energies

MDPI

Article

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

August Wierling [1,*], Jan Pedro Zeiss [1], Veronica Lupi [2], Chiara Candelise [2,3] and Alessandro Sciullo [4] and Valeria Jana Schwanitz [1,5]

1 Department of Environmental Sciences, Western Norway University of Applied Sciences, Røyrgata 6, 6856 Sogndal, Norway; Jan.Pedro.Zeiss@hvl.no (J.P.Z.); Valeria.Jana.Schwanitz@hvl.no (V.J.S.)
2 GREEN Research Centre, Bocconi University, Via Röntgen 1, 20136 Milan, Italy; veronica.lupi@unibocconi.it (V.L.); chiara.candelise@unibocconi.it (C.C.)
3 Imperial Centre for Energy Policy and Technology (ICEPT), South Kensington Campus, Imperial College London, London SW7 2AZ, UK
4 Department of Culture, Politics, and Society, University of Turin, Via Verdi 8, 10124 Turin, Italy; alessandro.sciullo@unito.it
5 The Create Centre, The Schumacher Institute, Bristol BS1 6XN, UK
* Correspondence: augustw@hvl.no; Tel.: +47-57676240

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

check for updates

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

Academic Editor: Bruno Henriques Dias

Received: 25 February 2021
Accepted: 6 April 2021
Published: 17 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

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.

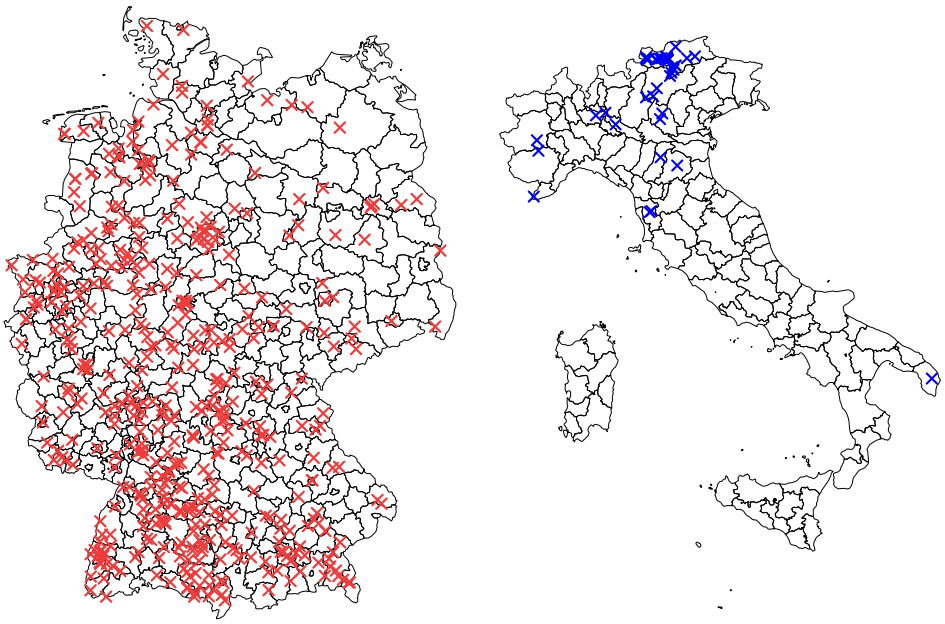

Figure 1. Data samples for Germany (l.h.s, 470 entries) and Italy (r.h.s., 37 entries). Crosses mark registered addresses of headquarters of energy communities.

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.

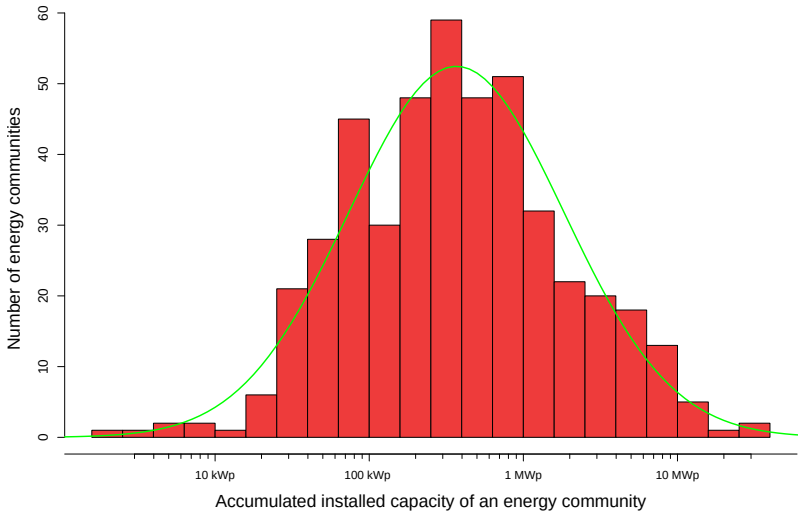

Figure 2. Number of EC in Germany for given bins of accumulated installed capacity. The green line is a normal distribution fit.

