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Business Models for Peer-to-Peer Energy Trading in Germany based on Households' Beliefs and Preferences

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Abstract

With the expansion of distributed energy resources and the phaseout of the feed-in-tariff scheme in Germany, self-consumption and electricity sharing within a community of prosumers are becoming more profitable. This paper derives optimal business models for a sustainable peer-to-peer (P2P) energy trading platform (ETP) in Germany. It examines data from 1618 residential households collected from an online survey, including 1311 consumers and 307 prosumers. Our research aims to better understand under what circumstances these households would participate in a P2P ETP and how business models can support such platforms to create added value for private households. Therefore, households' beliefs concerning their attitudes, perceived behavioral control, and subjective norms are analyzed according to the Theory of Planned Behavior, and business models are designed correspondingly. In order to evaluate the developed business models' effectiveness and usefulness, we apply them to fifteen existing pioneer energy communities and platforms in Germany. We find that cost-saving and other financial benefits for households must be considered to be the primary value proposition offered by a service provider. Business models which help households to become more electricity self-sufficient and to consume less electricity from the public grid are the second-most important source of value creation from a household's point of view. By connecting the business models and the P2P prosuming market model, recommendations for companies, policy-makers, and regulatory authorities are made.

Keywords: Peer-to-peer, theory of planned behavior, business model, value creation, beliefs, private households, electricity self-sufficiency, platform business, network economics, peer-to-peer trading

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List of Acronyms

DERs distributed energy resources
ETP energy trading platform
PBC perceived behavioral control
PPA power purchase agreement
P2P peer-to-peer
FiT feed-in-tariff
HH (private) household
VP value proposition
PV solar photovoltaic
TPB theory of planned behavior
RES renewable energy sources
BM business model

1 Introduction

The combination of distributed energy resources (DERs) [1], including rooftop solar photovoltaic (PV) panels, energy storage, and control devices, together with consumer-level communications and control, includes adopting smart meters and energy management systems [2] supporting traditionally passive electricity end-consumers to become 'prosumers' [3]. Energy prosumers are proactive consumers with DERs who actively control their own consumption, generation, and energy storage [4, 5]. Government-sponsored feed-in-tariff (FiT) schemes or existing electricity retailers with buy-back schemes remunerate prosumers for their excess energy generation fed back into the grid. Nevertheless, as subsidies are reduced and finally phased out, prosumers are being left in a post-subsidy period with no alternative income model for their green surplus electricity (except maybe for marketing green electricity [6]).

There is increasing interest in post-subsidy market models that can offer new value propositions to energy prosumers [7,8]. Parag and Sovacool [9] have concentrated on the engagement of more prosumer-oriented electricity markets by introducing three separate possible prosumer integrating market models, namely (1) peer-to-peer (P2P) prosuming models, (2) prosumer-to-grid integration, and (3) prosumer community groups.

Hence, the focus of this paper is on the P2P prosuming market model. P2P markets are the least-structured market models so far and include decentralized, independent, and flexible P2P networks that begin almost entirely from the bottom-up. These markets may also include several long-term or ad-hoc contractual relations among prosuming agents or between another service provider and an energy consumer [9]. P2P markets can provide opportunities for all shareholders in the electric power system [10, 11]. The presentation of such new markets also creates new business models. One example of such a business model (BM) is the P2P market model [12–14], which in principle enables consumers and prosumers to trade with each other without requiring a utility or retailer as a middleman (broker).

Thus, the middleman is replaced by a third-party digital platform that empowers consumers and prosumers to communicate with each other directly and to bargain more negotiated prices for their electricity rather than relying on the offer from an authorized supplier [13]. Platforms are digital places where operators can interact, cooperate, and get permission to access products, services, or other general 'resources' provided by peers or parties. The aim of such platform is to promote more straightforward connections among people participating in an exchange-based market. They have become a robust economic and technological template model replicated across society, and they are reinforcing trends such as prosumption and digital energy services and technologies [15].

The existing literature in the field of business models for P2P energy-sharing communities or platforms does not propose business models from households' behavioral point of view and their preferences; little investigation has examined customer decisions in this context so far in Germany. For example, Hackbarth and Löbbe [16] identified the most promising customer segments and customers' preferences and motivations for participating in peer-to-peer (P2P) electricity trading based on a survey among customers of seven municipal utilities. They find that private households (HHs) with the highest willingness to participate in P2P electricity trading are mainly motivated by the ability to share electricity and – to a lesser extent – by economic reasons. Regarding consumer preferences, Hahnel et al. [17] investigated energy consumers' and prosumers' willingness to participate in a P2P energy-sharing community. The authors found that community electricity prices and state of charge of private energy storage systems are the main indicators of HHs' trading behavior. While the authors provided new insights into the design of P2P communities, they have not suggested any corresponding business models for HHs that would enable to engage them in a P2P energy-sharing community.

The international empirical evidence on P2P energy trading business models is still scarce. Studies in South Korea estimate the usage fee for a P2P energy trading platform by determining the willingness-to-pay of possible users [18] and analyze the economic feasibility of P2P energy trading [19]. Studies in the UK present a quantitative analysis of business models at the project level for energy communities [20,21]. Another study for the UK discusses the basic P2P energy-sharing and local community models and elaborates a single case study based on local matching trading [22]. Lüth et al. [23] presented the business models that concentrate on the end-user benefits of P2P trade and energy storage, recognizing that the perception of local markets triggers impacts demand response, and changes the interaction with other stakeholders in the electricity market. They implemented an optimization model based on historical demand, generation and price data, in order to analyze the P2P interactions in the presence of storage for a small community in UK.

Klein et al. [24] give insights related to P2P energy-sharing business models that will encourage the development of more complex business models for the setting of the Portuguese energy market, regarding and despite of its rigorous regulatory restrictions. The authors proposed a business model which resulted in immediate financial benefits due to the collaborative use of the surplus electricity generated from solar PV systems among end-users under the same low and medium-voltage transformer substations. Note that, we argue that an empirical study that offers business models for P2P energy-sharing platforms through responding to households' beliefs and preferences, does not yet exist. In our study, for the first time, we fill this important knowledge gap in the P2P energy trading literature by deriving optimal business models and presenting a German-wide business model analysis of the existing energy communities and platforms. Our findings give a more comprehensive review to researchers focusing on P2P energy trading business models, which is not completely examined in the existing literature. The descriptive methodological and empirical research presented aims at determining how business models for an ideal P2P energy trading platform (ETP) can be designed such that prosumers are motivated to engage with the platform and gain the necessary skills and knowledge to use it effectively and efficiently.

Therefore, the contribution of the current study to the literature is twofold. First, our methodological novelty employs "multiple methods" by combining the Theory of Planned Behavior (TPB) [25] in order to analyze household beliefs concerning their attitude, perceived behavioral control (PBC), and subjective norms, and Amit and Zott's (2012) business model approach [26] in order to develop optimal business models. We are also using data obtained from an online survey that measures consumers' and prosumers' beliefs and behavior towards energy generation and consumption. Second, our empirical analysis reveals important new insights about business models for P2P energy trading and enables a better understanding of the topic by analyzing and identifying the business models used in fifteen research and industrial projects, and startup companies in Germany which will also be of use for the international scientific community as well.

