sustainability

Systematic Review

The Prosumer: A Systematic Review of the New Paradigm in Energy and Sustainable Development

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Abstract: The deployment of distributed and affordable renewable energy has led to the development of the prosumer concept in the field of energy. To better understand its relevance and to analyse the main trends and research developments, a systematic literature review was performed. This work gathered 1673 articles related to this topic that were analysed following the PRISMA methodology with the help of VOSviewer 1.6.18 bibliometric software. These papers are classified into four clusters: smart grids, microgrids, peer to peer networks, and prosumers. The first two clusters show a certain degree of maturity, while the latter maintain a growing interest. The analysis of the articles provides a broad view of the prosumer's role in energy and its potential, which is not limited to simple energy exchanges. Furthermore, this systematic review highlights the challenges, not only technical but also in terms of electricity market design and social aspects. The latter require further research, as society is undergoing a paradigm shift in the way in which energy is produced and used. How this shift occurred will determine whether it can lead to true prosumer empowerment and a fairer energy transition.

Keywords: prosumer; smart grids; microgrids; peer to peer; systematic review; energy transition

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Citation: Parra-Domínguez, J.; Sánchez, E.; Ordóñez, Á. The Prosumer: A Systematic Review of the New Paradigm in Energy and Sustainable Development. *Sustainability* **2023**, *15*, 10552. https://doi.org/10.3390/su151310552

Academic Editor: Chi-Ming Lai

Received: 15 May 2023
Revised: 13 June 2023
Accepted: 27 June 2023
Published: 4 July 2023

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1. Introduction

Social progress largely represents new challenges to be faced [1] because, for example, of the need to respond to the distribution of limited resources among ever-increasing requirements as a result of a growing number of people worldwide whose impact is clear, for example, in agriculture [2], and may also be caused by the climate challenge itself [3]. Several actors and sciences are involved in the link to social development. An essential part of the current development, with strong concern about sustainability, is aligned with the development of disciplines, such as engineering (energy, computing) and economics [4]. Renewable energy sources (RES) offer a viable response to the climate challenge, and part of that solution lies in the mass deployment of distributed energy resources (DERs), which is difficult with the classical grid model and indicates the need for profound changes, not only in technical but also in socio-economic aspects. All this need is reflected in SDGs 7, 11, and 13: "Affordable and clean energy", "Sustainable Cities and Communities", and "Climate action", respectively.

In the specific case of economics, the relationships that occur in the production and exchange of goods are based on rational criteria [5], and the prosumer emerges strongly, combining production and consumption [6]. This concept is present from the perspective of a paradigm shift, with the user able to buy and sell surpluses with a different dimension of the involvement of the market as a system. This concept is not new; as far back as 1979, in their book *The Third Wave*, Alvin and Heidi Toffler brought the term *prosumer* to light and thus managed to designate those who create goods, services, or experiences for their use or enjoyment, rather than to sell or exchange them [7]. Their argument stated, "When, as individuals or collectives, we PROduce and conSUME our output, we are prosuming". As people advance in their knowledge, prosumption is not only an individual act. Still, part of the purpose of production is to share it with family, friends, or community (the latter being important in the energy market) without expecting a financial stream of its equivalent in return. Within the energy market, the transformation of self-consumption of electricity from renewable energy sources in all sectors that contribute to caring for our planet is a reality [8].

It is therefore necessary to understand the progress of the prosumer concept as it relates to energy. Numerous systematic and bibliometric reviews have been conducted in fields related to the prosumer concept. The backbone enabling the development of the possibilities associated with the prosumer is the smart grid concept, which was reviewed in [9,10]. Microgrids are closely linked with these concepts and are ideally suited to integrating RES and to uncovering the potential of the prosumer, as shown in [11,12]. Information and communications technology has been reviewed enabling the operation of smart grids [13], microgrids [14], and households [15]. Peer-to-peer energy transactions have also been widely reviewed [16–20], as has blockchain technology [21–24]. Transactive energy systems were reviewed in [25], as well as their relations with P2P and community self-consumption [26] and the emerging concept of the Energy Internet [27]. Energy communities are gaining great attention as the next step in the prosumer movement [28–33]. Prosumers as active market participants were reviewed in [34] and their new directions in [35]. The prosumer movement and the collaborative economy are set to bring about a change in electricity markets [36–38], also with socio-political implications [39]. It is essential to emphasize the reasonable alignment of the prosumer concept with sustainability, understanding that development is based on what are known as clean energies, the basis being photovoltaic energy. Although there have been numerous review articles on specific prosumer issues, no reviews have been found that specifically address the prosumer in energy in a general way. The most general review was presented by [34] on prosumers as active market participants, focusing on electricity tariffs and proposing a model to assess a prosumer's flexibility and return on investment.

With regard to the methodology used in the systematic reviews, the PRISMA methodology (Preferred Reporting Items for Systematic reviews and Meta-Analysis) was incorporated in [31,32] on the topic of energy communities. Given the large number of bibliographic references, it is advisable to incorporate bibliographic tools, such as VOSviewer 1.6.18 software, for the classification and analysis of works based on keywords. Few systematic reviews have been found that incorporate the use of these tools in relation to the prosumer. In the case of [40], VOSviewer was used to review the concept of prosumerism in the fields of social sciences and business studies. In the field of energy, the work of [41] stands out in the field of prosumer flexibility through its use of VOSviewer. The article presented here attempts to fill this gap by proposing a systematic review of the prosumer in the field of energy, incorporating an advanced bibliometric tool such as VOSviewer into the PRISMA methodology.

The article's contributions are essentially twofold. First is the incorporation of the use of VOSViewer software into the analysis of the search results as part of a systematic review in an adaptation of the PRISMA methodology. Second are the classification obtained in four clusters that are well-differentiated subject areas and the study of the evolution of the topics, as well as the review of the most cited articles in each area. These contributions indicate the progress of the prosumer from its foundations in smart grids and microgrids to research on the prosumer concept with more recent developments in all aspects related to P2P transactions in the field of energy. The remainder of this paper is as follows. The second section presents the basics of economic theory and current prosumer retribution mechanisms, followed by the methodology used for the systematic review. The third section presents the results of the review, grouped into the four thematic clusters that have been identified. Finally, the results are discussed, and conclusions are drawn.

2. Materials and Methods

A systematic review was performed to identify the existing relationships between the term prosumer, and, within social progress, engineering and energy. The first step is to introduce the basics of this concept in economics; followed by an outline of the currently most used tariff models, i.e., net-metering and net billing; and finally a detailed description of the methodology used.

From an economic point of view, classical economic theory integrates supply and demand into price determination [42], with the importance of money in determining competition, for example, in energy markets [43]. The organization of production and the distribution of output among consumers, occurring in markets, are constant concerns of economists [44,45] from price equilibrium [46] to economic equilibrium, which is the point at which the quantity supplied and that demanded are equal [47], as shown in Figure 1a. Two situations are explicit: when the actual price is higher than the equilibrium price, as shown in Figure 1b; and conversely, when the confirmed price is lower than the equilibrium price, as shown in Figure 1c.

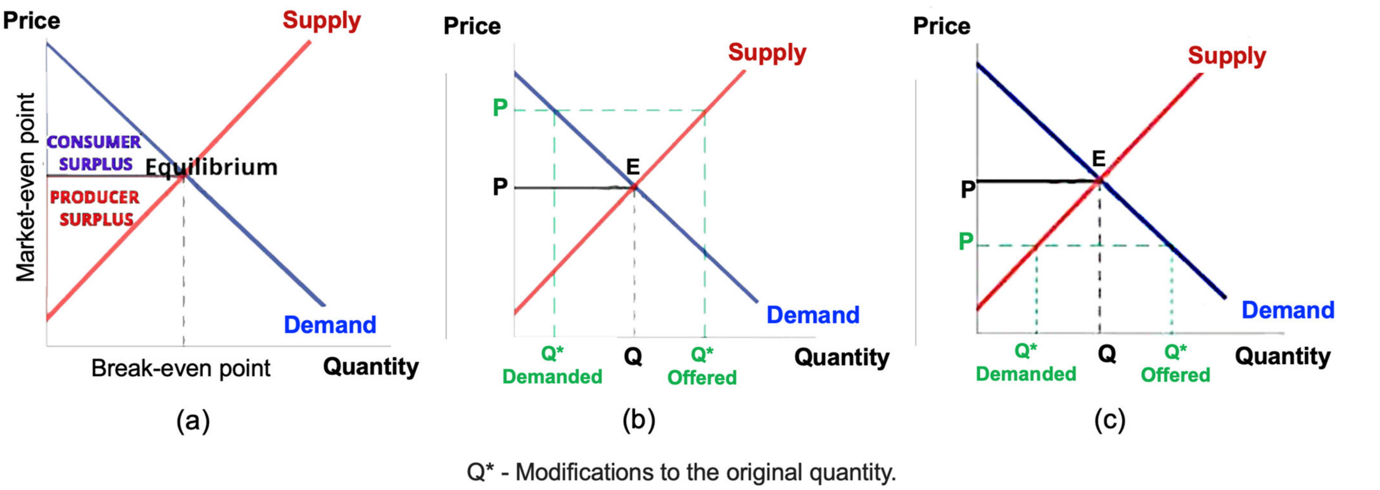

Figure 1. (**a**) General equilibrium; (**b**) oversupply; (**c**) excess demand.

The concept of interdependent supply and demand was formulated by Walras [48] and led to the discovery that economics could be reduced to a disciplined mathematical analysis that still endures. Walras also advanced the importance of macroeconomics and microeconomics [49], with which he joined the theories linking production and consumption [50] and those linking income allocation to purchasing different goods and services in what is understood as consumer theory [51], which has great importance in the conception of the term prosumer.

Previously, sufficient economic theory was introduced but without going into the widely validated conception of consumer and producer movements or the behaviour of factors such as demand in the final motivation of prices [52]. Through the theories mainly exposed, the motivation of the economic agent as an essential unit within any economic system is extracted [53]. Based on the theories introduced above, a static role can theoretically be attributed to the prosumer, but economic dynamics have evolved so rapidly in the last century that economic agents are not necessarily anchored to one part of the activity [54]. The figure of the prosumer refers specifically to the capacity of the same agent to consume and produce [6], with the implications that may exist, for example, in the generation of prices or, in the field of energy, in the production of clean and sustainable energy [55].

The prosumer's ability to add value to a service or product by reducing costs is the result of the above [56]. Prosumer success in energy is mainly due to achieving PV grid parity. In most cases, it is allowed to feed the electricity surplus into the grid, and some type of compensation is received. Net-metering and net-billing are regulated arrangements in which the electricity surplus is rewarded with credits that can be used to compensate for consumption. Under net-metering, the credit is at the level of retail electricity, and the mechanism is as simple as discounting the surplus energy based on the consumed energy. If the balance is negative, in some countries, it is allowed to save this credit to use later, generating a time-limited rolling credit. The net-billing scheme consists of valuing energy economically according to electricity prices. In general, the electricity surplus is valued in relation to the wholesale price of electricity, which is less than the retail price. Therefore, net-billing is less beneficial from an economic point of view [57].

As the number of prosumers has increased, some problems have arisen, mainly two. First, the decrease in the bills of prosumers also decreases their contribution to grid costs, resulting in higher costs for traditional consumers. Second, there is a lack of incentives to synchronize local production and consumption [58]. As a result, many states and provinces are phasing out net-metering policies in a transition to net-billing and, in the future, to more evolved models, such as P2P transactions.

This systematic review was conducted using a methodology based on the PRISMA statement [59,60] and incorporating the use of VOSviewer 1.6.18 software [61] for bibliographic analysis, as shown in Figure 2.