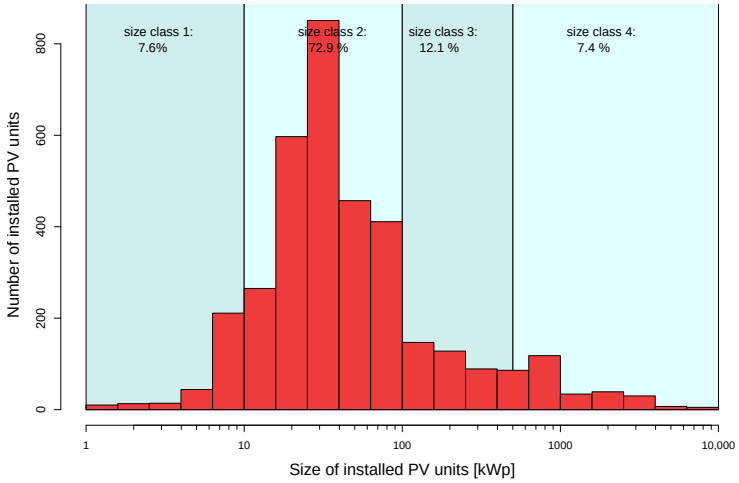

Figure 3. Number of units with certain sizes managed by EC in Germany. Azur fields indicate the size classes of single PV installations.

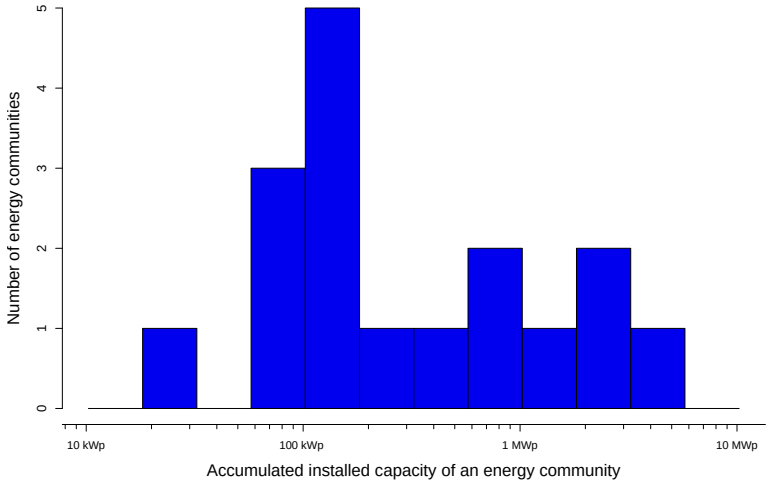

Figure 4. Number of EC in Italy for given bins of accumulated installed capacity. Note that the sample is limited to available data for capacities.

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.

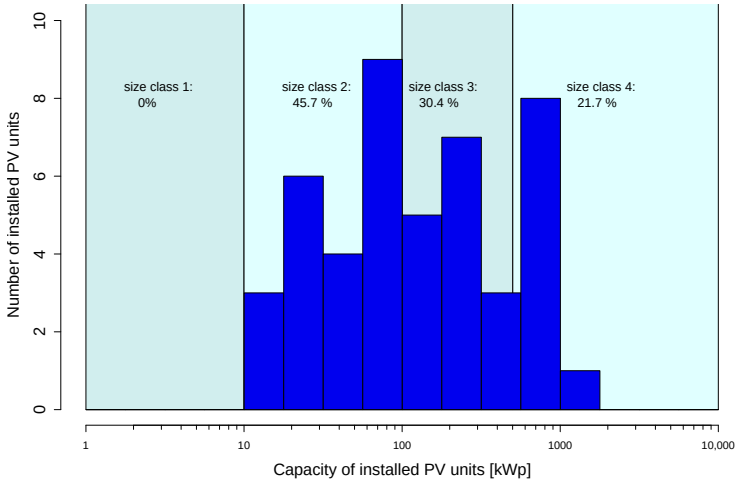

Figure 5. Number of units with certain sizes managed by EC in Italy. Note that the sample is limited to available data for capacities.