The remainder of this paper is organized as follows. Section 2 presents the conceptual background and the theoretical frameworks related to the research question. The data and methodology of the current study are outlined in section 3, and the analysis results are presented in section 4. The taxonomy of the proposed business models and their applications follows in section 5. Finally, the conclusion and policy implications of this research are drawn in section 6.

2 Conceptual background

P2P trading platforms (see Figure 1) have developed in various divisions, helping small suppliers to compete with incumbents supplying the same goods and services. Whereas vertically combined companies take control of the interactions between producers and consumers, P2P trading platforms enable direct transactions between users, with the users being in control of setting the terms of transactions and delivering goods and services [27]. These platforms could present value by enabling prosumers to contract as collaborative organizations while distributing information and uncertainty ("a sharing economy"). It has been proven that groups of wind power generators can grow their corporate benefits by engaging together in wholesale energy markets in order to share risks and benefits due to economies of scale from pooling resources [28]. Thus, prosumers could exchange information with one another, and then more efficiently negotiate as a group with their suppliers.

Hence, P2P ETPs act as a marketplace providing information and matching buyers and sellers. They enable self-regulation of the P2P trading through a platform. The nature of a P2P ETP is not only the creation of a technology or a software package. It demands a systemic method of value creation through facilitating electricity and price negotiations among several interdependent actors in the P2P ecosystem, such as consumers and prosumers. The platform has to afford an efficient and secure marketplace for both buyers and sellers [29]. ETPs utilize a digital interface in order to connect consumers and prosumers. They are designed to connect DERs, either when ownership of assets is decentralized or when spatial dispersal is a solution to the platform's service/s. Thus, digital platforms often do not provide or own physical infrastructures and assets but merely operate as a service provider on top of these. Therefore, they promote decentralized and digitalized exchanges among DERs [15]. According to Mengelkamp et al. [30], most business models in local energy markets will be centered around implementing a platform.

Zepter et al. [31] created a platform for the integration of prosumer communities into intraday and day-ahead market operations. The authors evaluated the potentials of P2P trading and battery storage flexibility in a multi-market system, and developed a two-stage stochastic programming method to demonstrate the various cases of the decision-making process under uncertainty covering possible scenarios on the realization of renewable generation and intraday electricity prices. Their results show a trade-off between wholesale market participation and self-sufficiency of the community. They find that, due to the possibilities of P2P trade and residential household battery storage, power generation from DERs can be utilized locally to a higher extent.

Most existing literature on P2P energy sharing concentrates on residential households, which are typically equipped with solar PV systems. Consequently, most P2P sharing mechanisms are developed considering solar PV systems as the main source of energy in the renewable domain. Thus, solar PV systems have been broadly used in P2P trading to reduce energy costs, reduce peak load, balance supply and demand, and manage network losses [32]. For example, Tushar et al. [33] proposed an opportunistic energy-sharing mechanism adopting solar PV systems and batteries that support prosumers to decrease their energy costs. In their study, a coalition formation game is designed, which enables a prosumer to compare the benefit of engaging in P2P trading with and without utilizing a battery and, consequently, enables the associated prosumers to form proper social coalition groups in the network in order to manage P2P trading.

Jiang et al. [34] proposed a multi-leader and multi-follower-based P2P sharing model that reduces the cost of buyers by 4.36%, while improving the benefit of sellers by 12.61% compared to the FiT scheme. Moreover, several other studies [35–37] developed a coalitional game-theoretic P2P energy trading approach that requires the prosumers to rely on each other in order to trade electricity. Then, the authors set trading prices through the mid-market rate, according to the prosumers' total available surplus and demand energy. They showed through numerical case studies that their suggested model can always reduce the prosumers' cost of energy in comparison with trading via the FiT scheme.

Indeed, the ultimate objective of P2P trading participants is to address several challenges related to energy trading, including decreasing energy consumption costs, increasing and supporting the sustainable consumption of RES, and increasing social engagement of prosumers. Studies proposed in the existing literature mainly focus on developing P2P energy-trading mechanisms based on suitable pricing schemes that can enable the participation of a large number of prosumers. Financial transactions are necessary to be securely handled without requiring a third-party administrator. At the same time, trading should lead to the achievement of reducing prosumers' cost of energy, balancing local generation and demand, incentivizing prosumers, and developing pricing mechanisms [38].

Research on the P2P prosuming model has rapidly progressed over the last years, and three main research lines arise from the earlier literature: (1) business model development, (2) P2P market design, and (3) communication and control engineering. In this study, we concentrate on the business models part. Although the studies into P2P energy trading communities and platforms are still at an early stage, several pilot projects and use cases do already exist. Still, studies in the context of business models for P2P ETPs have contributed to the problem of designing business contracts between different prosumers [39, 40].

Zhang et al. [41] discuss a business model and a design for an online trading platform called 'Elecbay' during the bidding process. It establishes a four-layer system architecture model for P2P energy trading and presents more results on P2P energy trading benefits. Park and Yong [42] compared five different P2P energy trading projects based on their business models, including commercialized and pilot services. Their research identified the potential development and coming challenges based on the business model components of each case.

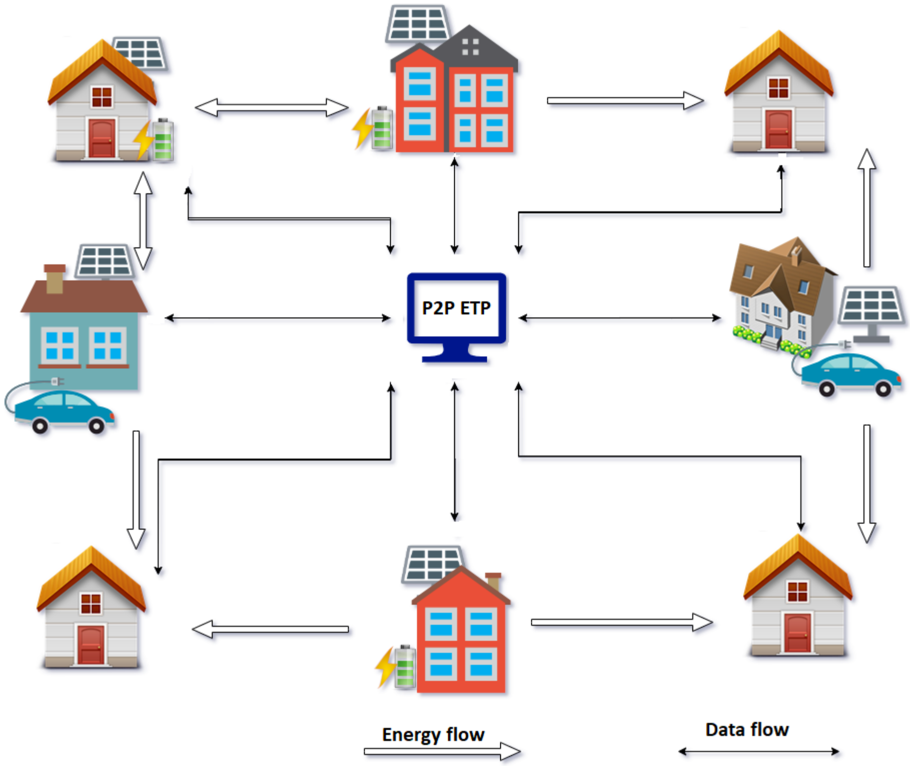

Figure 1. Illustration of a typical P2P energy network among private households.

