closely represent the ideals of this degrowth imperative.

Finally, we find a strong alignment of CEI with the local sufficiency imperative. Based on a large cross-national sample, we find that CEI predominantly install renewable energy facilities within close proximity of their headquarters. Evidence from a smaller German sample also indicated a re-focussing on local self-consumption. The only variation that could be observed relates to the brand of used PV panels, where we find that French CEI have a stronger focus on using European panels, compared to German CEI. This imperative is, however, also the most controversial one. Mocca (2020) points out that a somewhat idyllic depiction of local communities dominates within the degrowth community, not grounded in robust scientific findings. Trainer (2012) and Bauhardt (2014), for example, envisage a degrowth society based on local, self-sufficient and frugal neighbourhoods, that are increasingly also in charge of public services currently provided by the state, such as retirement, health and education services. Other authors point out the need to expand public services which small local communities will not be able to provide (Hickel, 2020; Kallis, 2018). Depending on the perspective on this issue, our results can be interpreted differently.

6. Conclusion

Rommel et al. (2018, p. 1751) see CEI "at a crossroads" between a green growth or degrowth pathway. Our empirical compilation drawing from a large cross-country sample shows that CEI align strongly with the environmental, governance and local sufficiency imperatives of degrowth. At the same time our results indicate that the alignment with the economic re-orientation and equality imperatives varies across countries and indicators. In the literature (see Table A1 in appendix), the governance and local sufficiency imperatives are mentioned less frequently compared to the other three imperatives. Thus, we find a closer alignment with the less frequently mentioned imperatives. Further research will be necessary to better understand the reasons for the observed variability in some of the imperatives. For instance, the fact that French CEI show a greater alignment with the economic re-orientation and equality imperatives may be a result of the strong roots of the degrowth movement in France. In fact, the degrowth movement (*"Decroissance"* in French) is often stated to have originated in France (Demaria et al., 2013; Petridis et al., 2015).

Finally, it is important to note that the controversies discussed in Section 5 show that degrowth remains a 'concept in the making' (Petridis et al., 2015, p. 176; see also: Demaria et al., 2013; Eversberg and Schmelzer, 2018; Sekulova et al., 2013). Its value therefore lies not necessarily in its scientific robustness, but in its potential to offer a counter-narrative to the dominant growth narrative, aiming to inspire various new ideas and rally social movements that envisage more sustainable ways of living (Augustyn, 2024; Kallis, 2018; Petridis et al., 2015). As such, our findings should therefore be interpreted as indication of the alignment of CEI with the currently dominant narrative of degrowth. Whether the alignment of CEI with the different imperatives of degrowth truly has the potential to advance a transformation to a sustainable society will require further research on the scientific robustness and feasibility of the different degrowth strategies in general.

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CRediT authorship contribution statement

Jan Pedro Zeiss: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Valeria Jana Schwanitz:** Writing – review & editing, Data curation, Conceptualization. **August Wierling:** Writing – review & editing, Data curation, Conceptualization. **Timothy Peter Marcroft:** Writing – review & editing, Data curation. **Constantin von Beck:** Writing – review & editing, Data curation. **Arnaud Diemer:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2025.145612.

Appendix 1. Overview over degrowth imperatives mentioned in scientific literature and activist movements

Tab. A1
Degrowth imperatives used in commonly cited journal articles and books, as well as on websites of known degrowth activist initiatives.