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%

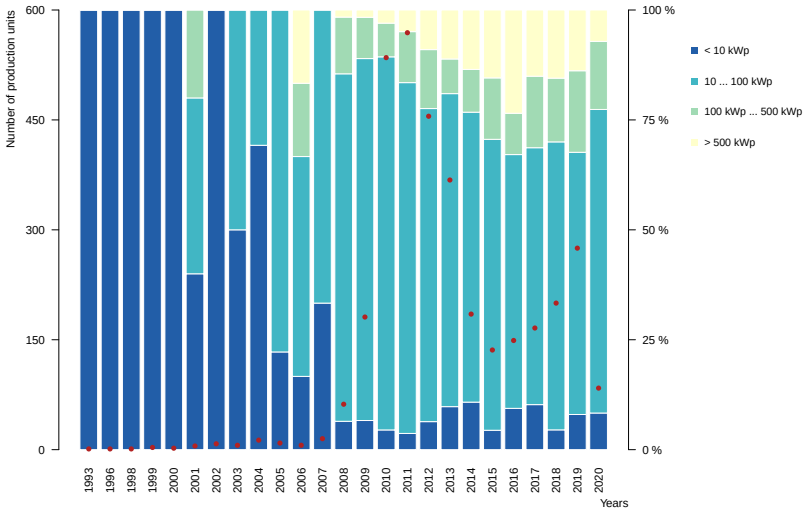

Figure 6. Change in number of PV units (red dots and axis to the **left**) and distribution of size classes in a year for Germany (see axis to the **right**).

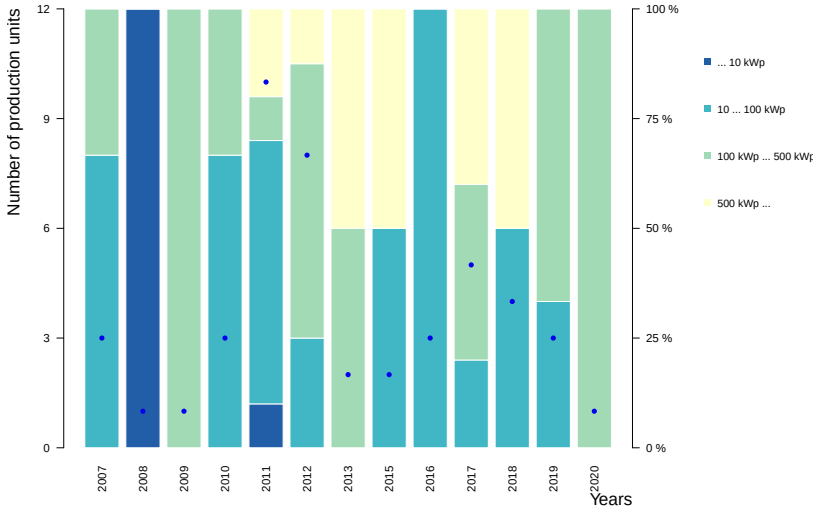

Figure 7. Change in number of PV units (blue dots and axis to the **left**) and distribution of size classes in a year for Italy (see axis to the **right**).

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.

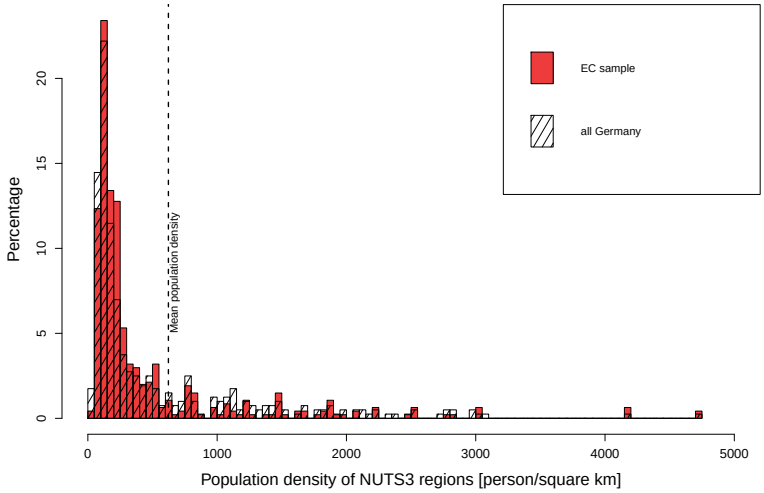

Figure 8. Comparison of the distribution of population density at country level and for the EC sample in Germany.