3 Data and methodology

3.1 Setting

Our analysis is based on cross-sectional data obtained from an online survey conducted in January 2020 by a specialized market survey company among 3102 HHs living in Germany, which resulted in 1618 polls being available, including 307 prosumers and 1311 energy consumers. The online survey was designed to be answered in approximately 15 minutes and focused on electricity consumption characteristics. In the survey, we aimed to measure consumers' and prosumers' beliefs towards energy generation and consumption. It also focused on the drivers and barriers that consumers experience in the decision-making process, which may influence PV system purchase intentions of the population in Germany [43].

Among the four dominant survey methods, e.g., online, mail, personal, and telephone, we have chosen the online experimental survey. The advantage of online experiments is that they have high internal validity; the negative side is that it may be at the risk of low external validity [44]. They are also impersonal, often considered to be junk mail, have a low response rate, and have unclear instructions. However, online surveys are fast, have low administration costs, and can include diverse and/or dichotomous questions requiring the completion of answers. They provide convenience for respondents to easily enter their data at any time and also can tailor the survey regarding the respondent's answer [45]. The use of web-based questionnaires has been a crucial innovation in behavioral science. This approach mixes high efficiency with access to a broader spectrum of participant pools. Via suitable pre-screening, it is likely to target quite distinct groups of people utilizing web-based testing. In our case, an online survey allows separating actual and potential prosumers from consumers who own a house. The following section explains how we have selected the target groups.

3.2 Case selection

Our sample consists of HHs who own a house and thus, in contrast to tenants, can decide on energy matters in their HH. Previous research on the openness towards P2P electricity trading [16] has investigated that the respondents' home ownership plays an essential role in participating in P2P energy trading. Thus, respondents were selected to participate in this study on the basis of two selection criteria according to the flowchart depicted in Figure 2.

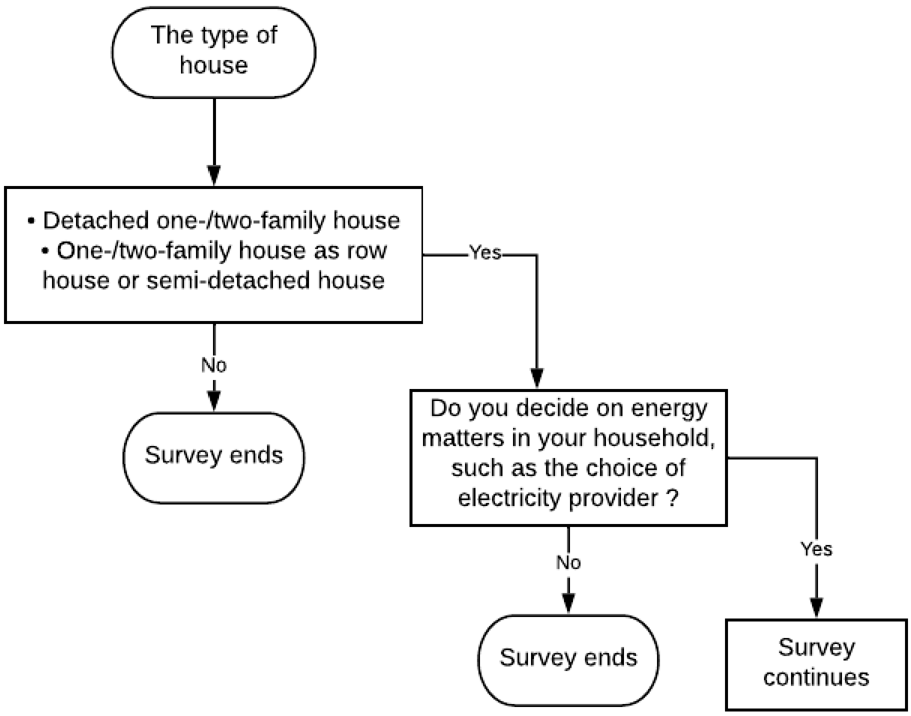

Figure 2. The process of HH selection for participation in the survey.

3.3 Data collection

The measured characteristics of HHs and prosumers are energy concern in terms of attitudes and the actions that a respondent takes to conserve energy, pro-environmental self-identity to realize whether the respondents see themselves as environmentally-friendly or not, perceived financial situation, and demographics including gender, age, education, and type of HH (see Table 1). The participants' characteristics are measured at the end of the survey. When measuring pro-environmental self-identity and energy concern at the start of the study, this could already put respondents in a certain mindset to make energy-efficient choices. It could also be the case that consumers report having a higher likelihood of buying solar panels than they actually have, creating a bias in the responses.

3.4 Data analysis

We have checked histograms and frequencies for all variables to make sure whether any strange values are occurring in the data set. Moreover, we checked response patterns to see whether they were following any response tendencies, such as answers only marked “overall important” even though there are also reversed-coded items. In terms of consistency, respondents should answer “overall not important” instead of “overall important” on reversed-coded items. For respondents who seem to have a response tendency, the individual responses on all other variables and the completion time are checked. For each case, a decision needs to be made as to whether the respondent is a person who will provide final answers or who is not serious. Respondents who have final answers can remain in the data set, whereas non-serious respondents cannot. Thus the additional deletion of data sets regarding other quality control criteria, such as response time and missing values, has been carried out. The summary of the socio-demographic make-up of the total sample based on gender, age, and education-level characteristics for HHs is reported in Table 1. As comparative statistics for the population of household customers in the energy sector are usually not accessible, we examine our survey data against the German population statistics (Table 1).

Table 1. The demographic characteristics of the 1618 HHs surveyed.

Characteristic	Group	Sample	Ratio [%]	Population [%]
Gender	Female	610	37.6	50.6
	Male	1008	62.2	49.4
Age (years)	26-39	172	10.6	18.0
	40-49	228	17.8	12.0
	50-59	468	28.9	15.0
	60-69	440	27.2	13.0
	above 70	250	15.6	16.0
Education	Secondary school certificate	493	30.6	29.6
	Higher education entrance qualification	266	16.5	31.9
	Degree from a technical college	290	18.1	47.5
	University (of applied sciences) degree	560	34.7	17.6
Household disposable income per month	Less than €1500	124	7.6	17.8
	€1500 to €2500	287	17.7	25.3
	€2500 to €3500	395	24.4	17.8
	€3500 to €5000	482	29.8	16.9
	Above €5000	209	12.9	22.2
	Not stated	121	7.5	-
Type of house	Detached one/two-family	1118	69.1	-
	One-/two family	500	30.9	35.2
Role of HH	Prosumer	307	19	-
	Consumer	1311	81	-

In our descriptive methodological study, we apply the methodological triangulation [46] as our primary form of novelty by combining Ajzen's TPB [25] together with the business model concept from Amit and Zott (2012) [26]. Methodological triangulation explain the use of multiple methods in order to observe a given social phenomenon in multiple perspectives [46]. Effective implementation of multiple methods ("mixed methods approach") can bring more sophisticated answers to research questions, and help overcome the limitations of individual research approaches [47]. According to the TPB, consumers may have several beliefs that shape their attitudes and perceived behavioral control and social norms. It presents a model for foretelling human behavior while impling that intention defines the behavior and is based on the assumption that behavioral intention belongs to three prominent circumstances: attitudes towards the behavior, social pressure to enact the behavior (subjective norms), and perceived behavioral control (PBC) for performing the behavior. In order to respond to the HHs' beliefs, we are developing business models according to the Amit and Zott's appraoch, and configure our proposed P2P ETP by subdividing our main research question into the following six research questions:

(1) What consumer demands will the new business model serve?