Reference	Scopus/ Google Scholar Citations	Journal	Journal Impact Factor	Reduce environmental impact	Re-orient economic priorities	Reduce inequality	Foster democratic decision making	Re-localize production & consumption
Peer-Reviewed Publications								
Hickel (2020)	178	Globalizations	2.5	x	x	x		
Trainer (2012)	97	Futures	3	x	x	x	x	x
Cosme et al. (2017)	179	Journal of Cleaner Production	11.1	x	x	x		
Schneider et al. (2010)	703	Journal of Cleaner Production	11.1	x	x	x	x	x
Research and Degrowth (2010)	78	Journal of Cleaner Production	11.1	x	x	x	x	
Demaria et al. (2013)	506	Environmental Values	2.2	x	x	x	x	
Kallis (2011)	671	Ecological Economics	6.6	x	x	x		
Asara et al. (2015)	219	Sustainability Science	6.8	x	x	x	x	
Fournier (2008)	218	International Journal of Sociology and Social Policy	1.9	x	x	x	x	
Weiss and Cattaneo, 2017	169	Ecological Economics	6.6	x	x	x	x	x
Beling et al. (2018)	80	Ecological Economics	6.6	x	x	x		x
Muraca (2013)	78	Environmental Values	2.2	x	x		x	
Jarvis, 2019	73	Progress in Human Geography	6.3	x	x	x	x	x
Books & commentaries								
Hickel et al. (2022)	128	Nature Comments	n/a	x	x	x		
Latouche (2009)	1577	Mille et une nuits/ Polity Press	n/a	x	x	x		x
Kallis (2018)	526	Agenda Publishing	n/a	x	x	x	x	x
Activist Movements								
degrowth.info, n.d.	n/a	n/a	n/a	x	x	x	x	x
degrowth.org, n.d.	n/a	n/a	n/a	x	x	x	x	x

(*continued on next page*)

Tab. A1 (*continued*)

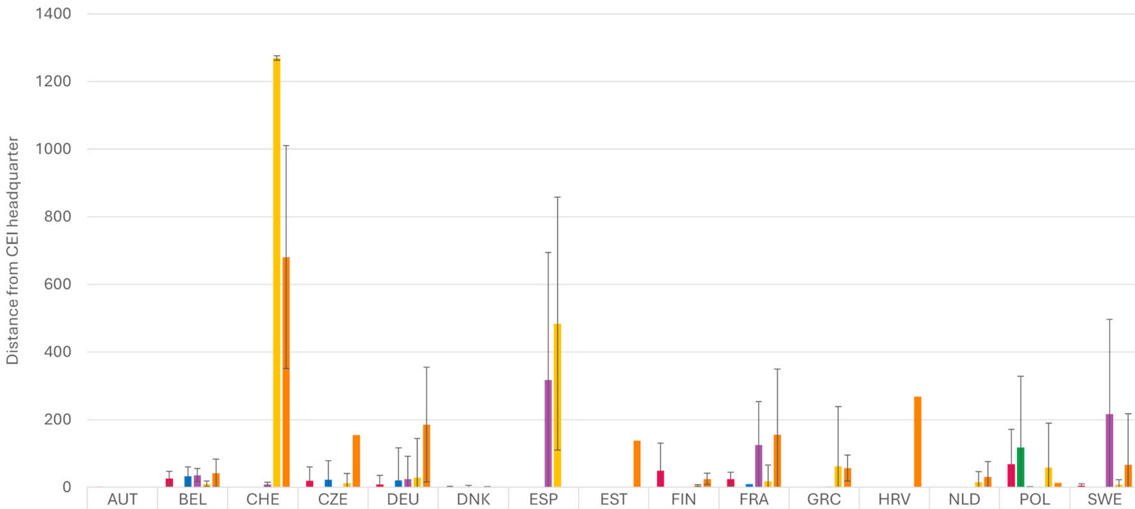
Reference	Scopus/ Google Scholar Citations	Journal	Journal Impact Factor	Reduce environmental impact	Re-orient economic priorities	Reduce inequality	Foster democratic decision making	Re-localize production & consumption
Associazione per la Descrecita, n.d.	n/a	n/a	n/a	x	x	x		
OPCD, n.d.	n/a	n/a	n/a	x	x	x	x	
Degrowth aotearoa, n.d.	n/a	n/a	n/a	x	x	x	x	x
Degrowth California, n.d.	n/a	n/a	n/a	x	x	x		x
Degrowth Central Victoria, n.d.	n/a	n/a	n/a	x	x			
Degrowth Copenhagen, n.d.	n/a	n/a	n/a	x	x	x		
Degrowth Switzerland, n.d.	n/a	n/a	n/a	x	x	x	x	
Degrowth Vienna, n.d.	n/a	n/a	n/a	x	x	x		
Institute for degrowth studies, n.d.	n/a	n/a	n/a	x	x	x		
Rede para o decrescimento, n. d.	n/a	n/a	n/a	x	x	x	x	

Appendix 2. Indicators for testing alignment of CEI with degrowth imperative

Tab. A2
Summary of indicators, data samples and data sources for each investigated degrowth imperative.