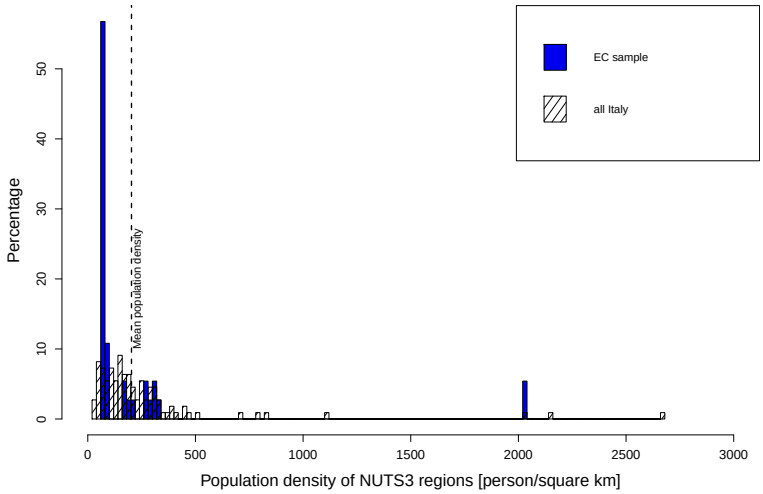

Figure 9. Comparison of the distribution of population density at country level and for the EC sample in Italy.

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.

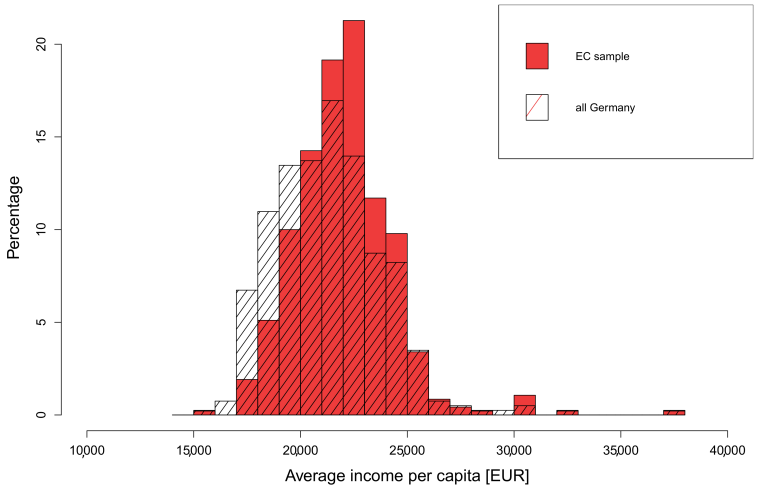

Figure 10. Comparison of the distribution of available income for households for all NUTS-3 regions in Germany (hatched bar) with the distribution of available income for households in NUTS-3regions where EC are active (red bar). The year for comparison is 2015. Source: Income data from [42].

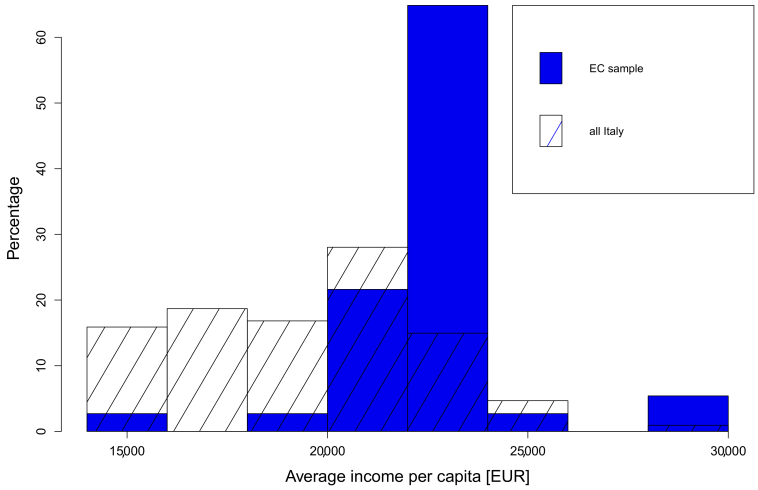

Figure 11. Comparison of the distribution of the regional income for all NUTS-3 regions in Italy (hatched bar) with the distribution of selected NUTS-3 regions where EC are active (blue bar). The year of comparison is 2015. Source: Income data from [43].