(2) What unique actions could help meet those demands?

(3) How could the actions be combined in unique styles?

(4) Who should conduct the actions and what unique governance organizations can we discover?

(5) How will economic, social, technological, and environmental value be created for every partner?

(6) What revenue streams can be adjusted to complement the business model?

Therefore, the current study's objective is to develop business models that can motivate prosumers to participate in a P2P ETP by describing the characteristics of the data. The collected data from employing our online survey include relevant measures for intention, e.g., attitude, subjective norm, and PBC under the TPB model. As an attitude, we measure the perceptions of the authenticity and effectiveness of PV systems and expectations in terms of cost savings and generating revenues. We measure the affinity with technology and awareness regarding saving energy vis-a-vis participants' perceived behavioral control. The first one explains the degree to which participants perceive that they have some knowledge of and like technology, while the second describes how participants think that they know enough about saving energy and jointly controlling their energy consumption. Concerning subjective norms, we include the descriptive and injunctive norms established by close peers; for example, whether many neighbors, colleagues, and family members have PV systems and helped participants to acquire them. Thus, our research describes the data characteristics, including means and proportions.

To identify the main drivers for prosumers, they were asked to indicate the importance of and their agreement with several statements that eventually made them decide. We also analyzed the reasons which prevented the consumers from buying PV systems, evaluated by the correctness of those barriers. Table 2 shows the response of prosumers' motivations and consumers' obstacles towards purchasing solar PV systems. The definitions in Table 2 are categorized according to the TPB and explained in more detail in the following results section.

Table 2. Variables used in the survey.

Components	Definition	Mean (Min =1, Max =4)	Standard deviation	Ratio [%]
Prosumers' motivations towards purchasing solar PV systems	Savings/financial incentives	3.45	0.040	93.4
	Independence from utilities	3.10	0.053	74.2
	Climate protection/ecological reasons	3.07	0.058	73.9
	Interest in new technologies	2.99	0.051	76.8
	Influence of friends and relatives	1.80	0.057	25.1
	Legal obligation of the local authority	1.53	0.056	15.9
Prosumers' behavior towards energy use	Good feeling towards consuming self-generated electricity	3.24	0.056	85.1
	Becoming more aware of their own energy consumption	2.94	0.055	74.6
	Paying more attention to using energy economically	2.92	0.056	73.2
	Interest in sustainable energy transition	2.84	0.063	68.7
	Being aware of the source of consumed electricity	2.72	0.065	60.0
	Trying to consume the generated electricity completely	2.38	0.066	45.5
	Ignoring the volume of consumed electricity	1.97	0.057	29.3
	Ignoring the purchase of energy-efficient home appliances	1.68	0.058	21.5
Consumers' obstacles towards purchasing solar PV systems	Financial reasons	2.75	0.032	64.2
	Technical or structural reasons	2.56	0.032	56.1
	Unclear legal framework	2.04	0.029	33.5
	Lack of interest in solar PV systems	1.84	0.029	25.9

4 Results

4.1 Households' electricity data

For the data analysis, we have categorized the HHs' annual energy consumption into four different groups in 2000 kWh steps, because this makes the data analysis easier for HHs and gives a clear insight into their energy consumption. We perform this analyses using a data set on the behavioral characteristics of HHs, collected from our survey undertaken in Germany. Table 3 presents the taxonomy of HHs in terms of their annual electricity consumption and incurred costs in 2018.

Table 3. Classification of HHs according to their annual electricity consumption and incurred costs in 2018.

Electricity consumption	Electricity consumption [kWh p.a.]	Ratio [%]	Electricity cost [€ p.a.]	Ratio [%]
Low and very low	0-2000 (349)	21.5	0-600 (311)	20.7
Normal	2001-4000 (845)	52.3	601-1200 (810)	54.0
High	4001-6000 (276)	17.0	1201-1800 (270)	18.0
Very high	above 6000 (148)	9.2	above 1800 (110)	7.3
Total number of HHs in sample	(1618)	100	(1501)	100

Note: The numbers in parentheses represent the number of HHs in each category.

As reported in Table 3, 52.2% of the HHs have an electricity consumption level of between 2000-4000 kWh per year. The average volume of electricity consumed in Germany is 3501 kWh, and the mean cost of electricity is €1044 per year. The cost of residential electricity for HHs is given in €600 steps. This classification is selected because the price of the electricity for the residential sector in Germany, according to the Agency for the Cooperation of Energy Regulators (ACER) Market Monitoring Report in 2018 [48], was 29.9 €-ct/kWh. Therefore, every 2000 kWh of electricity will cost almost €600 on average. Regarding the type of electricity tariff, of the 1380 respondents, almost 20% are supplied with electricity from 100% renewable energy resources. The rest have electricity produced from a mixture of renewable and non-renewable energy resources.

Of the 1618 respondents, 307 HHs are equipped with solar PV systems. Table 4 shows the prosumer HHs' data regarding PV system capacity, feed-in volume, self-supply, and remuneration cost with their mean values.

Table 4. Two different prosumer groups according to their PV system capacity, feed-in volume, self-supply, and remuneration in 2018.

Variable	PV capacity [kWp]	Feed-in volume [kWh]	Self-supply [kWh]	Remuneration [€ p.a.]
Small prosumers	0.1 - 9.9 (162)	0 - 5000 (114)	0 - 1500 (31)	0 - 1000 (108)
Mean/standard dev.	5.9/0.19	2478/136.9	849.6/72.5	480.5/28.4
Total	957.6	282,576	26,339	51,892
Large prosumers	above 9.9 (82)	above 5000 (81)	above 1500 (36)	above 1000 (98)
Mean/standard dev.	N.A.	8378/579	3753/672.5	2715/132
Total	N.A.	678,621	135,124	266,107
Sum of prosumers	(244)	(195)	(67)	(206)

Note: The numbers in parentheses represent the number of prosumers in each category.

Aside from the substantial heterogeneity in the size of solar PV systems above the 10 kWp capacity limit, we find that other summary statistics are more homogeneous with acceptable standard deviations. However, large prosumers could feed-in a higher volume of electricity and generate significantly higher revenues than small prosumers could. Out of 307 prosumers in the survey, 211 use their solar PV systems to generate electricity for their supply, whereas the remainder act mainly as electricity suppliers and generates revenues through FiTs and sales to energy companies (direct marketing). Thus, only data of 67 prosumers regarding their self-supply volumes are presented in Table 4.