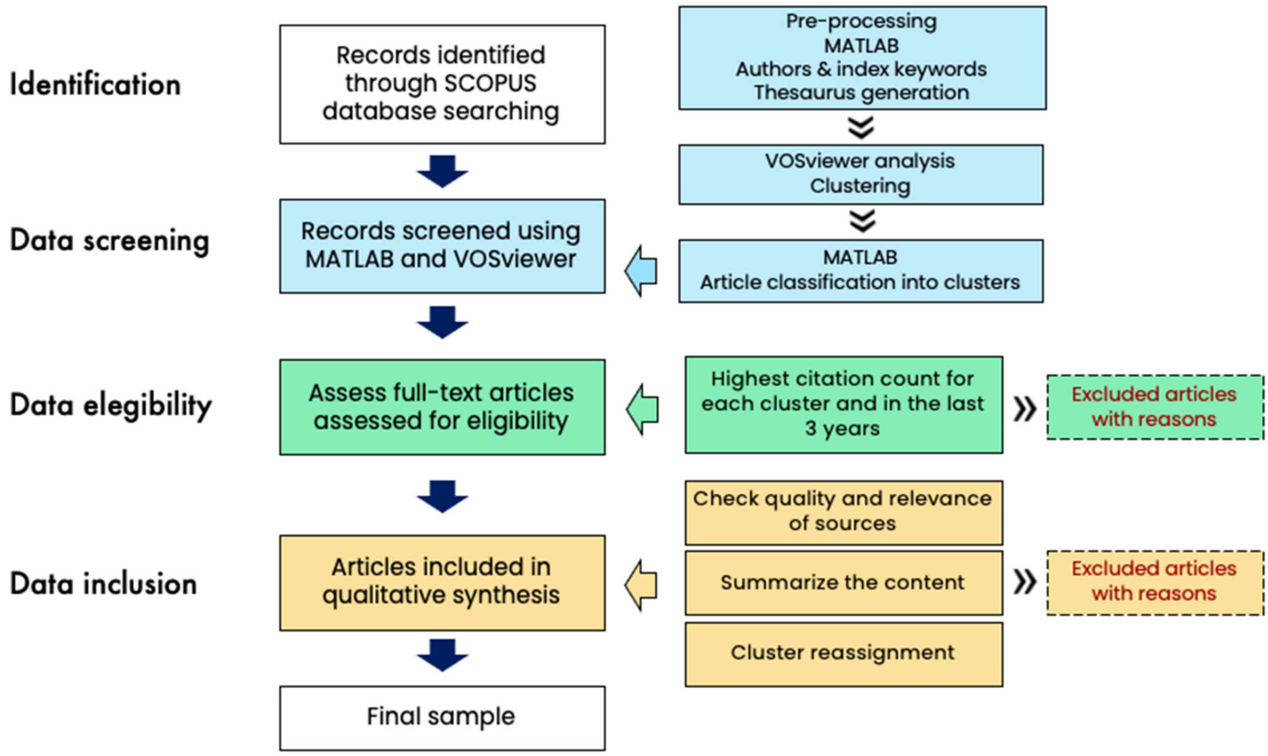

Figure 2. Adaptation of PRISMA methodology for use with VOSviewer.

The bibliographic data were acquired through Scopus because this database provides the most complete account of articles without dependence on International Scientific Indexing (ISI) indicators that can leave potential voids [29]. These data were analysed using VOSviewer, which performs the clustering of keywords based on their co-occurrences in the bibliographic references from the dataset, allowing for the creation and visualization of maps of keywords and for organizing them in clusters. When properly organized, clusters allow articles to be classified into categories, in a process called coding.

If the raw data generated by Scopus are used in the software, it is possible that hundreds of keywords are identified, with very complicated maps that are not useful for this systematic review. Therefore, it is important to use a thesaurus to reduce the number of keywords and to achieve clearer maps with a more coherent division into clusters. The raw data from Scopus were pre-processed using scripts written in MATLAB, that analyse the keywords defined by the authors and those automatically generated by the database according to the search criteria. These keywords are studied and grouped, taking as keywords those with the highest number of occurrences to generate the thesaurus.

In the present case, due to the large number of bibliographic references and keywords, the analysis was limited to the keywords defined by the authors. Adjusting the input parameters of VOSviewer, "minimum number of occurrences of a keyword" and "minimum cluster size", it is possible to obtain a minimum number of coherent clusters. As long as one of the purposes of this work is to investigate how research in the prosumer field develops and what directions it takes, it is necessary to classify the papers into the most appropriate clusters. This process was not possible with this software, so one path was through additional searches in the Scopus database using the keywords from each cluster. This approach proved not to be operational for several reasons, one of them being the repetition of numerous jobs in several clusters. As a result, some MATLAB script programming was used again so that the thesaurus performed the translation of the keywords in the articles, and the keywords belonging to each cluster were counted. Thus, each paper was assigned to the cluster in which it had the highest relative weight. Since several sets of articles were eligible for analysis, the most relevant articles in each cluster were considered to be those with the greatest number of citations. For each cluster, the 20 most cited articles were selected for full reading. One possible drawback of this approach is possible bias in citation because older papers obtain more citations. To overcome this situation, a screening was performed in each cluster, sorting the papers by date and number of citations to identify emerging relevant works, and the papers from 2020 with more than 10 citations per year were selected. Additionally, a quality check was performed, and some works were manually reassigned after full reading.

3. Results

3.1. Data Collection

The preliminary search equation was not restricted since a broad analysis of the results was intended, so the term "prosumer" was searched in all fields with the equation [ALL (PROSUMER)]. This search returned 10,296 results as of November 2022, which were downloaded and analysed using Microsoft Excel 16.74 software. To investigate the extent of the prosumer concept in economy and energy, two different searches were performed: the search [ALL (PROSUMER) AND ALL (ECONOMY)] returned 3248 results, and [ALL (PROSUMER) AND ALL (ENGINEERING) AND ALL (ENERGY)] yielded 5888 results.

These preliminary searches show the relevance of the term "prosumer" in the fields of engineering and energy. Since the next step in the bibliometric analysis involved software for the identification of keyword clusters, a stronger constraint on the dataset was necessary to focus on the more relevant works. The inclusion criteria limited the results to peer-reviewed journals, published in their final form from all years in the English language. Books and chapters, reports, and grey literature were not considered. The fields explored in this new search were limited to titles, abstracts, and keywords, and the search string used was TITLE-ABS-KEY (PROSUMER AND ENERGY) AND (LIMIT-TO (SRCTYPE, "j") OR LIMIT-TO (SRCTYPE, "p")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBSTAGE, "final")). This search yielded 1673 papers by the end of 2022, and these results were analysed with VOSviewer and MATLAB.

3.2. Clustering

The dataset used comprised 9859 different keywords and was first imported to VOSviewer using the criterion of co-occurrence of all keywords (author and database given) and was limited to a minimum of five occurrences, resulting in 1018 keywords that were organized in nine clusters of more than 25 keywords. This clustering was not useful for the purposes of the current investigation, so the dataset was processed using a thesaurus, as described. For further simplification, the criterion of co-occurrence was limited to the authors and keywords with more than 20 occurrences. This process resulted in a set of 29 keywords grouped into four clusters of size greater than three keywords, shown in Figure 3. The clusters were named according with the name of the most relevant keywords: "microgrids", "prosumer", "smart-grids", and "peer to peer". The map was organized around the cluster "prosumer", which occupies the central position, and the keyword "prosumer" was connected with all the other keywords. Of the other clusters, only the keyword "smart grids" related to all the remaining keywords in the map.

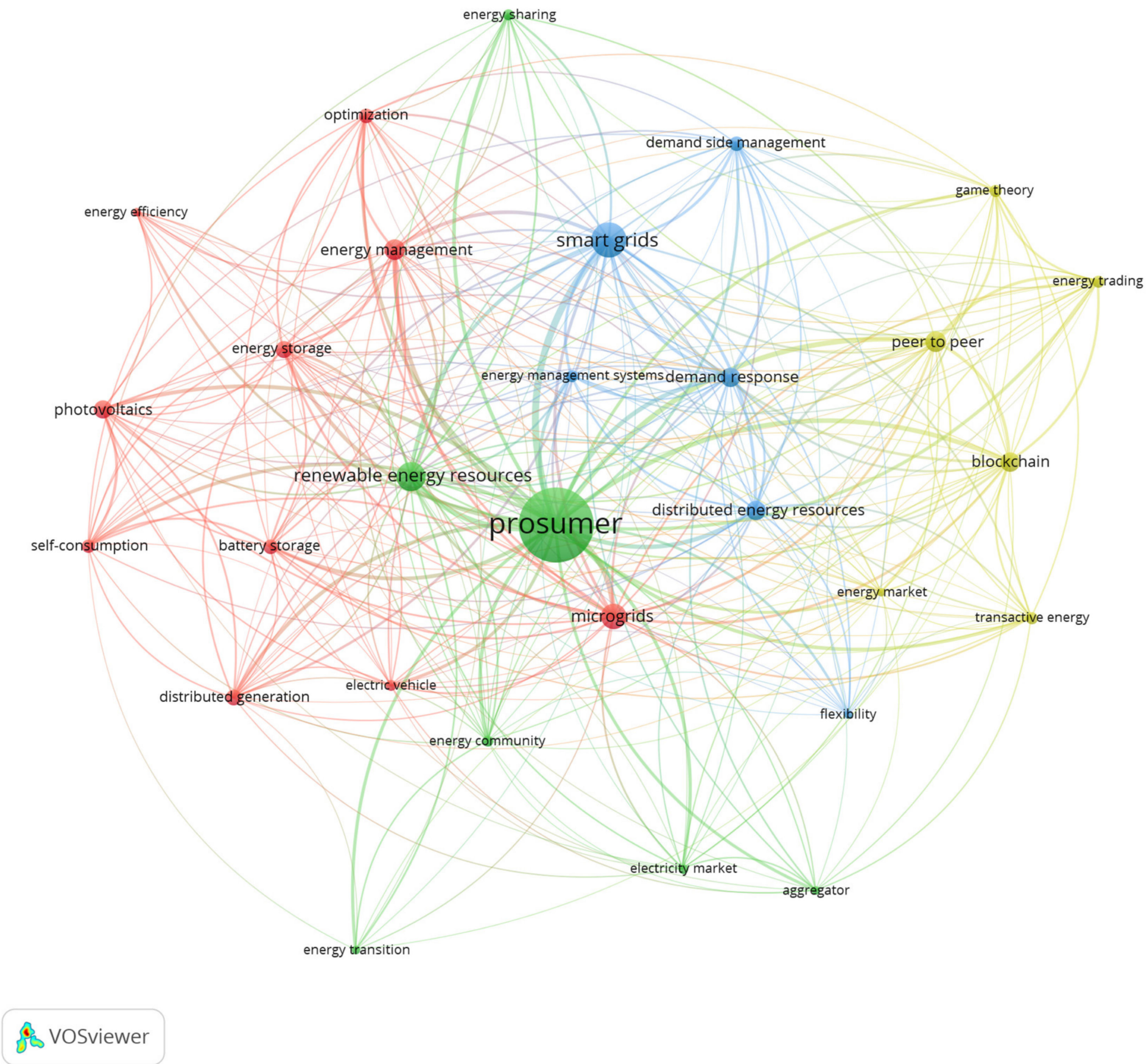

Figure 3. Map of the clusters. Each node represents a keyword, and its size indicates the number of occurrences of that keyword. The lines connecting keywords represent the co-occurrences of those keywords. Based on these connections, clusters are established, indicated by different colours.

The analysis of the keywords indicated that the clusters were coherent and with a thematic unity, so four categories were established, as shown in Table 1. Following the methodology, all the papers were classified into clusters, (Figure 4) for retrieving, and the most relevant were fully read.

Table 1. Categories, definitions and keywords.

Clusters	Categories	Definitions	Keywords/Occurrences	
1	Microgrids	Clusters of loads and microgenerators operating as small power distribution systems that supply electricity and heat.	microgrids	115
			energy management	83
			photovoltaics	71
			energy storage	68
			distributed generation	55
			optimization	51
			battery storage	49
			self-consumption	48
			electric vehicle	36
			energy efficiency	22
2	Prosumer	Consumer of a product or service who at the same time participates in the production of the product or service.	prosumer	609
			renewable energy resources	144
			energy sharing	34
			energy community	33
			electricity market	31
			energy transition	25
			aggregator	22
3	Smart grids	Electricity networks that integrate information and communications technology to obtain a bidirectional flow of energy and information that allows for integrating distributed energy resources and optimizing energy efficiency.	smart grids	191
			demand response	81
			distributed energy resources	79
			demand side management	49
			energy management systems	42
			flexibility	26
4	Peer to peer	A decentralized network in which all or some aspects operate without fixed clients or servers, and its nodes behave as equals to each other in fulfilling the function without hierarchy, allowing for the direct exchange of information.	peer to peer	84
			blockchain	82
			energy trading	42
			transactive energy	40
			game theory	38
			energy market	26