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.

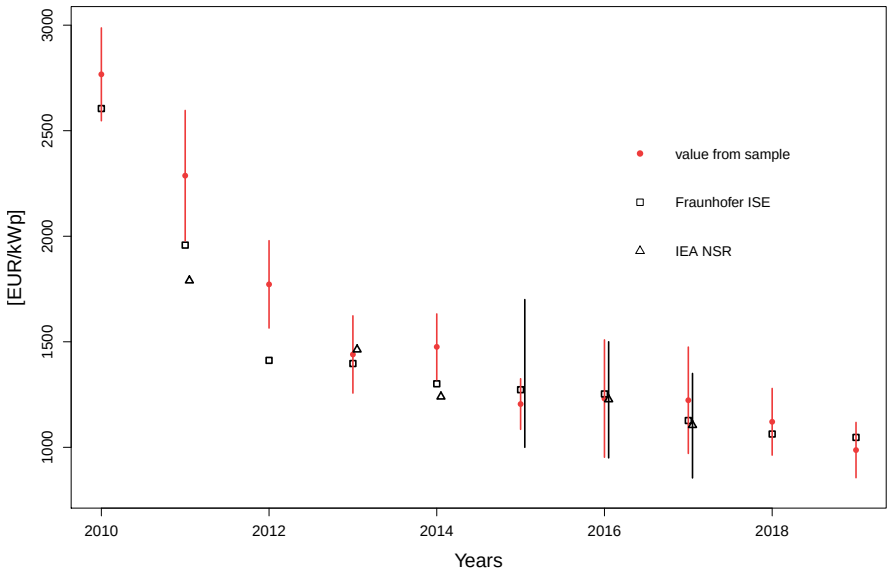

Figure 12. Market prices of PV installations compared to average prices for PV installations managed by EC in Germany (size class 2). Market prices are taken from Fraunhofer ISE [36] and IEA-NSR [39]. If available from the sources, the uncertainty ranges are added, indicated as black lines. Red lines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

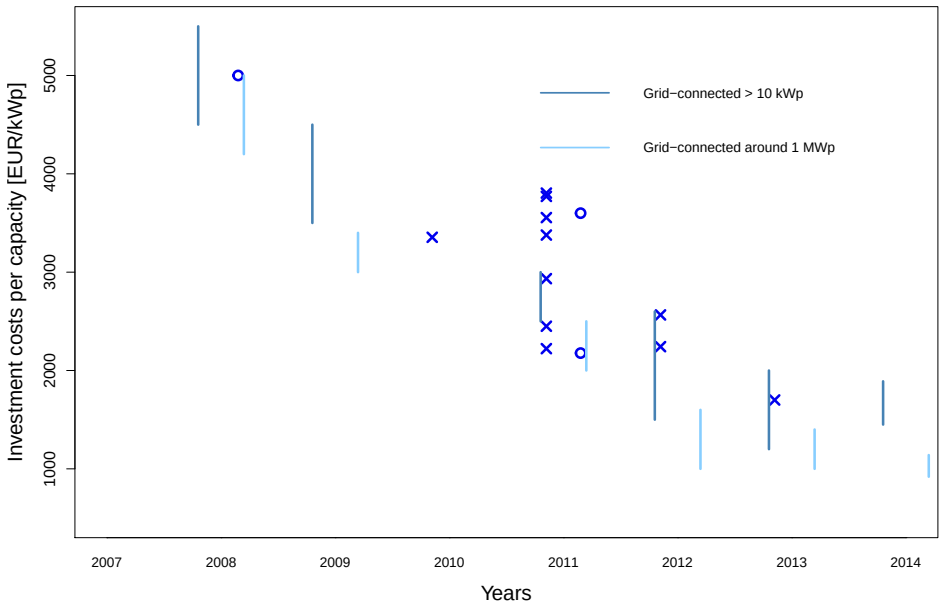

Figure 13. Investment costs per installed capacity by EC compared to the range of prices in the primary market in Italy. Ranges for market prices are taken from in [39] and shown as lines. Crosses indicate grid connected units >10 kWp and circles >1 MWp (own data sample).

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.