4.2 Households' beliefs towards energy

According to the TPB [25] and research in the field of energy [49], attitudes towards a particular behavior or product are a significant predictor of behavioral intention.

4.2.1 Attitudes

Our survey focuses on the attitude of consumers and prosumers in terms of costs and benefits. The results provide a general picture of prosumers' experiences and attitudes, which can help to better understand the financial and non-financial drivers for becoming a prosumer.

- **Costs: high initial costs, long payback period, lack of funding**

Cost/benefit beliefs can influence people's attitudes towards purchasing solar PV panels [25]. It emerged that cost savings and financial incentives were by far the most frequently mentioned consideration, with average values greater than 2 ('average importance') for purchasing PV systems. Of the 307 prosumers in our survey, 287 purchased a PV system after buying their houses, 156 considered the cost of PV systems to be very important, and 112 believed costs were an important reason. Therefore, 93.4% (mean: 3.45) care about financial factors.

Out of 1311 HHs, 87 were planning to implement a PV installation in the near future. Moreover, 835 of them (almost 63%) have already thought about installing a PV system on the rooftop of their houses. They believe that due to financial reasons, they could not afford to buy a PV system (mean: 2.75). Therefore, the cost issues are an especially dominant barrier to the consumer group for becoming prosumers.

- **Benefits: reliability, effectiveness, saving, and earning money**

Households decide to become prosumers in order to generate enough energy and to save on energy costs. They received a question regarding whether they want to become self-sufficient and to consume less electricity from the public grid, and more specifically, whether they want to become independent from utilities. The result shows that this was the second-most important reason for purchasing PV systems. Out of 287 prosumers, 119 considered it to be very important, and 94 found independence from electricity suppliers to be an important motivation, which accounts for 74.2% (mean: 3.10) of the group of prosumers. Only 15% of the prosumers did not care about the self-generation feeling, whereas the rest (85%) had a positive experience (mean: 3.24).

When asking the 307 prosumers about consuming energy economically, 73.2% (mean: 2.92) mentioned that, since they are generating electricity by themselves, they pay more attention to using it economically. Accordingly, 45.5% (mean: 2.38) of the prosumers declared that if their self-consumption is lower than the amount of electricity produced, they change their behavior to consume the self-produced electricity as fully as possible. Moreover, being self-sufficient has informed 60% (mean: 2.72) of the prosumers in terms of the source of their consumed energy, whether it is self-generated or drawn from the public grid, and has raised their interest in the development of the sustainable energy transition in Germany.

4.2.2 Perceived behavioral control

For examining the respondents' perceived behavioral control, we measured the following beliefs:

- Affinity with technology: the extent to which HHs perceive that they possess knowledge of and like technology.

- Knowledge of energy-saving and efficiency: the extent to which HHs think they know much about saving energy and closely monitor their energy consumption.

The higher a consumer has perceived behavioral control, the higher the consumer's intention to participate in a P2P ETP will be. For example, if a consumer believes that they can understand all the technical information provided about solar panels and P2P energy trading, the probability that they will purchase them and participate in such a platform is higher.

- **Affinity with technology**

An interest in technological issues and having a more than average knowledge of technology can encourage people to seek out that technology. When we asked about having an interest in new technologies, out of 287 prosumers over three quarters of them (mean: 2.99) mentioned that they had already purchased a PV system due to their enthusiasm for PV technology.

- **Knowledge of energy saving**

When looking at prosumers' behavior towards energy saving and energy efficiency, it emerged that not all 307 prosumers are necessarily experts in this field. Still, 29.3% (mean: 1.97) mentioned being impassionate about energy consumption and ignoring the volume of consumed electricity, and only 21.5% (mean: 1.68) ignored the potential purchase of energy-efficient home appliances. Additionally, 74.6% (mean: 2.94) indicated that they had become more aware of their self-generated electricity consumption.

The two supplementary Tables 5 and 6 show the impact of HHs' net income and education on the interest in solar PV technology and knowledge of energy savings and energy efficiency.

Table 5. Impact of households' net income on the interest in solar PV technology and knowledge of energy savings and energy efficiency

Components	Income below 3500 EUR		Income above 3500 EUR	
	Mean	Standard dev.	Mean	Standard dev.
Interest in solar PV technology	2.95 (112)	0.085	3.01 (151)	0.071
Being passionate about energy consumption	3.09 (119)	0.089	2.85 (159)	0.085
Ignoring the purchase of energy-efficient home appliances	1.67 (119)	0.089	1.65 (160)	0.081
Becoming more aware of self-generated electricity consumption	2.98 (120)	0.082	2.89 (162)	0.076

Note: The numbers in parentheses represent the number of prosumers in each category.

Table 6. Impact of households' education on the interest in solar PV technology and knowledge of energy savings and energy efficiency

Components	Without university degree		With university degree	
	Mean	Standard dev.	Mean	Standard dev.
Interest in solar PV technology	2.99 (173)	0.065	2.95 (114)	0.086
Being passionate about energy consumption	2.98 (181)	0.078	2.95 (121)	0.091
Ignoring the purchase of energy-efficient home appliances	1.62 (183)	0.073	1.68 (120)	0.088
Becoming more aware of self-generated electricity consumption	2.92 (184)	0.070	2.87 (122)	0.087

Note: The numbers in parentheses represent the number of prosumers in each category.

It can be seen that, unlike the minor impact of education (see Table 6) on the interest in solar PV technology and knowledge of energy savings and energy efficiency, HHs' net income (see Table 5) plays an important role. This is evident when HHs with a net income lower than 3500 EUR per month are more passionate about energy consumption than the other groups with higher disposable incomes per month. Moreover, HHs with lower incomes are more aware of their self-generated electricity consumption.

- **General perceived influence**

Perceived influence on the environment may influence consumers' perceived control. At the top of the non-financial motivators, climate protection also ranked high, only second to the top driver, i.e., independence from electricity suppliers. Of those 287 prosumers who purchased the PV system after buying their houses, almost three-quarters (mean: 3.07) indicated that they care about climate protection and about contributing to a better environment.

- **Specific perceived influence**

The analysis focuses on the barriers consumers may face, especially during decision-making about purchase solar panels. Technical and building issues have influenced 56.1% (mean: 2.56) of the consumers as important barriers. These problems are mainly reported as roof-related problems, monument protection, and existing trees near the houses.

About 20% of the consumers indicated that problems such as difficulties in implementing the PV systems, or the perceived inability to find an appropriate skilled craftsperson, are their primary concerns. Also, due to the anxiety about fire, 14% of the respondents mentioned that they refused to install a PV system.

4.2.3 Subjective norms

Normative beliefs are affected by the likelihood that important peers or organizations will support or oppose a behavior [25]. Normative beliefs foresee a perceived social norm (e.g., perceived social pressure to show or not to show a particular behavior). The study suggests that consumers are influenced by (subjective) social norms for judgments regarding energy utilization [50, 51].