Indicator	Sample size	Data source
Imperative 1 – Reduce environmental impact		
Total renewable energy capacity installed by CEI	Total sample of 10546 European CEI	Schwanitz et al. (2023b)
Share of CEI conducting energy consumption reduction activities	10546 European CEI; 562 German PV CEI	Schwanitz et al. (2023a), Wierling et al. (2022b)
Imperative 2 – Re-orient economic priorities		
Presence of non-economic goals in CEI purpose	374 German PV CEI	Wierling et al. (2022b)
Share of CEI offering non-profit generating, public benefit services	366 German PV CEI 127 French PV CEI	CEI Websites
Use of financial profits	44 CEI across Europe	Energy Communities Repository (European Commission, n.d.)
Reliance of CEI on voluntary work or formal employment	540 German CEI	CEI yearly reports (Bundesanzeiger Verlag, 2024)
CEI financial assets – equity or loans	Two samples of 265 and 191 German PV CEI.	Wierling et al. (2022b)
Imperative 3 – Reduce inequality		
Stated purpose of CEI – mutual or public benefit focus	374 German PV CEI	Wierling et al. (2022b)
Conducted activities specifically targeted towards disadvantaged groups	366 German PV CEI 127 French PV CEI	CEI Websites
Size of membership fee of CEI	1176 CEI, Thereof: BEL: 53, CHE: 159, CZE: 33, GER: 721, FRA: 210	ENBP Database
Member demography - inclusivity of CEI	92 CEI across Europe	Energy Communities Repository (European Commission, n.d.)
Imperative 4 – Foster democratic decision making		
Formal governance principles of CEI - adherence to one member - one vote principle	Analysis of general adherence based on chosen legal form for 9078 CEI; Detailed analysis based in individual statutes for 294 French CEI	ENBP Database
Member participation in decision-making processes	85 CEI across Europe	Energy Communities Repository (European Commission, n.d.)
Imperative 5 – Re-localize production and consumption		
Energy self-sufficiency – Degree of fulfilment of members' energy needs	Total sample of 10546 European CEI	Schwanitz et al. (2023b)
Focus on self-consumption or feed-in of electricity into national grid	3811 German CEI-owned PV installations	ENBP Database
Geographic distribution of members	46 Danish CEI & 286 German PV CEI	Wierling et al. (2020, 2022b)
Geographic spread of energy production facilities	12724 CEI-Unit pairs Thereof: AUT: 1, BEL: 98, CHE: 39, CZE: 37, DNK: 395, ESP: 11, EST: 132, FIN: 26, FRA: 876, GER: 10108, GRC: 49, HRV: 5, NLD: 707, POL: 43, SWE: 197	ENBP Database
Use of local resources – Country of origin of PV panel producer	366 French CEI-owned PV units 1018 German CEI-owned PV units	ENBP Database

Appendix 3. Breakdown of distances between CEI and owned renewable energy generation facilities



	AUT	BEL	CHE	CZE	DEU	DNK	ESP	EST	FIN	FRA	GRC	HRV	NLD	POL	SWE
BIO	3	27		20	9	1			49	24				69	5
GEO														118	
HEAT		33		23	21	2				9				1	
HYDRO		36	9		24		318			125	3				217
SOLAR		10	1269	13	29	1	484	0	5	18	62	0	16	59	8
WIND		42	681	155	186			139	25	155	57	269	31	14	67

Fig. A1. Breakdown of average distances between CEI and owned renewable energy generation facilities. Separated by technology type and country. Error bars show 1 standard deviation.

Data availability

This study largely uses data contained in the open access ENBP database on European CEI, which is available on dataverse.no (2022a). Additional information on compilation and usage of the ENBP database can be found in Wierling et al. (2023). This data was extended by additional datapoints which are attached as supplementary file to this study. Further data was collected from the European Energy Communities Repository (European Commission, n.d.).

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