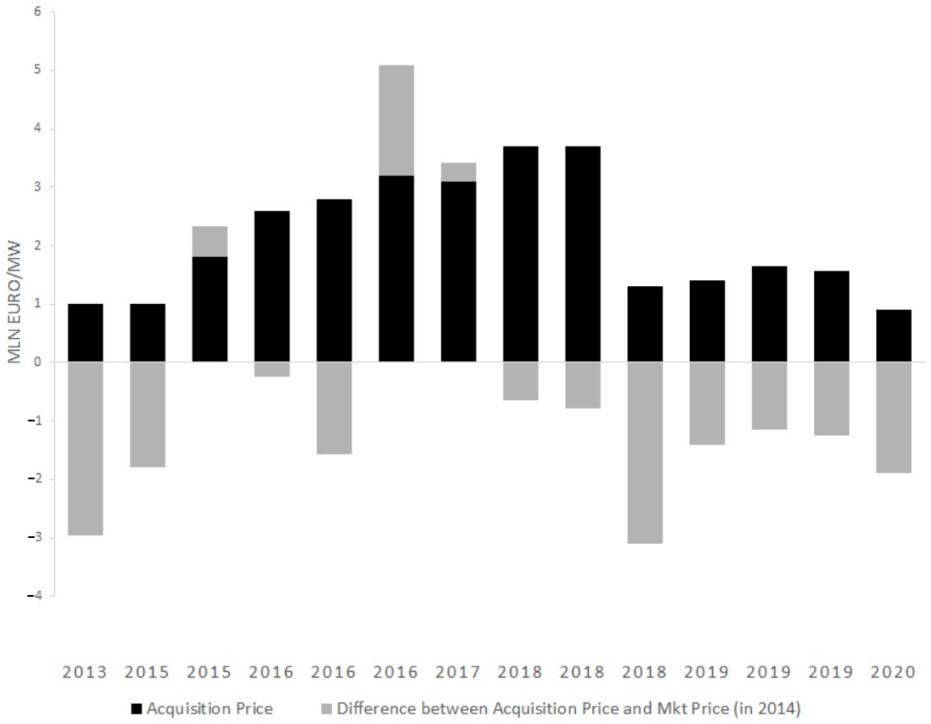

Figure 14. Acquisition prices faced by community energy initiatives vs. the difference between acquisition prices and the secondary market prices.

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.

Author Contributions: Conceptualization, all; methodology, all; validation, all; formal analysis, A.W.; Investigation, A.W., J.P.Z., V.J.S. for Germany and C.C., V.L., A.S., A.W., J.P.Z. for Italy; Resources, all; Data curation, A.W., J.P.Z., V.L., C.C., A.S.; Writing—original draft preparation, V.J.S.; Writing—review and editing, all; Visualization, A.W., V.J.S., V.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 837722, project COMETS (COllective action Models for Energy Transition and Social Innovation).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available data sets were analyzed in this study. The final data set was compiled from a number of sources, for which the details are provided in the Supplementary Material available at the zenodo repository. The following DOI has been reserved: 10.5281/zenodo.4562256.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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