In the context of solar panels, a consumer's decision (not) to buy a solar panel might be influenced by people who are close in terms of physical proximity (neighbors and colleagues), and people who are close in terms of emotional proximity (family/friends). The more that purchasing solar panels is perceived as the social norm, the higher the consumer's purchase intention. For example, if a consumer is encouraged by friends and family members to purchase solar panels, that consumer is more likely to purchase them. In order to analyze the subjective norms, we measure the descriptive and injunctive norms set by close others, for instance, whether many neighbors, friends, and family members have solar panels and thus (actively or passively) encourage the respondent to also purchase solar panels.

- **Descriptive and injunctive norms through neighbors, friends, and family**

Consumers may have perceptions regarding which behavior is typically performed by these important peers (descriptive norm). For example, if many important peers have solar panels, the typical behavior among them is to purchase solar panels. The consumer may perceive that purchasing solar panels is the norm, thus increasing the consumer's intention to buy solar panels. However, prosumers who choose solar PV because of the influence of friends, relatives, and neighbors were among the lowest proportion of the technology installers (mean: 1.80).

5 Taxonomy of the proposed business models and their applications

Next, we want to better understand how business models can help P2P ETPs to create a range of economic, technological, social, and environmental values for different groups of HHs in terms of attitude, perceived behavioral control, and subjective norms. The proposed business models would categorize the HHs, similarly to Table 4, into two different groups, including the consumers, depending on the type of energy activity undertaken (generation versus consumption), installed capacity, and trading volume (feed-in versus consumed), self-supply, and remuneration costs. For designing a P2P energy trading scheme, it is assumed that several consumers and prosumers with rooftop PV systems (without batteries) are connected to a P2P ETP. The prosumers are connected through a secure information system via their smart meters for all required communication and P2P trading transactions.

5.1 BM 1: Business models for attitudes

5.1.1 BM 1.1: High initial costs, lack of funding

As mentioned above, almost 64.2% of the consumers have already considered the installation of a PV system in their houses. However, due to financial reasons, they could not afford to buy a PV system. Therefore, the cost issues are an especially dominant barrier for the consumer group to becoming a prosumer. Energy service providers can tackle this problem by adopting consumers through a leasing model. Consumers can be financed and rent PV systems instead of paying substantial upfront costs. This business model can guarantee to the provider a long cooperation with HHs with base-load generation. Moreover, operators can offer additional services, such as planning, installation, and regular maintenance, in order to generate some marginal revenues for themselves. So far, a few German utilities, such as Sonnen[1], have added a PV leasing business model to their portfolio.

5.1.2 BM 1.2: Saving and earning money

We find that almost all the prosumers in our survey are relying on revenues through the FiT scheme, and only a few are registered in a P2P ETP or other energy-sharing communities. However, after removing the FiT scheme, only a small group of prosumers can create a financial surplus. The baseline projections assume that existing financial support regarding self-generation and FiT over the period to 2020 will be discontinued. Therefore, prosumers who want to generate revenue may sign a contract with utilities as intermediators or join an energy-sharing platform to sell and share their surplus electricity and, consequently, to achieve financial benefits. For these groups of prosumers, we recommend that energy service providers exploit one or more of the following six business models:

[1] https://www.sonnen.de/

BM 1.2.1: Power purchase agreement (PPA), auction, and bilateral-based contracts:

Several studies propose auction-based and bilateral contract-based P2P electricity trading in which platform operators can enable consumers and prosumers to trade energy based on their bid and ask prices [52–54] and operate as something like an 'Energy-eBay' [40]. For instance, real-world platforms, such as Lition Energie[2] and Enyway[3], are operating based on the bilateral contracts and blockchain-based online marketplaces for energy in Germany. However, the PPA business model can guarantee prosumers an extended revenue stream, and thus P2P ETP operators can increase their predictability through a low-cost transaction trade (buy once and sell recurrently) and provide the base-load for the other customers. With this model, on the one hand, a bid which is higher than the utilities' bids can be submitted (utilities consider this surplus electricity as non-dispatchable and, therefore, are typically not willing to offer high bids); on the other hand, this bid must be lower than the retail ask price to be sufficiently attractive for P2P ETP operators' arbitrage.

BM 1.2.2: Free energy up to a certain percentage of the feed-in volume:

Small prosumers can be provided with free-of-charge services and electricity corresponding to their surplus volume of electricity that they have already fed into the community platform. In the long run, it can save the cost of purchasing electricity and create financial benefits especially for prosumers with higher energy generation capacities and lower consumption rates. As a real-world example, Sonnen [55] offers this business model and enables prosumers to feed in their excess solar power into the grid and share it with other members of the energy community . In return, prosumers will receive an individualized volume of free electricity that they can consume on less sunny days.

BM 1.2.3: Self-supplied electricity, and contributing to a virtual battery provider:

With this business model, small prosumers are enabled to save their surplus energy in a virtual account and consume it whenever they want. Being electricity self-sufficient and independent from utilities is stated as the second-most important reason from a HHs point of view for purchasing the PV systems. Moreover, prosumers get a good feeling when they consume electricity that has been generated by themselves. Therefore, P2P ETP operators can help HHs to become more electricity self-sufficient and to deliver some extra value proposition (VP). In this regard, E.ON SolarCloud[4] and SENEC.Cloud[5] operate as virtual electricity accounts and let prosumers store their surplus electricity in virtual batteries. Thus, prosumers can consume the stored electricity in their virtual accounts whenever they need it and become more independent and self-sufficient. The motivation to increase electricity self-sufficiency from energy suppliers could result in a more positive attitude towards participating in P2P electricity trading

[2]https://www.lition.de/
[3]https://www.enyway.com/
[4]https://www.eon.de/
[5]https://www.senec.com/

among the HHs [16] since they have the potential to increase the degree of self-sufficiency [17].

BM 1.2.4: Sharing energy with friends:

P2P ETP can bring a community of small prosumers and consumers together in a platform by forming a private P2P network and enabling them to select their energy trading partners specifically to share their surplus electricity with them. This business model can save the cost of energy for the prosumers within an energy community, and since they share their surplus generation, a higher energy self-consumption can be achieved. For instance, through the SENEC.Cloud, prosumers are able to share their electricity with two other HHs located in Germany. Hackbarth and Löbbe [16] state that HHs who consider sharing generation and consumption to be a critical factor, are more expected to participate in a P2P ETP.

BM 1.2.5: Subsidized business model: A P2P ETP may offer several VPs for free or at very low prices to prosumers and consumers by being cross-subsidized through reliable revenue streams. The "Virtual Power Plant" is the name of a research project of the University of Wuppertal in Germany, which belongs to the local energy utility WSW and has been a registered non-profit organization since 2017. It aims to investigate the local urban energy supply and flexibility of HHs with demand response via incentive signals, which represent energy inadequacy and surplus based on market prices and local generation data[6].

BM 1.2.6: Donation business model:

Prosumers may donate their surplus electricity to low-income consumers. This business model based on altruistic behavior can be implemented to counteract fuel poverty or to support the low-income groups of society and to create social and economic values for them. The Brooklyn Microgrid P2P ETP project [56], as a real-world example, has enabled philanthropic prosumers to donate electricity to low-income HHs.