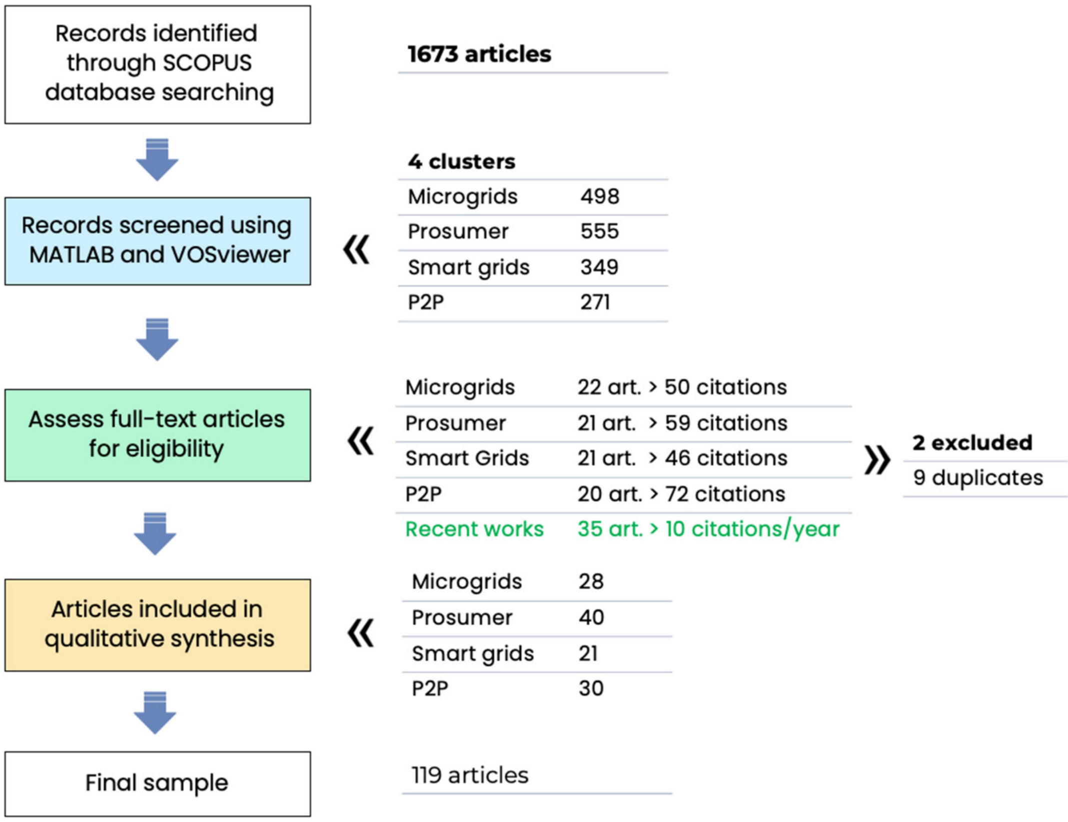

Figure 4. Systematic review real information flow (following PRISMA methodology in Supplementary Materials). A summary of the articles is presented in Appendix A.

3.3. Evolution

Bibliometric analysis makes it possible to study the evolution of publications over time. Figure 5 shows the evolution of the term "prosumer" in the fields of engineering and energy, with a steady upward trend since 2010 but showing signs of peaking soon.

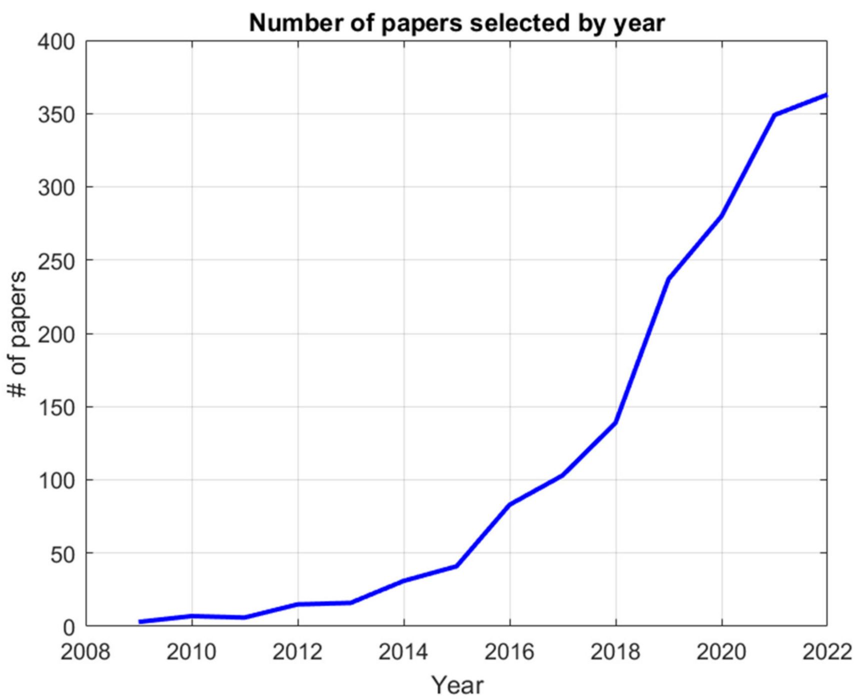

Figure 5. Evolution of scientific publications over time on the prosumer concept.

Moving on to the bibliometric analysis, in Figure 6, the most active journals in terms of publications related to the term "prosumer" can be seen. The most immediate current order is *Energies, Applied Energy, IEEE Access, Energy, IEEE Transactions on Smart Grids and Renewable,* and *Sustainable Energy Reviews*.

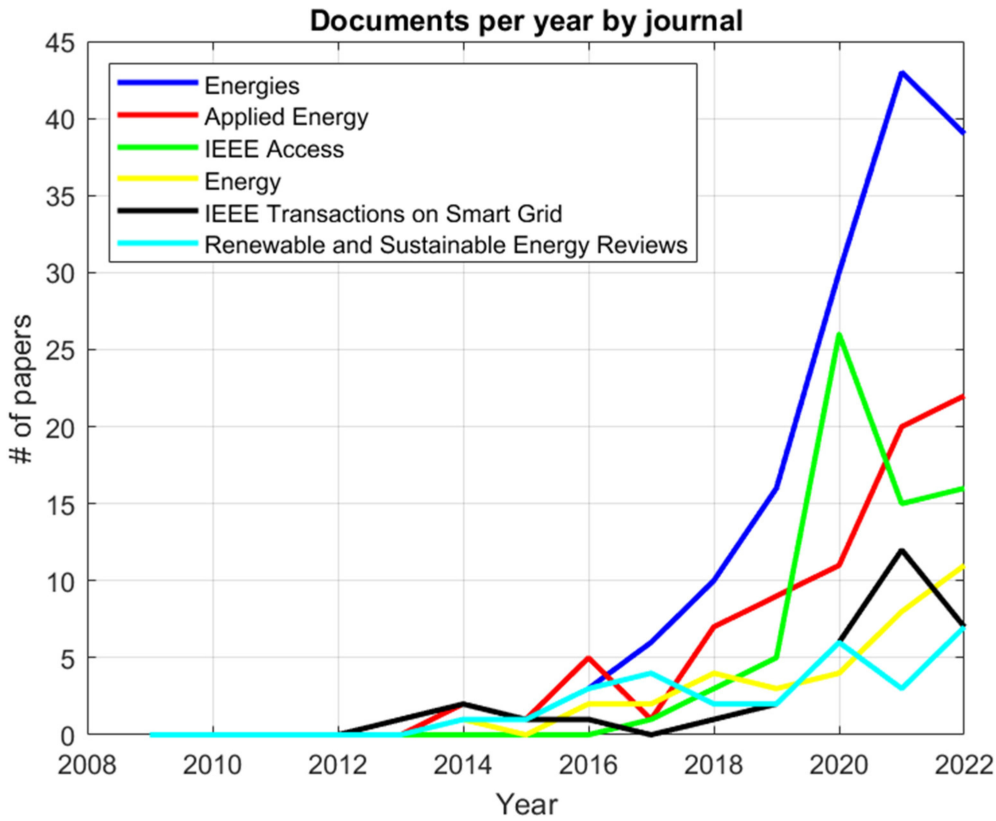

Figure 6. Evolution of scientific publications over time on the prosumer concept by journal of publication.

Using the keyword map configured in VOSviewer, the average year of publication of each keyword can be observed using a colour scale (Figure 7). Proceeding with the data processing, the number of articles for each year and cluster is further explored, highlighting the leading role of research on basic technologies and their initial attractiveness (from smart grids to microgrids) giving way to prosumer-oriented research (Figure 8).

3.4. Approach to the Importance of the Prosumer in Energy

Once the quantitative results have been presented, it is time to analyse the importance of the term "prosumer" in its relationship with energy and its contribution to economic, social progress, and sustainable development to shed light on the evolution of the clusters that have been identified. Without forgetting the meaning of the present work, in the past, the foundations of the work on energy and its implication in the development of the prosumer were somehow already beginning to be laid. Implicitly, within it were laws such as the Public Utility Regulatory Policy Act of 1978 [62], which made it mandatory for utilities to purchase excess power from homeowners whose wind generators met specific requirements. Beyond the historical implication, it can be seen how the evolution has been towards the incorporation of more advanced technological systems that favour efficiency in the use of self-produced energy.

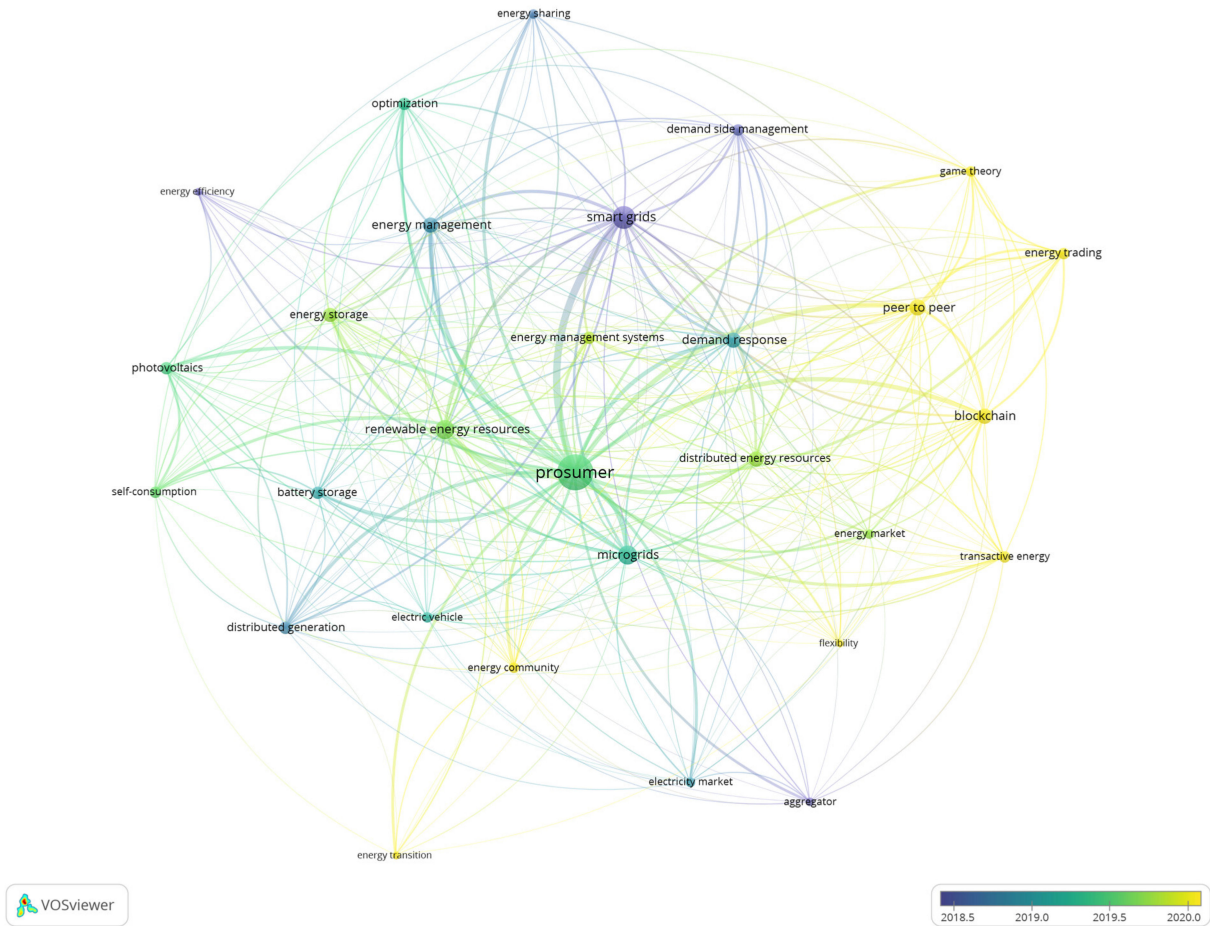

Figure 7. Evolution of keywords related to the prosumer. Based on the structure of Figure 3, the average date for each keyword is represented by a colour code, with blue representing the keywords used in older articles and yellow the most recent ones.

