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.
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 greenhouse 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, Blaziejewski 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
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.
For 255 out of the 584 cooperatives information about the initiators of an EC could be collected. Figure 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 Figure 2, we find
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
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 Abtsgmünder 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.

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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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** |            |           |
| By activity                             |            |           |
| 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             |            |           |
| Production                              | 488        | 87%       |
| Distribution                            | 76         | 14%       |
| Storage                                 | 65         | 12%       |
| Demand reduction                        | 53         | 9%        |
| By technology                           |            |           |
| 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.
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.

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 in these periods. Source: Own data compilation based on Bundesnetzagentur [21].

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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.
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.
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
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
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.
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

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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

![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].](https://doi.org/10.1371/journal.pstr.0000029.g011)
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-sell 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
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
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)

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