5.2 BM 2: Business models for perceived behavioral control

5.2.1 BM 2.1: Affinity with technology

In order to respond to the technological interest of HHs, P2P energy trading should be oriented as a tech-based VP with a low-cost structure that may operate based on blockchain technology or other technological novelties for creating a communication channel via the platform. According to Mengelkamp et al. [30], most business models in local energy markets are focused on presenting a platform or process management. Thus, an easy-to-use platform needs to be designed, which can integrate HHs in order to create new VPs in well-being, convenience, economic growth, and societal impacts.

[6]https://www.evt.uni-wuppertal.de/forschung/forschungsgruppe-betriebskonzepte-und-sektorenkopplung/vpp-virtual-power-plant.html

Regarding knowledge of energy-saving and efficiency, P2P ETPs need to provide prosumer services which enable them to carefully monitor their energy generation, consumption, load profile, trading transactions, energy savings, and efficiency measures. Reuter and Loock [57], Mengelkamp et al. [58], and Hahnel et al. [17], state that interest in technological applications is a critical determinant for participation in local energy markets.

5.2.2 BM 2.2: General perceived influence

In order to create environmental value, P2P ETPs must only integrate renewable energy sources inside the portfolio in order to decrease emissions and avoid non-renewable power generation. This can also provide social VPs and help to form a community of members with shared climate protection concerns. According to [16], the respondents' attitudes towards the environment are one of the largest predictors of openness towards P2P electricity trading.

5.2.3 BM 2.3: Specific perceived influence

Technical and building issues, including roof-related problems, monument protection, and existing trees near the houses, difficulties in implementing the PV systems, or the perceived inability to find an appropriate skilled craftsperson were indicated as some of the main concerns for consumers who have resisted buying a PV system. In order to tackle all these problems and provide consumers with self-generation, P2P energy traders can invest in partners' renewable power plants on behalf of consumers, as e.g. in the form of stocks or bonds, and supply them with the energy generated from their invested assets. For example, Enyway enables consumers with the issues mentioned above to invest in its solar systems and become electricity self-sufficient even as a tenant without owning a roof, or an insufficient budget.

5.3 BM 3: Business model for subjective norms

As a quarter of the prosumers were found to be influenced by friends, relatives, and neighbors in the decision about installing solar PV systems, P2P operators can use this peer-based marketing channel as an opportunity and offer a friends referral bonus. On the one hand, this channel will create a business opportunity for both prosumers and consumers to trade electricity via the P2P ETP. On the other hand, it can also help the participants to gain status and to generate more revenue, a powerful incentive to increase the market share of a P2P ETP. Lition Energie has added friends referral bonus to its business model and offers incentives to HHs that invite others to join the energy platform. Additionally, peer outcomes – i.e., relying on friends and family as the primary sources of information for energy-related topics – reveals a more positive attitude towards participating in P2P electricity trading within the

HHs [16, 59].

5.4 Case study analysis

In order to examine the developed business models' validity and applicability further, which are summarized in Table 5, we apply them to the fifteen pioneer existing energy communities and platforms (see Table 6), including eleven companies and four research projects in Germany. The case studies' data are collected from their websites from January to February 2021 and are briefly introduced in the Appendix. Using qualitative methods, we characterize these fifteen ETPs and project business models systematically. Thus, we offer a package of business models and can be utilized in future projects' perspectives.

According to Tables 5 and 6, both the packages of business models and taxonomy fill an essential gap in the ETP literature by providing a Germany-wide analysis of different financing mechanisms for energy platform and community projects, HHs' needs, and value propositions. We find that there is a considerable difference in the number of applied business models offered by the cases. Of the fifteen case studies, the majority (twelve) are integrating RES (BM 2.2), in which nine projects offer smart contracts in the form of an 'Energy-eBay' platform (BM 1.2.1), thus enabling HHs to sign a contract with their favorite energy supplier. Among these use cases, eight exploit blockchain technology in their business models for creating communication channels between the prosumers and consumers within the ETP (BM 2.1). Other remaining projects use different technologies, such as Cloud solutions, Software-as-a-Service, Platform-as-a-Service, etc., in order to create a communication channel. Concerning the energy cost-saving business model (BM 1.2.2), the LAMP and SonnenFlat case studies enable HHs to receive free electricity under some circumstances.

Table 5. Summary of the most promising business models for P2P ETP.

Beliefs	BMs	Serving household needs	Action taken	Value proposition(s)	Revenue streams	No. of cases
	BM 1.1	Lack of initial investment	Leasing model	Economic	Leasing and maintenance	1
	BM 1.2.1	Purchasing electricity	Smart contracts	Economic, social	Energy-eBay	9
	BM 1.2.2	Saving cost of energy	Free electricity	Economic, social	Energy service contracts	2
Attitude	BM 1.2.3	Energy self-sufficiency	(Virtual) battery	Social, environmental	Subscription fee	4
	BM 1.2.4	Sharing electricity	Community creation	Social, environmental	Subscription fee	9
	BM 1.2.5	Low-cost electricity	Subsidized platform	Economic, social	No revenue stream	4
	BM 1.2.6	Fuel poverty	Donating energy	Economic, social	No revenue stream	-
	BM 2.1	Employed technology	blockchain tech.	Technological	Energy service contracts	8
PBC	BM 2.2	General perceived influence	RES integration	Economic, environmental	RES to local consumers	12
	BM 2.3	Specific perceived influence	Invest in bonds	Economic, social	Energy service contracts	1
Norms	BM 3	Friends referral	Community creation	Economic, social	Signing extra contracts	5

Table 6. Taxonomy of P2P energy trading platforms and existing research projects in Germany with respect to their business models.

Case studies	BM 1.1	BM 1.2.1	BM 1.2.2	BM 1.2.3	BM 1.2.4	BM 1.2.5	BM 2.1	BM 2.2	BM 2.3	BM 3	Sum
LUtricity		X				X	X	X			4
SonnenFlat	X		X	X	X		X	X		X	7
Lition		X			X		X	X		X	5
Pebbles		X				X	X	X			4
SENEC.Cloud				X	X						2
Tal.Markt		X			X		X	X		X	5
E.ON SolarCloud				X							1
Buzzn		X			X			X			3
sonniQ+				X							1
LAMP		X	X			X	X	X			5
Shine Community					X			X			2
Regional-energie					X			X		X	3
Enyway		X			X		X	X	X	X	6
Stromodul		X			X			X			3
RegHEE		X				X	X	X			4

Since most of the ETPs and projects belong to newly established start-ups, sufficient data for each case study were not available to the authors. However, the financial mechanisms are clearly defined. The revenue stream from subscription to the community/platform (BM 1.2.4) is the most crucial aspect across the existing business models for financing mechanisms. Except for the four research and pilot projects, which belong to non-profit organizations and are mainly financed by the German government or other private institutions and companies (BM 1.2.5), the other eleven cases rely on single or multiple finance resources, in which seven cases (64%) generate revenue mainly from fixed subscription fees through the creation of communities. Only one company (Enyway) uses the community investment bonds to develop regional RES, and none of the cases donate electricity in order to reduce fuel poverty.

6 Conclusions

According to our survey results based on a broad sample of German homeowners, to the applied business models, and to the limitations, we can carefully draw some lessons learned. Thus the current paper is not only primarily interesting for researchers in Germany, but the details and findings from the topic covered, also make it appealing for readers around the world.