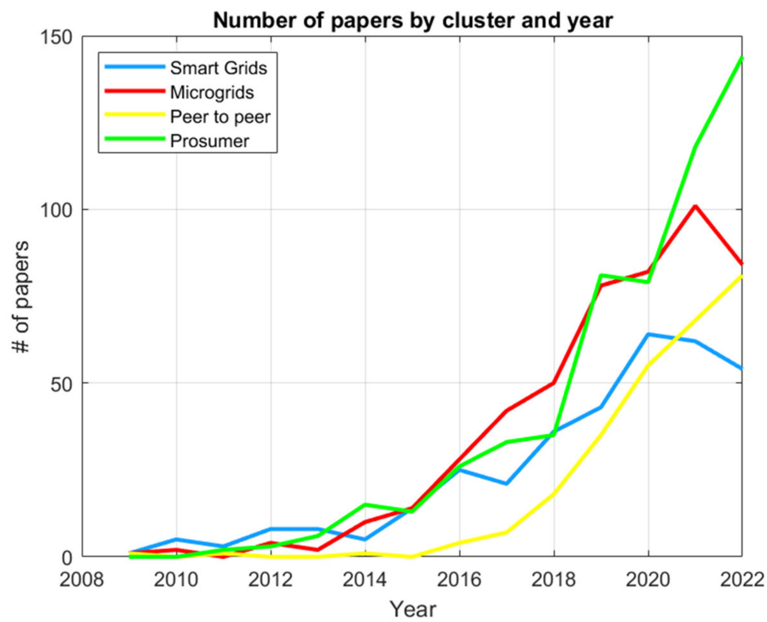

Figure 8. Annual number of papers for each cluster.

3.4.1. Smart Grids

The smart grid is arguably one of the most important topics in today's electricity grid. It extends the performance of the traditional electricity grid by adding information and communications technology (ICT) capabilities that facilitate DER integration, efficiency gains, and prosumer development [63]. The growing research interest in the smart grid concept was extensively reviewed in [9], and it was found that the top research category was distribution automation, followed by system efficiency efforts and a very strong relationship with ICT, with 95% of the papers referring to it. The eight main characteristics of the smart grid are listed in the Energy Independence and Security Act of 2007 [64]. Most of these categories are found as keywords in the present study related to the prosumer concept (distributed energy resources, demand response, demand side management, energy management systems, and flexibility), while smart metering technology is also treated in several papers.

Demand response (DR) is defined by the Federal Energy Regulatory Commission as "Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [65]. The former research on this topic aimed to map those factors that influence the load profile to provide a methodology for modelling the behaviour of electricity prosumers [66], emphasizing the importance of including a large number of small-size prosumers in power systems simulations. The aggregation of prosumers tends to shave the peaks that occur on the households' load profiles, not only easing the modelling of the electricity demand but also allowing them to form coalitions that can coordinate user demand response, reducing the reverse energy flow and maximizing economic yield [67]. Blockchain technology is gaining importance for the decentralized management of demand response, as in [68], which used a ledger that securely stores information on energy consumption and smart contracts, allowing for energy flexibility in near real time. The operation of prosumer microgrids as active users in smart grids under uncertainties such as stochastic behaviour of loads and weather conditions was studied in [69] based on a hybrid machine learning method with a DR programme based on the forecasted data and considering the battery degradation costs with an improvement in operating costs.

Demand side management (DSM) encourages the end-user to become more energy efficient, using measures such as efficient lighting, heating ventilation and air-conditioning (HVAC), variable frequency drives, and automation upgrades. There is great interest in the interaction and aggregation of prosumers and consumers in different ways to implement DSM programmes, beyond the standalone efforts of all the stakeholders. Energy marketplaces are envisaged, in which prosumers from smart city neighbourhoods can manage their energy more efficiently and dynamically. Even if this approach becomes technically feasible, some challenges are presented in [70], such as the lack of a general simulator, and security, risk, and privacy issues for the stakeholders and the market itself. The necessity of automated trading agent strategies is also highlighted, both in cooperative and non-cooperative ways. The relationship with the grid of prosumers participating in DSM programmes is a subtopic of great interest. A single user virtual power plant (VPP) was proposed in [71] for the optimal management of the DERs owned by prosumers, based on a service-oriented approach, in which multiple agents cooperate and also consider different forms of DR requests. This consideration means a move from the system level to the level of the single prosumer, who is allowed to provide flexible power profiles through the aggregation of multiple DERs.

Flexibility is another important aspect of electrical grid operation, understood as the ability to maintain or restore system stability in the face of fluctuations in consumption or generation, which are expected to be very common in the future scenario of massive, distributed energy sources, such as photovoltaic (PV) rooftops, electrical vehicles, and batteries. Cost-optimal and rule-based control techniques for buildings with PV using heat pumps, thermal and electrical storage, and shiftable loads were investigated in [72], finding that cost-optimal control under a time of use (TOU) tariff achieved up to a 25% savings in electricity bills and up to an 88% decrease in electricity surplus fed into the grid. Heat pumps with thermal storage and a battery were found more effective at providing flexibility than shiftable appliances in residential buildings. The willingness of prosumers to provide flexibility to the grid is of great importance to achieve success in this domain [56]. Through a series of choice experiments with 902 actual and potential flexible prosumers, positive willingness was confirmed to co-create flexibility, and there is significant potential if prosumers' preferences are addressed (Figure 9). However, it is important to note that prosumers prioritize comfort over providing flexibility to the grid: prosumers with PVs plus batteries and/or EVs are more likely to provide flexibility than heat pump users due to the possible direct impact on their personal comfort. In addition, prosumers might be less opposed to automated modes of flexibility provision, but they expect to be compensated for it. A local flexibility, market-based framework for managing multiple flexibility services was presented in [73], with aggregators acting as local market operators and supervising flexibility transactions of the local energy community. Flexibility is sold by means of loads, generators, storage, and electrical vehicles. This work pointed out multiple open questions, such as the minimum viable size for the local flexibility market and its economic profitability. The work in [74] proposed short-term decision-support models for aggregators to exchange electricity with prosumers, with the possibility for the aggregator to control flexible units for the prosumers being essential. This model result in two-stage stochastic mixed integer linear programming (MILP), with the bidding decision made in the first stage and the scheduling in the second. The model was simulated in a case study based on a community and an industrial plant, obtaining a value of flexibility on the order of 12% of the total costs.

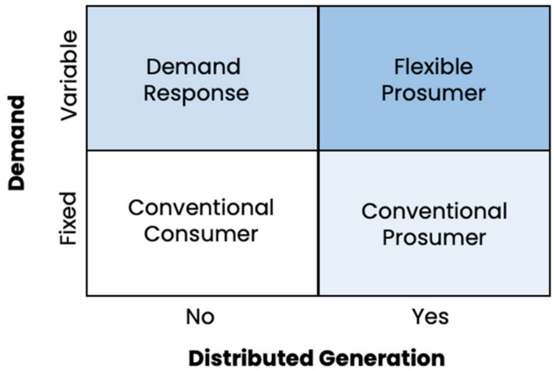

Figure 9. Taxonomy of consumers and prosumers. Adapted from [56].

Prosumers of electricity are the most common but not the only prosumers. The energy trading of heat and power among residential and commercial prosumers in a case study in Shanghai was presented in [75], and it was found that the energy cost for the prosumers could be minimized with fair strategies for electricity and heat, with savings of up to 4.9%. The method used a Nash-type game, with McCormick relaxation and linearization through MILP. A relevant conclusion of this work is that there is a trade-off between fairer trade with a slight sacrifice in cost savings and achieving the greatest cost savings with a relatively unfair allocation of benefits.

One of the first smart grid demonstrations was the "Power Matching City" [76], which presented most of the main characteristics: DER, DR with smart hybrid heat pumps and smart appliances, electricity storage, automatic meter reading, energy service gateways, data communication networks, detailed data access, and advanced distribution automation. This integrated solution demonstrated the potential of the smart grid to implement new market models and coordination mechanisms, using the flexibility provided by the various technologies without impacting the comfort of the end-user or compromising the safety requirements.

ICT enables the operation of smart grids, with one of its pillars being smart metering. The technology, applications, and state of deployment of smart meters were extensively reviewed in [13]. The applications of smart metering can be summarized as electricity signal quality, distributed generation and storage control, billing, home area network applications, and anti-fraud. A detailed study of the smart metering infrastructure deployment in Spain was presented in [40], and significant shortcomings that need to be addressed through regulations were found. At the household level, ref. [77] proposed a smart home energy management system (HEMS), shown in Figure 10, that allows the prosumer to manage domestic appliances, PV, storage, and electric vehicle (EVs), and it was found that smart home scheduling could guarantee both the lowest cost and the comfort of the users. The information provided by the different stakeholders can feed a platform that enables offering several energy services for the smart grid [78], such as energy monitoring, energy prediction, management, energy optimization, billing, brokerage, and other services. ICT adoption has a positive impact on the energy efficiency of prosumers and consumers, reflecting the prosumers' concern for the environment and allowing for the motivating of consumers to switch their consumption patterns from non-renewable to renewable energy sources [79].

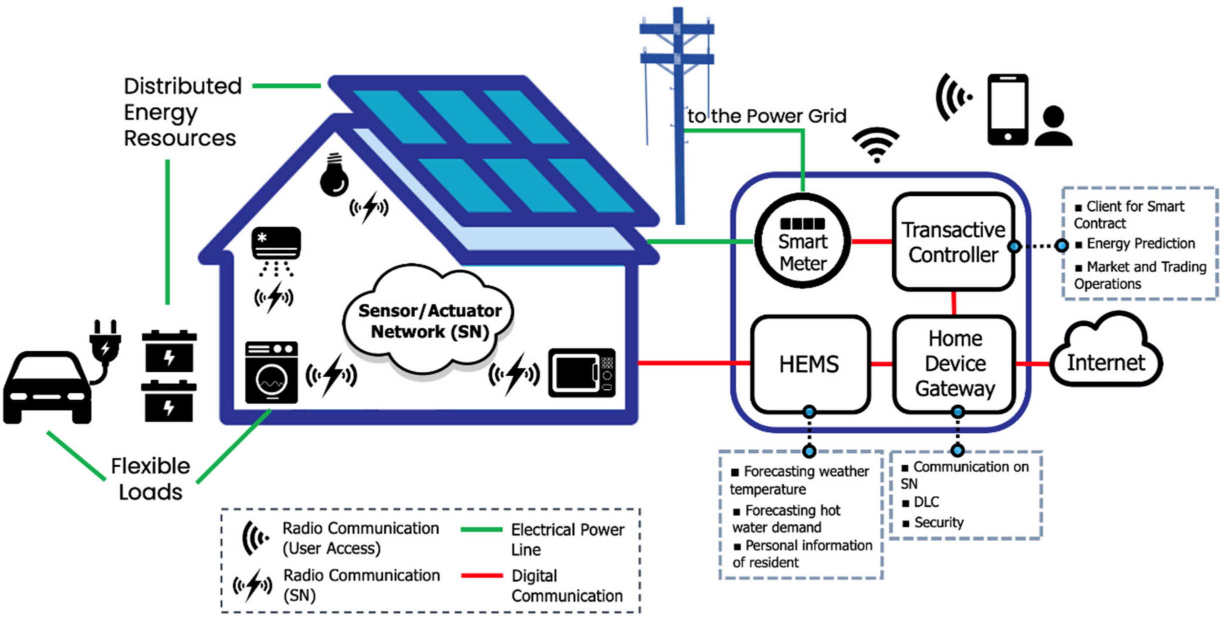

Figure 10. Smart energy home management system (HEMS). Adapted from [72,80].

3.4.2. Microgrids

Microgrids are clusters of loads and microgenerators operating as small power distribution systems that supply electricity and heat [81]. Microgrids can include RES (usually PV), storage, and other distributed generators, such as microturbines and combined heat and power (CHP), and they provide an environment suitable for interaction with electric vehicles, as shown in Figure 11. They supplement the main power grid in the smart grid environment. Regarding utility, microgrids can be seen as cells controlled as a single dispatchable load. To the customer, they can be applied for many uses, mainly for integration of DERs, increased efficiency, use of waste heat, and to provide economic savings through local energy exchanges between prosumers.

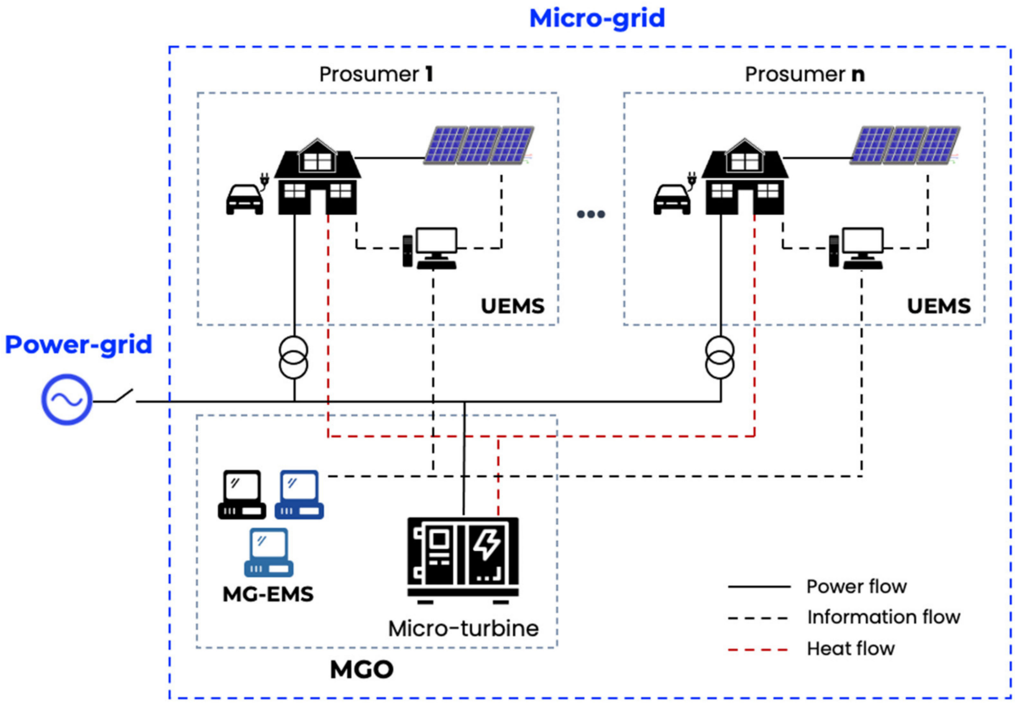

Figure 11. System architecture of a microgrid. Each prosumer is individually managed using a user energy management system, and the microgrid is coordinated through a microgrid operator. Adapted from [82].