References

1. European Union. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources. Available online: http://data.europa.eu/eli/dir/2018/2001/oj (accessed on 1 February 2021).
2. European Union. Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU. Available online: http://data.europa.eu/eli/dir/2019/944/oj (accessed on 1 February 2021).
3. Yildiz, Ö.; Rommel, J.; Debor, S.; Holstenkamp, L.; Mey, F.; Müller, J.R.; Radtke, R.; Rognli, J. Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. *Energy Res. Soc. Sci.* **2015**, *6*, 59–73. [CrossRef]
4. Holstenkamp, L.; Radtke J. *Handbuch der Energiewende und Partizipation*, 1st ed.; Springer: Wiesbaden, Germany, 2018.
5. Spinicci, F. Le Cooperative di Utenza in Italia: Casi di Studio. Euricse Research Report N.2/2011. 2011. Available online: https://www.euricse.eu/wp-content/uploads/2015/03/1323957261_n1894.pdf (accessed on 1 April 2021).
6. Wierling, A.; Zeiss, J.P.; Hubert, W.; Candelise, C.; Gregg, J.S.; Schwanitz, V.J. Who participates in and drives collective action initiatives for a low carbon energy transition? In *Paradigms, Models, Scenarios and Practices for Strong Sustainability*; Diemer, A., Nedelciu, E., Schellens, M., Morales, M., Oostdijk, M., Eds.; Editions Oeconomia: Clermont-Ferrand, France, 2020; pp. 239–256.
7. Wierling, A.; Schwanitz, V.J.; Zeiß, J.P.; Bout, C.; Candelise, C.; Gilcrease, W.; Gregg J.S. Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries. *Sustainability* **2018**, *10*, 3339. [CrossRef]
8. Volz, R. Bedeutung und Potenziale von Energiegenossenschaften in DeutschlandEine Empirische Aufbereitung, Informationen zur RaumentwicklungHeft 9/10.2012. Available online: https://www.bbsr.bund.de/BBSR/DE/veroeffentlichungen/izr/2012/9_10/Inhalt/DL_Volz.pdf?$__$blob=publicationFile&v=3 (accessed on 22 March 2021).
9. Debor, S. *The Socio-Economic Power of Renewable Energyproduction Cooperatives in Germany: Results of an Empirical Assessment*; Wuppertal Papers, No. 187; Wuppertal Institut für Klima, Umwelt, Energie: Wuppertal, Germany, 2014. Available online: http://nbn-resolving.de/urn:nbn:de:bsz:wup4-opus-53644 (accessed on 1 April 2021).
10. Klagge, B.; Schmole, H.; Seidl, I.; Schön, S. Zukunft der deutschen Energiegenossenschaften. Herausforderung und Chancen aus einer Innovationsperspektive. *Raumforsch Raumordn* **2016**, *74*, 243–258. [CrossRef]
11. Klagge, B.; Meister, T. Energy cooperatives in Germany—An example of successful alternative economies? *Local Environ.* **2016**, *23*, 697–716. [CrossRef]
12. Candelise, C.; Ruggieri, G. Status and evolution of the community energy sector in Italy. *Energies* **2020**, 13, 1888. [CrossRef]
13. Phimister, E.; Roberts, D. The Role of Ownership in Determining the Rural Economic Benefits of On-shore Wind Farms. *J. Agric. Econ.* **2012**, *63*, 331–360. [CrossRef]
14. Seyfang, G.; Hielscher, S.; Hargreaves, T.; Martiskain A.; Smith, A. A grassroots sustainable energy niche? Reflections on community energy in the UK. *Environ. Innov. Soc. Trans.* **2014**, *13*, 21–44. [CrossRef]
15. Yildiz, Ö. Financing renewable energy infrastructures via financial citizen participation—The case of Germany. *Renew. Energy* **2014**, *68*, 677–685. [CrossRef]
16. International Energy Agency. *Cost and Financing Aspects of Community Renewable Energy Projects*; Volume I: Main Report; Ricardo Energy & Environment, IEA-RETD Operating Agent, IEA Implementing Agreement for Renewable Energy Technology Deployment (IEA-RETD): Utrecht, The Netherlands, 2016. Available online: iea-retd.org/archives/publications/fin-community (accessed on 15 March 2020).
17. Ministry of Justice of Germany. Genossenschaftsgesetz-GenG, 1889/2017. Gesetz Betreffend die Erwerbs- und Wirtschaftsgenossenschaften. Ministry of Justice of Germany: Berlin, Germany. Available online: https://www.gesetze-im-internet.de/geng/BJNR000550889.htmlhttps://www.gesetze-im-internet.de/geng/BJNR000550889.html (accessed on 22 January 2021).
18. Government of Italy. Decreto Legislativo 17 Gennaio 2003, Riforma Organica Della Disciplina Delle Societa' di Capitali e Societa' Cooperative. Available online: https://www.camera.it/parlam/leggi/deleghe/03006dl.htm (accessed on 1 February 2021).
19. Ministry of Justice of Germany. Bundesrepublik Deutschland, Erneuerbare Energien Gesetz, 2000/2017. Gesetz für den Ausbau erneuerbarer Energien. Available online: https://www.gesetze-im-internet.de/eeg_2014/ (accessed on 1 February 2021).
20. Antonelli, M.; Desideri, U. The doping effect of Italian feed-in tariffs on the PV market. *Energy Policy* **2014**, *67*, 583–594. [CrossRef]
21. GSE. Energia da Fonti Rinnovabili in Italia—Dati Preliminari. Available online: https://www.gse.it (accessed on 15 July 2020).
22. Registeranzeiger GmbH. Online-Handelsregister. Available online: https://www.online-handelsregister.de/ (accessed on 15 July 2020).