Our findings show that cost-savings and financial benefits play an essential role in HHs' decisions to purchase solar PV systems and to become prosumers. In this case, these groups of prosumers may not care about ecological reasons, energy-sharing within a community of prosumers, or having a good feeling about the consumption of self-generated electricity, but simply want to increase their financial benefits by participating in a P2P energy-sharing community or platform, and thus save on their energy costs. This is also in line with the study of Kaschub et al. [60] which was conducted in Germany. However, other studies show that HHs which intend to participate in P2P electricity trading appreciate the opportunity of sharing energy generation and consumption more than saving on energy costs [5, 16, 58]. Thus, we have suggested a package of business models for future energy service providers in order to increase HHs' financial benefits and to enable them to share their surplus electricity and at the same time to increase HHs' energy self-sufficiency.

Although by 2020, there were more than 2000 electricity suppliers and utilities operating in the German energy market, we could identify very few case studies (fifteen) that offer P2P energy trading within a platform or some energy-community-building for HHs. Nevertheless, according to our key findings, we predict that more energy companies and utilities will apply our proposed P2P energy trading business models to their core business in the coming years. This argument is also in line with previous research [61], based on which future electricity retailers are expected to take a more consumer- and prosumer-centric approach and provide their private customers with energy-sharing platforms.

We find that future energy retailers' business models for P2P ETPs and communities are more prone to follow two primary business models. Firstly, companies' policymakers need to focus more on creating P2P energy-sharing communities or platforms where prosumers and consumers can trade electricity together rather than a rigid online tool that only enables them to store electricity. Secondly, they may integrate regional RES and concentrate on supplying local energy consumers. This is apparent because more than half of the case studies only offer services to regional prosumers and consumers and exclude households living outside of their district. Moreover, regional RES integration will offer economic VPs by suggesting the chance for low-cost or premium local energy prices [62] and environmental VPs through decreasing local emissions during generation by shifting towards renewables [63].

Although all the cases seem similar in practice (all offer energy trading and sharing possibilities through a digital platform and/or community), they can vary fundamentally according to their presenting value, fulfilling HHs' needs, and operating business models. This is evident considering that two case studies apply only one business model from our proposed business model package, whereas the rest employ at least two business models in their leading business model portfolio and consequently deliver more VPs to the households. Valuable business models in P2P markets establish a multi-directional value chain and enable different stakeholders to participate [64]. The multi-directional value chain can oppose utilities' traditional business models by creating innovative ways in order to secure profitability for their respective P2P stakeholders [65].

Besides the business model development process and operational improvement of the P2P ETPs, legal frameworks must be reviewed. Regulatory policymakers need to pave the way for new market participants – such as start-ups, research institutions, investors, and other stakeholders – by removing the existing legal obstacles and attracting their attention to grow the number of dedicated businesses developing or operating energy communities and platforms.

Although our study expands previous research in the P2P ETPs business model field, it is necessary to mention some limitations. First, our results are reflected from a survey sample consisting of 1618 HHs in Germany (excluding commercial and industrial buildings), including 307 prosumers and 1311 energy consumers, which may deliver potentially biased results. This can be observed in Table 1, where the ratio of participants is considerably different from the German population statistics in terms of participants' gender, age, education, and – more importantly – their disposable income. Second, as business models are dependent on different circumstances and settings such as regulatory limitations, we have not tested our proposed business models yet on any P2P ETP to check whether they might be successful in practice or not. This can be done in principle and that consumer acceptance of business models, and thus diffusion/upscaling, has an impact on the commercial success, also because of economies of scale and sunk costs to be recouped, e.g. for smart grid technology investment. Since most business case studies are young and have not yet published any financial report of their operation, we also could not find sufficient data to assess their business models.

Additionally, since P2P electricity trading platforms are currently relatively unknown opportunities for HHs, we did not ask them directly about these and how they operate in our survey, but instead just pointed to the opportunities they can offer to prosumers based on our in-depth literature review. Consequently, we recommend future research to apply, adapt, and promote the suggested business models and measure their success quantitatively. Moreover, it needs to focus on the implementation of sustainable business models on the P2P ETPs, specifically since studies that have been undertaken in this field so far are still scarce, future research can address business model issues by gathering survey data from members and interviewing stakeholders of real-world P2P ETP projects. In our study, we did not use the households' electricity usage pattern. The potential of P2P energy trading is strongly dependent on the load and the generation profiles. Considering households having solar PV systems which are only able to operate during the daytime (generation side), these are then matched with the load profile. Therefore, the usage patterns are important for the volume of P2P trading possible. This is a case study of Germany, and there are others from South Korea [18, 19], the UK [20–23], Portugal [24], and Australia [33]. The literature is still scarce regarding such country studies investigating preferences and motivations for P2P electricity trading, despite of its global, path-breaking potentials. Thus, we need more such country case studies to broaden the empirical analysis in this field.

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Appendix: Research and pilot projects

The Landau Microgrid Project (LAMP)[7] is a German research project run by the Karlsruhe Institute of Technology (KIT) and Energie Südwest AG's energy utility since 2017. It aims at analyzing local energy market behavior, promoting the use and expansion of local renewable generation, establishing an energy community, and establishing local energy balances to reduce grid expansion. LAMP has been live since October 2018 and has 20 residential consumers and two producers trading local electricity on a 15 min merit-order market.

Pebbles[8] is a German demonstrator and research project run by Allgäu Netz, Allgäu Überlandwerk, Siemens, Hochschule Kempten, and Fraunhofer FIT since 2018. Its goals are developing and demon-

[7] https://energie-suedwest.de/unternehmen/projekte-dienstleistungen/lamp/

[8] https://www.pebbles-projekt.de/en/

strating concepts for P2P energy sharing, grid services, and new business models, and especially the allocation of decentralized flexibility for increasing the share of local self-consumption. Trading began in 2020. It comprises 15 local and numerous virtual participants trading electricity on a 15 min basis in a day-ahead market.

In the LUtricity[9] research project, Technische Werke Ludwigshafen AG (TWL) investigates how an autarkic, sustainable power supply can be achieved by using decentralized energy. The plan is to simulate an independent electricity community made up of private and commercial consumers and producers. The LUtricity research project participants are connected to an extensive TWL electricity storage system to form a virtual network. In addition to the existing electricity meter, all participants receive a device that continuously and securely transmits energy consumption and electricity generated to the blockchain. Based on this data, a balance between electricity supply and demand is to be simulated.

The RegHee[10] research project aims to explore, develop, and test a blockchain-based P2P market for distributed generation and storage units, including labeling in Germany. To this end, existing blockchain systems will be analyzed to inform the system architecture design. Afterwards, on- and off-chain solutions, such as smart contracts, will be developed to enable direct automated trade between local prosumers and end-users. It is an explicit objective that, where possible, the developed platform will operate under current regulatory and energy economics frameworks. A reference system employing a centralized architecture and exhibiting comparable functionality will be implemented and compared.

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2020

Klie L., Madlener R. (2020). Optimal Configuration and Diversification of Wind Turbines: A Hybrid Approach to Improve the Penetration of Wind Power, FCN Working Paper No. 1/2020, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

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