The energy management for microgrids with PV and storage in a variable grid price scenario was investigated in [83] with a multi-objective optimization method, showing advantages in computational effort in a number of test cases with different trading options. The energy management inside the microgrid and sharing between consumers were developed in [84] using the concept of a microgrid operator (MGO) as a central entity responsible for microgrid energy management. As the microgrid participants have different motivations (energy savings, economic profits), the MGO acts as the leader in a Stackelberg game, and the rest of the participants act as the followers, adjusting their energy behaviours to the TOU prices. This approach results in an hour-ahead pricing model that can generate profits both for the MGO and for the prosumers. The same approach was used in [82] including CHP and PV prosumers, and in [85], storage was included, allowing for improvement of the scheduling.

Local electricity markets were investigated in [86] when battery storage was added, and peer-to-peer energy transactions between prosumers were allowed. Two models were used, one incorporating local trade and distributed batteries at the house level and the other using central storage. Linear optimization was used on a nine-month dataset with demand profiles, grid consumption, and electricity prices, finding that storage and peer-to-peer (P2P) trade lowered the cost of electricity in both designs, with 50% of the savings due to flexibility, but the distributed batteries model offered a better yield. A unified approach of optimally designing and managing community microgrids with an internal market was presented in [87] using a Monte Carlo tree search algorithm on the bilevel problem, finding levelized cost of electricity (LCOE) reductions from 20% to 40% for a real microgrid. The shift from passive to active end-users through demand response and transactive energy frameworks was explored in [88] with a building energy management system operating with a bidding strategy for day-ahead bidirectional electricity trading using a MILP solver and case studies indicating possible savings between of 22% and 51% compared with other optimization methods. The impact of prosumers' energy resources on the distribution system can cause network congestion. A virtual battery model was introduced in [89], and using iterative distribution locational marginal prices (iDLMPs) to optimally schedule prosumer resources, it was possible to prevent network congestion.

Cost reductions have made PV the technology of choice for most prosumers. Thus, there have been many techno-economic studies on different aspects of this topic. Through case studies from the UK and India, ref. [90] found cost reduction were necessary in countries with lower solar resources, highlighting the importance of location and load-matching. Research based on 302 UK households from a smart grid project found that an average UK household can achieve a 24% reduction in annual electricity demand from the grid [91]. PV plus batteries research found that self-consumption (SC) is profitable, but additional battery cost reduction is needed [92–94], and 100% SC with batteries is not realistic without oversizing PV and/or batteries [95]. A methodology for jointly optimizing the sizing and power management of PV household prosumers was developed in [96], finding that a battery is cost-effective for enhancing PV self-consumption in southern Spain. The optimal sizing of PV and batteries for households was studied in [97], and in [98] PV was managed to provide frequency containment reserves. The scheduling of a microgrid with PV, battery storage, and diesel generation was addressed with MILP in [99], and economic savings of around 30% were found.

Despite thermal heat being included in the original definition of microgrids, this topic has attracted limited attention but with several case studies of interest. The transformation of an existing residential cluster in Sweden into prosumers [100] considered how electric vehicles, thermal storage, and energy sharing affect PV sizing and placement. A research campus of 17 buildings in Germany with heating using a network for heating and cooling [101] concluded that bidirectional low temperature networks are an efficient technology to recover waste heat in urban districts. Ref. [102] presented the cost-optimal mix of different technologies and the threshold for maximum battery capacity per installed PV, along with self-consumption ratios, demand cover ratios, and heat cover ratios for 145 regions worldwide.

Excess heat provided by prosumers in district heating networks raises issues about their use and remuneration, as well as technical issues. A case study was presented in [103] with a potential of around 50–120% of the annual demand, even when excess heat is produced during the summer months, and there is greater potential for prosumer contributions in areas with buildings of different uses. The issue of current heating price models not supporting reverse heat supply from prosumers to district heating systems resulting in no economic benefit for prosumers was solved in [104] through tank thermal energy storage. The optimization problem was tested on a district heating campus in Norway with annual savings of up to 9%. It is found that simulating the effect of prosumers using real data on the low temperature of the water contributions of prosumers can cause disturbances that may provoke increased fatigue in the pipes [105]. Bidirectional heat flow due to the reuse of waste heat from cooling requires new hydraulic concepts, such as the reservoir network presented in [106], which integrates heat sources and sinks at various temperatures operated at a variable mass flow rate.

3.4.3. Peer to Peer

Peer-to-peer refers to a peer-to-peer network. It is important to note that these networks operate without clients or servers but instead through a series of nodes that behave as equals to each other. One of the essential concepts to be considered is that simultaneous work as clients and servers concerning the other nodes of the network since peer-to-peer networks allow for the direct exchange of information in any format and between different connected units. Proof of the above is the importance of blockchain systems in offering novel solutions for small and large consumers to monetize their assets in the renewable energy market, according to the review work conducted by [21], although this importance was also explored by [107], considering the ongoing disruptive aspects of blockchain technology based on knowledge sharing, joint learning, and multi-stakeholder collaboration; all of the above raise the possibility of developing a blockchain-assisted adaptive model that can improve the scalability and decentralization of the prosumer pooling mechanism in the context of peer-to-peer energy trading [108]. Concern for the prosumer within the peer-to-peer paradigm continues through work on energy efficiency [109]; furthermore, it can be seen how studies are beginning to introduce depth with the classification of the types of peer-to-peer market networks as pure or hybrid, benefiting from the sense of platforms that allow them to work with blockchain techniques [110]. It is empirically remarkable that energy efficiency is achieved by decreasing the so-called import costs of the whole community, and the total energy imports are reduced [111]. Decentralized P2P energy trading between retailers and prosumers can also be beneficial, not only for prosumers but also for retailers, as shown in [112]. In protecting the environment from pollution, the prosumer is an important emerging concept from a research perspective [22]. In addition to the environment, the incentives of individual users are commercial, and these incentives can be developed in a cooperative game-theoretic framework to streamline stable trading algorithms, also resulting in social welfare [113].

Specific technologies, such as blockchain, enable the emergence of energy markets and trading systems typical of clean energy models, allowing for greater citizen involvement to the detriment of already consolidated companies [12], known as transactive energy and defined as "techniques for managing the generation, consumption or flow of electric power within an electric power system through the use of economic or market based constructs while considering grid reliability constraints" [114]. Authors such as [80], experimented with transactive energy, achieving promising results in these transactive systems in small communities. Additionally, within the research, real-time and even day-ahead work has been performed to propose inter-community energy sharing strategies and intra-community energy sharing strategies [115].

The review performed in the field of peer-to-peer is linked to the market as a natural form of evolution, and it is for this reason that the importance of energy trading and the energy market itself are emphasized from a scientific point of view. The first approach confirms the concern for social progress and for the resolution of social, institutional, and economic problems based on the strategies that can be developed by coordinating virtual power plants [116], enhanced by social cooperation between prosumers within the energy grid to establish their sustainable participation in the energy market [20] and to address the potential impacts of this peer-to-peer energy trading, linking it to local energy trading mechanisms in terms of the control, operation, and planning of peer-to-peer networks [117]. Work focusing on distributed electricity trading aims at facilitating the exchange of electricity between prosumers [118], as P2P trading (Figure 12) plays a vital role in the proliferation of renewable energy and system flexibility for low-carbon energy transition. P2P transactions allow not only the efficient exchange of energy between prosumers but also more advanced possibilities in terms of DSM, DR, and flexibility through the use of storage and/or pooling of prosumers, which may benefit all stakeholders. In addition, blockchain technology is an enabler, creating a trustworthy decentralized trading and billing platform [19]. The evolution of ICT [119] allows for the use of advanced P2P energy trading schemes that can even help to reduce the total electricity demand of customers/prosumers at peak hours using dynamic prices in double auction mechanisms (Figure 13), with the centralized power system acting as the leader and the prosumers as followers [120]. In research conducted in specific geographical areas, such as UK and South Korea, the results showed that P2P sharing has great potential in economic and technical aspects [121,122].

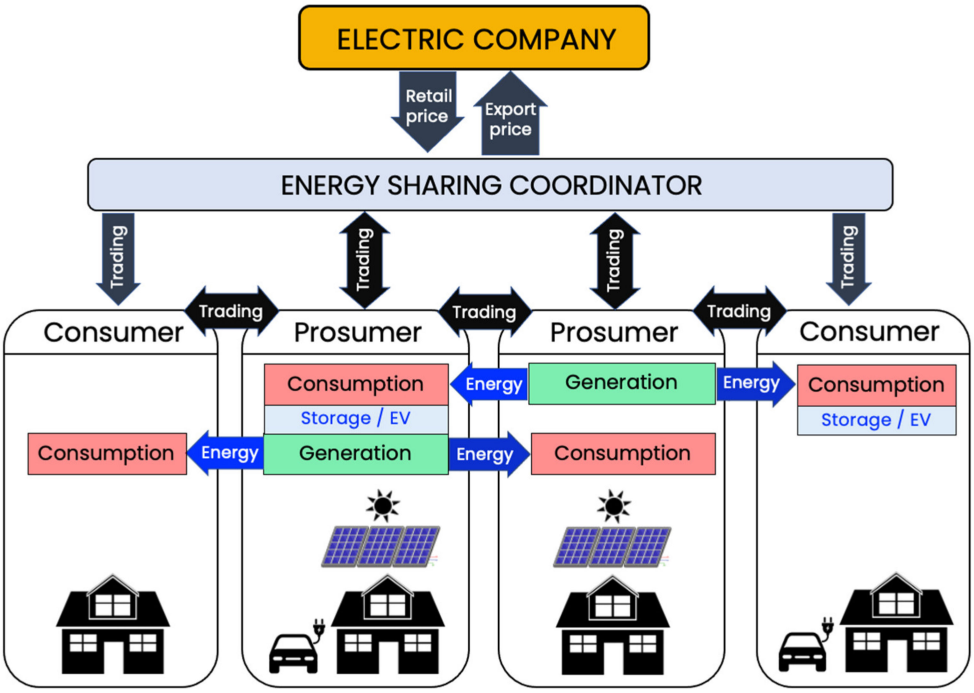

Figure 12. P2P trading architecture. Adapted from [19,121].

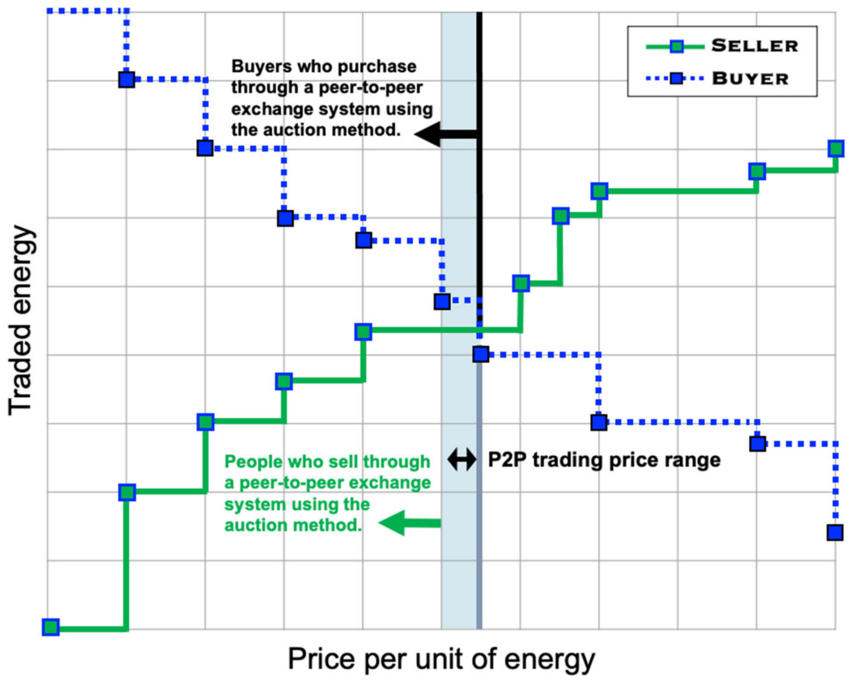

Figure 13. P2P trading model, following the economic equilibrium principles. Adapted from [120].