23. Bundesanzeiger Verlag. Unternehmensregister. Available online: https://www.unternehmensregister.de (accessed on 15 July 2020).
24. Land Nordrhein-Westfalen, Common Register Portal of the German Federal States. Available online: https://www.handelsregister.de (accessed on 15 July 2020).
25. Bundesnetzagentur. Core Energy Market Data Register-Marktstammdatenregister. Available online: https://www.marktstammdatenregister.de (accessed on 15 July 2020).
26. InfoCamere. Italian Business Registry. Available online: https://italianbusinessregister.it/italian-business-register (accessed on 19 February 2021).
27. Lam, N.; Quattrocchi, D.A. On the issues of scale, resolution and fractal analysis in the mapping sciences. *Prof. Geogr.* **1992**, *44*, 88–98. [CrossRef]
28. NUTS-3 Classification, Regulation (EC) No 1059/2003 of the European Parliament and of the Council of 26 May 2003 on the Establishment of a Common Classification of Territorial Units for Statistics (NUTS). Available online: http://data.europa.eu/eli/reg/2003/1059/2018-01-18 (accessed on 19 February 2021).
29. LAU Classification, Local Administrative Units. Available online: https://ec.europa.eu/eurostat/web/nuts/local-administrative-units (accessed on 19 February 2021).
30. EUROSTAT. The Methodological Manual on Territorial Typologies. 2018 Edition. Available online: https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-GQ-18-008 (accessed on 1 February 2021).
31. Delaney, D.; Leitner, H. The political construction of scale. *Political Geogr.* **1997**, *16*, 93–97. [CrossRef]
32. Marston, S.A. The social construction of scale. *Prog. Hum. Geogr.* **2000**, *24*, 219–242. [CrossRef]
33. Brenner, N. The limits to scale? Methodological reflections on scalar structuration. *Prog. Hum. Geogr.* **2001**, *25*, 591–614. [CrossRef]
34. Herod, A. Scale: The local and the global. In *Key Concepts in Geography*; Holloway, S., Rice, S., Valentine, G., Clifford, N., Eds.; Sage: London, UK, 2008; pp. 217–235.
35. MacKinnon, D. Reconstructing scale: Towards a new scalar politics. *Prog. Hum. Geogr.* **2011**, *35*, 21–36. [CrossRef]
36. Fraunhofer ISE-Institut für Solare Energiesysteme. Recent Facts about Photovoltaics in Germany. Available online: https://www.ise.fraunhofer.de/en/publications/studies/recent-facts-about-pv-in-germany.html (accessed on 15 January 2021).
37. Mukora, A.; Winksel, M.; Jeffrey, H.F.; Mueller, M. Learning curves for emerging technologies. *Proc. Inst. Civ. Eng. Energy* **2009**, *162*, 151–159. [CrossRef]
38. Candelise, C.M.; Winskel, M.; Gross, R.J.K. The dynamics of solar PV costs and prices as a challenge for technology forecasting. *Renew. Sustain. Energy Rev.* **2013**, *26*, 96–107. [CrossRef]
39. International Energy Agency, National Survey Reports of PV Power Applications. Available online: https://iea-pvps.org/national-survey-reports/ (accessed on 19 February 2021).
40. Lettner, G.; Auer, H.; Fleischhacker, A.; Schwabeneder, D.; Dallinger, B.; Moisl, F. Existing and Future Prosumer Concepts. Report from the EU Project PVP4Grid, Deliverable D2.1. Available online: https://www.pvp4grid.eu/wp-content/uploads/2018/12/D2.1_Existing-future-prosumer-concepts_PVP4G-1.pdf (accessed on 22 March 2021).
41. Welch, B.L. The generalization of "Student's" problem when several different population variances are involved. *Biometrika* **1947**, *34*, 28–35. [CrossRef] [PubMed]
42. Statistische Ämter des Bundes und der Länder, Gemeinsames Statistikportal. Einkommen der Privaten Haushalte in den Kreisfreien Städten und Landkreisen der Bundesrepublik Deutschland 1995–2018. Available online: https://www.statistikportal.de/de/veroeffentlichungen/einkommen-der-privaten-haushalte (accessed on 1 April 2021).
43. EUROSTAT Data Browser 2021. Gross Domestic Product (GDP) at Current Market Prices by NUTS-III regions (NAMA_10R_3GDP). Available online: https://ec.europa.eu/eurostat/databrowser/view/nama_10r_3gdp/default/table?lang=en (accessed on 1 April 2021).
44. Strupeit, L.; Neij, L.; Cost dynamics in the deployment of photovoltaics: Insights from the German market for building-sited systems. *Renew. Sustain. Energy Rev.* **2017**, *69*, 948–960. [CrossRef]
45. Energy Strategy Group, Solar Energy Report. Il Sistema Industriale Italiano nel Business dell'Energia Solare. Available online: http://www.energystrategy.it/ (accessed on 15 July 2020).