It is common knowledge that trade occurs in a market, which is also advanced and accounted for through the present work and the methodology that has been used. The market is positioned as the place where aggregators and prosumers agree on an outcome that is stable based on a set of individually beneficial transactions without rewarding any deviation from them [123]. In the market, two necessary conceptualizations must exist, such as optimal functioning in the creation of prices by the prosumers themselves in the electricity market [124] and profit maximization based on the idea of the energy hub, which in fact allows for participation in the daily market by submitting bids that maximize profits [125]. Studies have delved into new concepts that revolve around specific energy classes and that allowed for treating energy as a heterogeneous commodity that prosumers perceive as valuable [126], since doing so optimizes processes such as auctions or those based on bilateral contracts once their efficiency has been appropriately analysed [18]. The combination of algorithms is also mandatory when performing simulations to investigate energy trading between prosumers and to work on, for example, penalizing the contribution to the system peak demand of each prosumer; this goal is achieved with multi-agent coordination and the proposal of a new deep learning method [127].

From the present paper and in-depth study in previous works, it is clear that the real motivation of prosumers in the win–win game needs to be explored in greater depth, which is why all of the above, apart from the technical development of peer-to-peer, are approached in the current scientific literature. These topics range from the observation of game theory with the current importance of the direct application of the behavioural sciences in the study of the activation of prosumers to act as such from their collaboration with each other and with others in the energy market [16], including the psychological framework [128], and with results showing convergence between financial and technical benefits to the community, emerging as an alternative to high-cost energy storage systems [129], to the implication and future importance of game theory in future developments related to a consumer-centric model and the demonstrated benefit to the peer-to-peer network primarily [20]. Finally, the continued importance of simulations with new and promising ideas regarding P2P community design should not be overlooked, allowing policymakers to predict the risks and benefits associated with these projects, the results of which can enable the development of policy instruments to increase P2P trade [130].

3.4.4. Prosumer

As described in [131], the electricity grid has undergone four stages since the second industrial revolution, i.e., decentralized, centralized, distributed, and smart and connected energy systems. Currently, in most countries, energy systems are transitioning from a centralized to a distributed model, and in the long-term, they are foreseen as smart and connected models using advanced emerging information technologies, called the energy Internet (EI) [132]. This change of model was envisioned in [133], proving that any electric power system, irrespective of size, can be modelled as a prosumer, defined as an economically motivated entity that consumes, produces, and stores power; operates a power grid; and optimizes the economic decisions regarding its energy utilization. The authors proposed a prosumer-based, service-oriented architecture that was flexible and scalable, allowing for a 'flat' business paradigm capable of enabling several innovative grid features, such as interaction with potentially all the prosumers, consumer choice of generation of storage, support for distributed control, autonomous restoration, ancillary services provision, and remote coordination. Ref. [131] pointed out the business research agendas of the energy Internet from five aspects, namely strategic, data, behavioural, security, and regulatory issues, as well as highlighting that the specific roadmap for the EI is unclear, but its business values and social benefits are becoming increasingly apparent. To achieve a smooth transition to the EI, the concept of an energy body (EB) is proposed, analogous to the microgrid in smart grids because EB has inherent P2P functional relationships among different energy resources, allowing for cooperative energy management [134] with locally optimal operation and exchanged energy with neighbours.

As small-scale DERs are being massively deployed, their intermittency can cause severe supply–demand imbalances that can compromise the power system and make it difficult to participate in the electricity markets because they usually provide for penalties in cases of imbalances between the forecasted and the actual energy interchanged. It was shown in [135] that grouping consumers and prosumers diminishes forecasting errors. In addition, higher PV penetration led to erroneous trading and uncapitalized generation, which could reach 10% in case of 50% PV. Therefore, coordinated scheduling for prosumers is a topic that is gaining attention and has been investigated using VPP. Flexible DERs are integrated into a coupled transactive natural gas and power system by participating in the day-ahead and intraday balancing markets [136]. The day-ahead management of aggregate prosumers was addressed through a two-level Stackelberg game [137], and in [138], the net load forecast was calculated by deep learning, forming different prosumer clusters that decrease the model complexity and achieve greater accuracy.

The relevance of the aggregator concept has been made clear in key issues, such as prosumers' energy management and sharing (PEMS), reviewed in [10], with greater potential for cost savings, energy conservation, and peak load balancing. It is also recommended to allocate funds to incentivize both the prosumers and the utilities. This participation in the electricity markets was further explored in [139], noting that current market designs lack incentives and opportunities for consumers to become prosumers and actively participate in the market. Advanced frameworks have been proposed to integrate prosumer communities into the day-ahead and intraday markets (Figure 14), potentially decreasing electricity costs by half. In cases of inability to balance supply and demand, the community can procure electricity at reserve prices in the intraday market. Nevertheless, this local market is only applicable in a smart grid environment and depends on the total exchange of information between all technological devices, disregarding any game theoretical or particular profit maximization strategies.

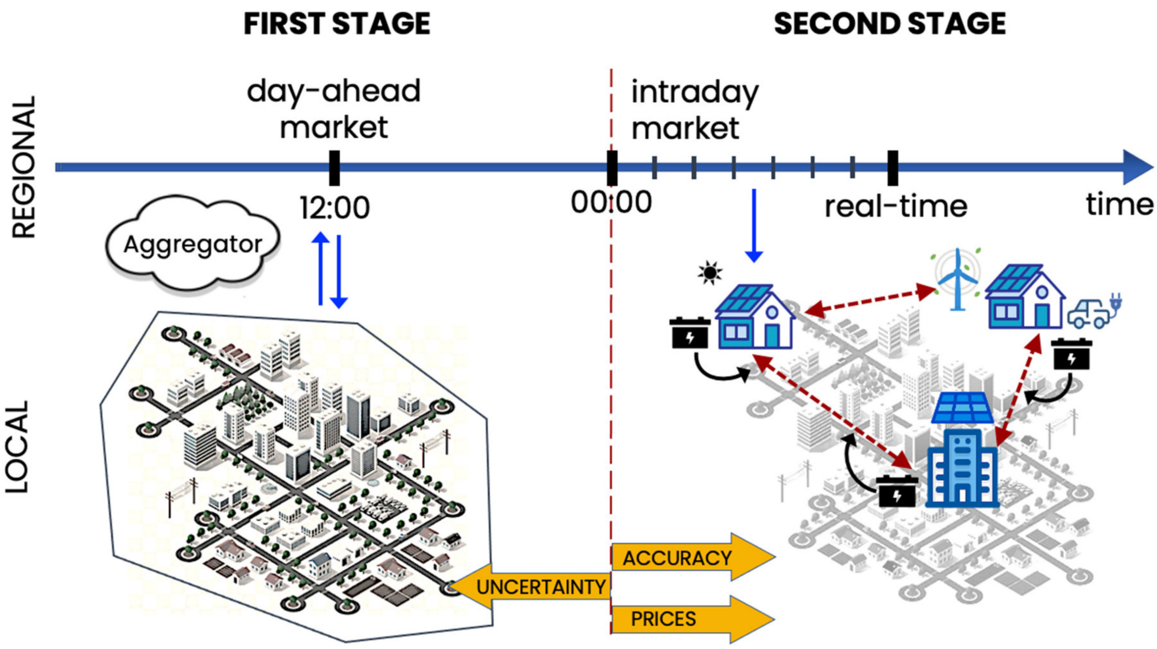

Figure 14. Two-stage market structure for participation in day-ahead and intraday markets. Supply–demand operations for each house are balanced in a single day-ahead forecast, and the deviations in renewable production are later adjusted with battery utilization and P2P trade. Adapted from [139].

The concept of the virtual microgrid (VMG) was proposed in [140] for grouping residential and corporate buildings using an aggregator that acquires not only energy from prosumers but also flexibility, which is offered to the market. Six clustering algorithms were compared with significant cost reductions over individual prosumers, and it was found that, for each algorithm, there was a threshold in the cluster size beyond which no significant gains were realized.

Energy hubs involving heating, cooling, PV, and storage (Figure 15) are widely used to meet regional energy demands. A dispatch model for regional multi energy prosumers (RMEPs) served by interconnected energy hubs in a ring heating/cooling network and a radial power grid to implement mutually complementary reserves were investigated in [141]. Partially visible multiagent systems (PVMAS) have been verified in different electrical and synthetic grids, demonstrating their effectiveness and efficiency compared to different state-of-the-art community detection approaches [142]. The management through a cooperative trading mode for the energy hub and multiple PV prosumers forming a community-level energy system were investigated in [143], showing that the cooperative model could promote local consumption of PV, increase the profit of the hub manager, and reduce the costs to prosumers. The cooperative approach not only rewards all participating prosumers financially, but it also benefits the electricity distribution grid by reducing the reverse flow of energy, as also seen in [144].

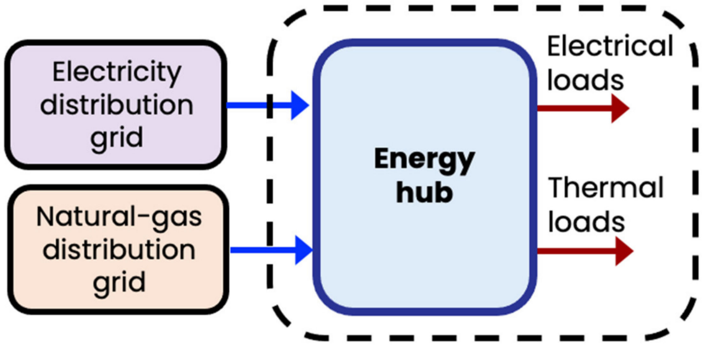

Figure 15. Example of a schematic of an energy hub. Adapted from [125].

A review of prosumers as active market participants was presented in [34], highlighting the shift from the incentive of lowering electricity bills to the opportunity to respond to dynamic prices and provide flexibility to the grid. The relationships among prosumers, communities, and SG were reviewed in [145], resulting in the taxonomy shown in Figure 16 and emphasizing that the socio-economic-technological aspects can act either as a barrier or as an enabler. These aspects include objectives, motivations to become a prosumer, and the interests to join prosumer communities, which can be goal oriented. The market design and prosumer management are key to transforming prosumers into active prosumers who can provide additional services to the grid, using the P2P and/or VPP model. Prosumer management is based on organization, motivation, and control, and the relationships between utilities and prosumers are key to the success of their collaboration. Failure to do so may result in prosumers' refusal to sell surplus energy to the grid. The integration of prosumer P2P decisions into energy communities has been found to drive higher community autarky when prosumers are enabled to trade energy, leading to financial benefits for prosumers and traditional users and reduced stress for the grid [146]. Community prosumers have been studied in their associated problems and key challenges associated with their development, presenting innovative proposals to address different challenges as demonstrated by [147] in a first study, supported by another study [148] in which they proposed a methodology to assess and classify prosumers to create a base of influential members. The fundamental role of the prosumer should be considered concerning two aspects also studied. On the one hand, work on digital platforms is an essential issue within interdisciplinarity to drive change in the energy system, identifying new domains and activities, the formation of new collectives, and creating digital environments that enable new types of engagement with energy assets and other network users [149]; on the other hand, the relevant social role of the prosumer within the strategy of public entities in their communication through social networks and mobile applications to improve their engagement is able to create a social pathway for a smart grid [150].

The aspect by which the prosumer also acquires importance is precisely its link with the electricity market, beyond participation in the communities. As indicated in the introduction, the market as an entity loses dimensions in the face of the irruption of the prosumer. Again, in this sense, the analysis of the term "prosumer" goes beyond the conceptualization that lays the foundations for the differentiation between groups of prosumers, emphasizing the principal risks and warnings regarding the figure itself with three possible prosumer structures, as shown in Figure 17 [151]. The incorporation of the market brings to light comparative studies of P2P electricity trading cases that are being promoted and thus have application in reviewing the development potential of future challenges [17]. In its relation to the market, the literature contains extensive compilations of proposals that reported a lack of sufficient information on how the prosumer obtains a significant advantage, leaving apparent a critical capacity in bidirectional management as part of the consumer's role within the smart grid [152]. However, it is perceived as positive that the main results suggest that the aforementioned technological advances are opening up several new value propositions, in turn deepening the exploitation of new business models [153]. Specific cases, such as direct application in the robust optimization of VPPs, consider the influence of markets that guarantee optimal transactions of energy supplies and reserve capacity, deepening the desired market equilibrium [154]. The importance of energy services and equivalent business models has not been overlooked. In addition to the traditional energy service typology, green energy services, cooperative energy services, prosumer energy services, and the role of the prosumer as an enabler are seen as necessary within the electricity market. Specifically, ref. [155] found all these typologies to be financially vulnerable due to increasing levels of variable renewable energy in the energy sector.

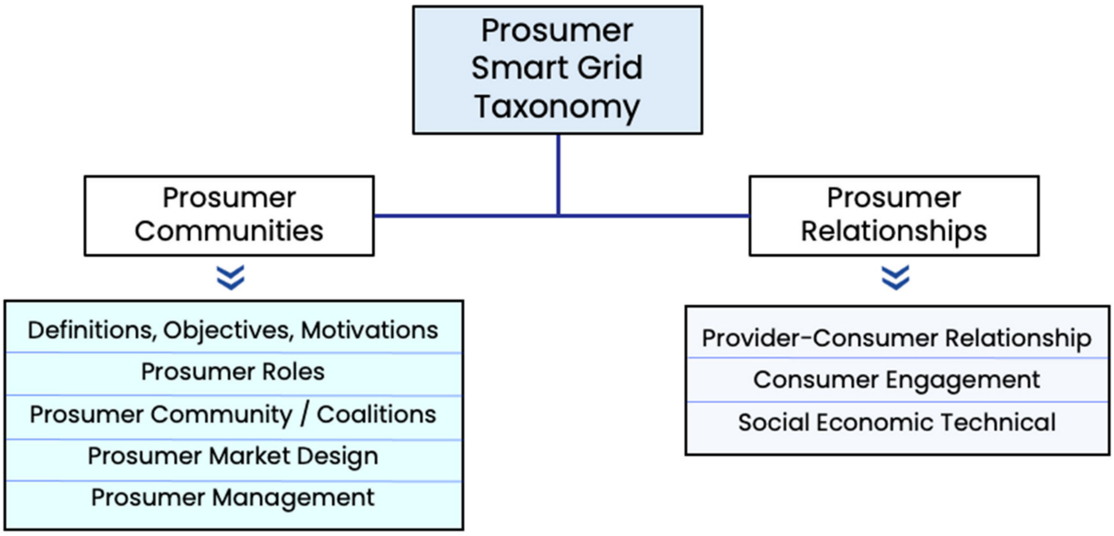

Figure 16. Prosumer smart grid taxonomy. Adapted from [146].

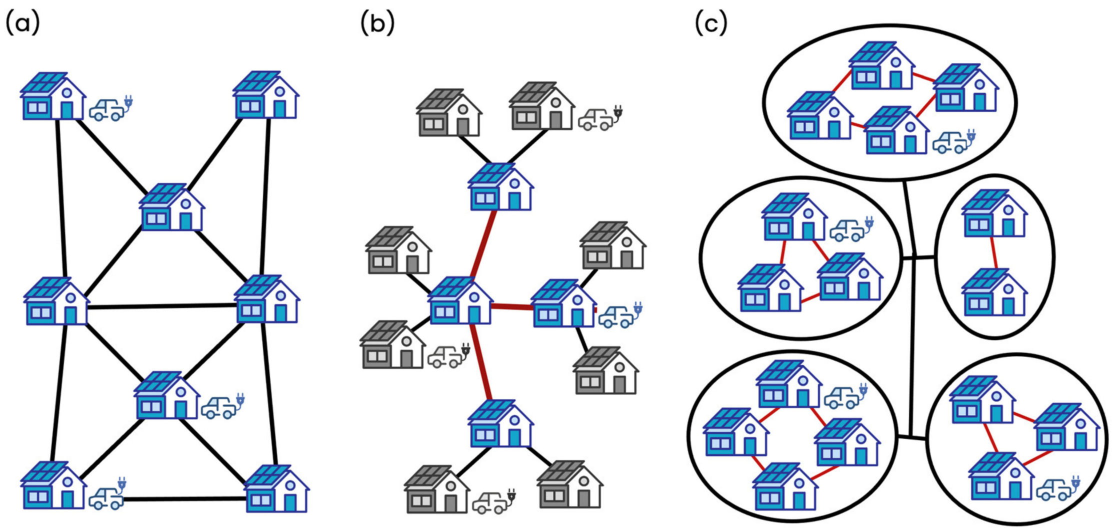

Figure 17. Possible structures of prosumer markets. (**a**) P2P model, with prosumers interconnected directly; (**b**) structured model with prosumers connected through microgrids; (**c**) organized model, in which a group of prosumers pools resources to form a VPP. Adapted from [151].

The social and political implications of prosumers also constituted a key topic investigated at different levels, linked to the emerging concept of 'energy democracy', which in turn is related to similar concepts: environmental, climate, and energy justice and environmental democracy [28,156]. In this context, the prosumer is presented as an ideal-typical citizen who has been enabled by means of technological innovation and the energy transition towards smaller scale, distributed, and renewable energy sources and who is conscious of the way that an energy system functions, its impacts, and his or her own role in it. Energy self-consumers and renewable energy communities were presented as new actors of the electric sector in [28], in which efforts to do so were identified, while some questions remained unanswered. One of the main issues is how to integrate the need to preserve self-consumption while providing ancillary services. Switching from one business model to another can be achieved through local energy management and smart contracts, allowing for virtual self-consumption and different remuneration schemes.

The concept of community in energy systems was reviewed in [29] with findings that suggest a weakening of scholarly attention to transformative notions of community in favour of instrumental ones. The prosumer movement was investigated as a social movement in [157], and it was found that active energy citizens are co-creating a new socially valuable energy model with the potential to radically change the energy market, which is more ethical and centred on people's needs while ensuring economic and environmental sustainability. The normative dimensions of prosumer business models, modes of governance, and understandings of value were critically evaluated in [158], and it was found that different forms of governance (market, municipal, and community) could lead to very different outcomes for the nature and directions of energy transitions. Electricity as a common good was studied in [39], and it was proposed that electricity must be redefined from a commercial private commodity delivered in a public grid towards a co-produced common good. The application of P2P is considered essential for this purpose, so policy must avoid interfering and should remove legal obstructions and transaction costs for P2P and self-production. Hopes are high for P2P to empower users, but as addressed in [159], knowledge is still lacking about what motivates users to participate in this trading model and their roles in its development and diffusion. This work found that the users who joined a P2P trial were affluent households sensitive to the environment and social equality. An investigation of the motivations of and barriers to homeowners installing PV in Sweden [160] was conducted by two series of interviews with homeowners in 2008–2009 and 2014–2016. This study found that, while in the first wave, early adopters were motivated by environmental reasons, the second wave was dominated by economic motivations. With regard to barriers, in the first wave were cost, lack of regulation, technology, and installation, and in the second wave were cost, administration, information, and installation processes. These results are perfectly comparable to other countries and are of interest to all stakeholders. This knowledge gap was further explored in [161] at a collective level in nine EU countries, revealing key differences, challenges, and needs across collective prosumers and national contexts, raising several red flags, including unclear political and regulatory settings, volunteer-run structures, and lack of tailor-made policies. This issue is investigated was [162], stating that, while microgeneration is on the verge of changing from a niche into a mass market, P2P remains a unknown option for many potential prosumers and that attention should be paid to users willing to install microgeneration, rather than to current prosumers.

The potential geopolitical implications of the geographic and technical characteristics of renewable energy systems were explored in [163]. Using a thought experiment that imagined a purely renewable energy system but kept all else equal, the prosumer concept was extended to the continental and national levels, the latter leading to the interesting concept of 'prosumer country', which was further developed in [164]. This paper drew on the technical and geographical differences between renewables and fossil fuels to develop the implications for states, identifying six clusters of policy implications to be manifested in different time frames. Overall, the impression is of a positive disruption but one that poses new challenges and is capable of redrawing international energy relations.

4. Discussion

When it comes to advanced research, the scope of a complete perspective offers great answers to all questions from a necessary, broad perspective. In addition, looking at the bigger picture allows for a more efficient approach to such disruptive and current concepts as the prosumer.

In the progress described above, it is essential not to omit any relevant articles for any of the subcategories close to the prosumer, which, by their choice, can omit articles that are very recent. For this research, VOSviewer was the appropriate software due to its scalability in terms of the necessary temporal depth and data processing in recent and not-so-recent research aimed at smart grids, microgrids, prosumers in their essence, and peer-to-peer, which have been gaining attention recently. The evolution, previously outlined in Figures 7 and 8, clearly shows how fundamental research developed in the early stages, giving way to prosumer-oriented research.

The evolution of the prosumer concept not only stands out in its temporal advances but also in what can be defined as its transversal advance. At this point, its true social impact can be contemplated individually or as a movement. It is essential to understand where it may be heading and its potential scope as a critical figure in the energy transition, with the potential to transform the energy sector. At this point, the prosumer's motivations should be remembered since these motivations are those driving the movement, from those that were initially configured as environmental [160] or those of image or corporate social responsibility for companies. When examining companies, research goes beyond what is described as social to examine more broadly the economic vision and to understand all the reasons for accepting the technologies that accompany the prosumer outlined in Figure 18 [165]. In particular, other problems can be addressed, such as the low profitability of small installations [57], which can exclude the most disadvantaged sectors of society, thus failing to meet energy justice goals [166] and with energy communities re-emerging as a possible solution. The socio-economic implications do not escape the high penetration of prosumers in many countries, giving rise to concerns about the financing of grid costs [58], or the discussion between the most popular models of surplus remuneration (net-metering and net-billing) with possible cross-subsidies and efficiency problems, in which it is observed that the real transformative power lies in the possibility of P2P exchanges between prosumers and consumers. These facts underscore the need for evolution of the electricity market, outlining three possible models: P2P, prosumer-to-grid, and organized prosumer groups [151].

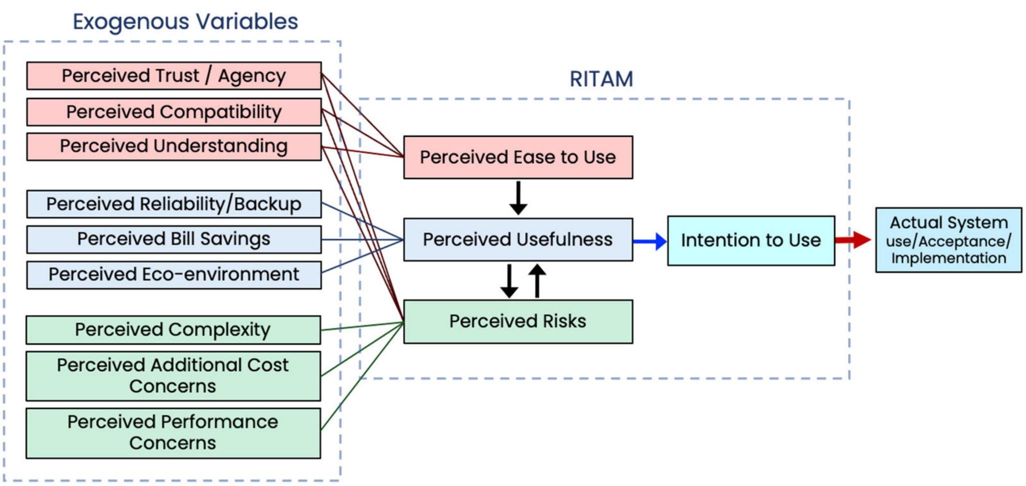

Figure 18. Risk integrated technology acceptance model applied to smart grids. Adapted from [165,167].

While explaining the impact of energy communities on energy justice, it should be borne in mind that the development and empowerment of the prosumer involve grouping in this way, at a local level through micro-grids or VPPs or through communities of shared objectives linked to social networks. In these aspects, there has been intense research activity on P2P transactions and smart contracts, with a predominance of the approach through collaborative and non-collaborative games due to the impossibility of having complete information about the movement of all prosumers.

The authors have observed the temporal evolution in the technological sense, with the importance of large-scale adoption of DERs posing a challenge to grid integration. Currently, photovoltaics act as a facilitator of this deployment, which will be joined by EV in the near future. However, DERs pose numerous problems due to the intermittency of renewable sources, such as PV, making it necessary to develop resource and demand forecasts. The increase in these DERs poses risks of grid saturation and production curtailment as high as 19% for SC prosumers in Spain in 2022 [168]. Technically, a smart grid/microgrid with prosumers can include PV, battery storage, and/or electric vehicles, so the contribution of prosumers is not only energy, but they can also provide the grid with additional services, such as DR, realized through load shifting and the use of storage/electric vehicles to offer even intra-day flexibility services, in addition to the better-known DSM, which allows for efficiency gains. The advancement of prosumers can bring numerous advantages to the electricity system, avoiding costly investments. Still, it depends on the proper development of their capabilities from technical and regulatory points of view to prevent market failure.

Beyond the tremendous success of the prosumer in a model of basic interaction with the electricity grid, there have been limited experiences in pilot tests and P2P services, such as Vandebron, Piclo, and Yeloha, and vendors, such as Sonnen, which allows its batteries to save solar surpluses and sell them to other consumers [17]. The interaction of prosumers with the market needs to be tested in a real environment, such as regulatory sandboxes [19,107]. Sandboxes can grant temporary exceptions to specific rules and confirm that an activity is allowed and to cases in which a rule blocks innovation [169]. Energy communities in the form of cooperatives are gaining momentum in the EU, with SOM Energy [170] being one of the best-known examples and a member of REScoop, which brings together 1900 cooperatives and 1,250,000 citizens active in the energy transition [171]. A new proposal from electricity companies in several countries considers virtual batteries, with surplus photovoltaic electricity accounted for in a similar fashion to net-metering. That is, the surplus electricity injected into the grid is registered, and it can be returned to the prosumer when needed or discounted at the end of the billing period [172]. This service can be provided at a monthly fee related to the stored electricity. Different mechanisms and offers are being implemented, adapted to national regulations.

Currently, there is significant growth in the number of prosumers within the traditional regulatory framework, severely limiting prosumers' possibilities as active users, which could lead to disenchantment when expectations are not met, slowing growth and even causing many prosumers to avoid injecting energy into the grid or even abandon it altogether [173] in a process of grid defection that could lead to the so-called utility death spiral. In addition, there is a lack of clear rules on energy exchange between buildings and the external grid [14].

5. Conclusions

Many advances have been revealed by their emergence in different fields. The prosumer as a concept was initiated to some extent in the 1980s and gained prominence with the rise of the Internet in fields such as co-creation and user-generated content. The importance of the prosumer in energy is more recent, and it has been studied in this work through a systematic review incorporating VOSviewer software into the PRISMA methodology. As a result, the reviewed works allows for establishing a classification of the research into four clusters: smart grids, microgrids, peer-to-peer, and the concept of the prosumer itself. This work has logical limitations, first in the bibliographic search, given that the term prosumer must be expressly cited and that other terminology, such as the self-consumer, can be omitted. Furthermore, the final sample was based on the number of citations as an objective criterion, attempting to weight the importance of the most recent papers because older papers tend to accumulate more citations.

This review indicates that, from a technical point of view, a great deal of work has been performed laying the foundations for the development of smart grids and microgrids, with numerous pilot tests. Information and communications technologies act as enablers of the smart grid and the proposed energy Internet. New possibilities have opened up for prosumers to participate in the electricity grid, beyond the sale of electricity or demand-side management, such as demand response and even flexibility. For these mechanisms to be operational, it is necessary to provide the prosumer with smart energy home management systems capable of interacting with the grid, not only by managing the flow of energy but also through market operations.

The research on microgrids focuses on the integration of DERs, storage, and even heat with different topologies and management strategies. New concepts are being settled, such as microgrid operators acting as central entities and the leader and the rest of the participants as followers, adjusting their energy behaviours to the TOU prices. Local energy markets are investigated, with P2P emerging as a promising solution that, in effect, is giving rise to a new branch of prosumer-related research. PV is the most popular renewable energy among prosumers, with many techno-economic studies highlighting the necessity of cost reductions for batteries accompanying it.

However, the move to commercial developments and large-scale implementation, especially in the domestic environment, is not as apparent. More effort should be placed on the commercial implementation of domestic system management techniques for the integration of renewables, batteries, heat pumps, and home appliance operation. Open-source environments could be an enabler of the integration of third-party equipment and tailor-made solutions adapted to each country's regulations, allowing for a more active role for the prosumer.

P2P research is more recent, and it is vibrant research, especially using blockchain systems in new energy markets, which allow for greater citizen involvement, with the concept of transactive energy as a driver. The evolution of these markets has given rise to the figure of aggregators as entities that coordinate them, presenting a set of prosumers and consumers as a single entity facing the global electricity market and with a local market in which their transactions are adjusted.

The following are needed: more viable and innovative business models for collective prosumers' incentive schemes, network tariffs, innovative infrastructure, taxes and levies, codes, and supplier licensing. All the above would incorporate experience and rigour using initiatives such as regulatory sandboxes and thus explore, for example, the fit of P2P energy exchanges in the electricity market. Regulation will allow for the robust assertion of concepts such as aggregation and community energy, enabling the incorporation of members who share and interconnect by collaborating in energy and resources.

Prosumer-related research brings together research in the previous areas with an integrating vision. Aggregators are being developed as energy communities, virtual microgrids, or energy hubs. Of great relevance are the social and political aspects of the prosumer, which in some ways can even be considered a social movement. The new energy model can be more socially valuable, with proposals of electricity being redefined towards a co-produced common good.

Society is facing a paradigm shift in the way that electricity is generated and distributed and the actors involved. The shift is from the current unidirectional paradigm, in which companies play an active role and consumers play a passive role, to a multidirectional paradigm in which prosumers play an active role, not only by contributing their excess energy to the grid but also by transacting directly with other prosumers and/or consumers and even participating in demand response and flexibility programmes. How this shift occurs will be crucial to enable true prosumer empowerment, with a fairer energy transition. The lines of research on the prosumer that are currently open must consider social evolution, motivations, consumption habits, emerging trends, decision-making processes, and the interaction with the energy market by all social strata without resulting in specific marginalities.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151310552/s1. File S1. PRISMA 2020 checklist prosumer. File S2. PRISMA 2020 abstract checklist prosumer [174].

Author Contributions: J.P.-D.: Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Writing—original draft, Project administration, Writing—review and editing; E.S.: Conceptualization, Formal analysis, Investigation, Methodology, Data curation, Writing—original draft, Supervision; Á.O.: Investigation, Writing—review and editing, artwork. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Smart Grids.

References	# Citations	Application	Techniques	Results	Data	Revised
Cardenas et al., 2014 [9].	60	Smart grid distribution	Literature survey	Strategies are mostly driven by the USA. Consumer/prosumer participation is going to play a key role and requires developing a new business model, including self-generation and selling back surplus energy.		ESH
Zafar et al., 2018 [10].	246	Investigation and review of the prosumer-based energy management and sharing enabled by smart grids.	Theoretical conceptualization through a review of the literature and state of the art.	There is an enormous potential for cost savings, energy conservation, and peak load balancing.		ESH
Uribe-Pérez et al., 2016 [13].	109	Description, technologies, and standards in smart metering.	Review of the main trends in the uses and deployments of smart metering worldwide.	Overview of the main smart metering applications and their development.	Types, characteristics, and deployment of smart metering,	ESH
Kubli et al., 2018 [54].	99	To investigate prosumers' willingness to co-create flexibility	Choice experiments with 2 changes. Choice-based conjoint analysis.	It is confirmed that there is actually a positive willingness to co-create flexibility.	902 actual and potential flexible prosumers across three domains of energy use	JPD, ESH
Tuballa and Abundo, 2016 [63].	453	Smart grid	Review	Concrete energy policies facilitate smart grid initiatives across the nations in an unbordered community of similar aspirations and shared lessons	248 sources from Science Direct database.	ESH
Lampropoulos et al., 2010 [66].	81	Methodology for modelling the behaviour of electricity prosumers.	A framework for modelling the behaviour of small-size electricity prosumers.	To assess the grid impact of electric vehicles charging in Dutch residential areas.		AO
Brusco et al., 2014 [67].	82	Demand response	Several prosumers are aggregated in a coalition, the energy district, and are coordinated through a central control entity, the coalition coordinator.	The coalition coordinator maximizes the coalition utility and reduces the reverse energy flows at the point of delivery.	Prosumers aggregated in an energy district.	ESH
Pop et al., 2018 [68].	366	Decentralized management of demand response programmes in smart energy grids.	Blockchain through ledger and smart contracts.	The grid can make timely adjustments to energy demand in near real time by enacting the expected levels of energy flexibility and validating all DR agreements.	Energy consumption and production profiles randomly selected from UK building datasets.	JPD, ESH, AO
Faraji et al., 2020 [69].	33	Energy management systems for prosumer microgrids.	Hybrid machine learning method to predict the load and weather data.	The performance of the forecasting process is improved over conventional processes.	Meteorological data based on one-year data from Kerman province, Iran.	ESH
Karnouskos et al., 2011 [70].	66	Demand-side management via prosumer interactions in a smart city energy marketplace	Analysis of indicative interactions between market stakeholders.	NOBEL approach to support energy trading and management in the neighbourhood.		AO

Table A1. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Pasetti et al., 2018 [71].	93	Virtual power plant	Conceptual study. Controller based on MILP optimization.	A VPP architecture is proposed that is limited to the physical domain of individual users.		AO
Salpakari and Lund, 2016 [72].	138	Cost-optimal and rule-based control for buildings with PV and flexible loads.	Annual optimal control on sequential 24-h horizons is studied, along with rule-based control.	The most effective flexibility measure turned out to be thermal storage with a heat pump and a battery.	Case study with empirical data from a real low-energy house in Southern Finland. 10-min meteorological data.	ESH
Olivella-Rosell et al., 2018 [73].	125	Local flexibility markets.	Simulation of case study. The aggregator acts as a local market operator and supervises flexibility transactions of the local energy community.	Local market framework could postpone grid upgrades, reduce energy costs, and increase distribution grids' hosting capacity.		AO
Ottesen et al., 2016 [74].	114	Minimizing the total cost by trading in a spot electricity market, considering the costs of grid tariffs, the use of certain fuels, and any penalties for imbalance.	Scenario trees for the treatment of uncertain parameters	It is found that securities are sensitive to the imbalance penalty	Fredrikstad Energi Nett and Norske Skog Saugbrugs datasets.	AO
Jing et al., 2020 [75].	75	Enabling P2P energy trading (heat and power) among prosumers (residential and commercial) through fair price strategy.	Nash-type game theory, McCormick relaxation, and piecewise linearization.	4.9% cost savings over stand-alone prosumers.	Case study in Shangai.	AO
Bliek et al., 2010 [76].	70	A generic design has been developed that allows for seamless coordination of hybrid heat pumps, μ-CHPs, electric cars, and smart appliances, such as freezers, washing machines, etc., in a single ICT solution.	Tests have been conducted to validate whether the comfort level of the end-users can be maintained.	Technologies have been applied to demonstrate the full concept of a smart grid.	Case study.	AO
Leiva et al., 2016 [40].	62	Smart metering infrastructures (SMIs)	Review of policies about smart metering infrastructure implantation in Spain, Europe, and around the world.	SMI implementation has significant shortcomings that need to be addressed through the appropriate development of regulations	Detailed study of the implementation of SMI in Spain	ESH
Hou et al., 2019 [77].	56	Smart home energy management optimization method considering energy storage and electric vehicle	Mixed integer linear programming (MILP) with CPLEX solver.	The energy schedule of the smart home can be derived to guarantee both the lowest cost and the comfort of the users	Datasets of 24 h with time granularity of 15 min.	AO
Karnouskos et al., 2012 [78].	47	A platform providing several Internet-accessible services to allow stakeholders to interact in a market-based way.	IEM services have been implemented as Java REST services with encrypted channel, i.e., HTTPS and a security framework.	It is proposed to move away from traditional heavyweight monolithic applications toward a more dynamic mash-up application development	Information coming from highly distributed smart metering points.	AO
Mansoor et al., 2022 [79].	12	Examines the moderating role of ICT adoption norms to assess the differences in energy efficiency behaviours among consumers/prosumers.	Motivation theory.	significant and positive direct and indirect impacts of the green intrinsic and green thinking GIM and GT on energy efficiency behaviour.	Two independent surveys on consumers/prosumers	AO
Siano et al., 2019 [80].	27	Distributed ledger technology in local energy markets.	Decentralized approach based on transactive energy systems and peer-to-peer energy transaction	A crucial point is the selection of a proper consensus protocol.		ESH

Table A2. Microgrids.

References	# Citations	Application	Techniques	Results	Data	Revised
Zia et al., 2020 [12].	140	Transactive energy.	Review. Case study comparison.	Reviews existing architectures and ledger technologies. Presents and analyses the local energy market concept.		AO
Yamashita et al., 2020 [14].	58	Building microgrids.	Review.	Some insights for forthcoming building prosumers are outlined, identifying certain barriers.	Literature review.	AO
Gomes et al., 2022 [15].	8	Techniques used in home energy management systems.	Review.	Four broad categories: traditional techniques, model predictive control, heuristics and metaheuristics, and other techniques.	Systematic review for 2018-2021	ESH
Ma et al., 2016 [82].	197	Energy management of microgrids (MGs) consisting of combined heat and power (CHP) and photovoltaic (PV) prosumers	Stackelberg game; microgrid operator (MGO).	Dynamic pricing and energy management optimization model for the joint operation of CHP and prosumers.		AO
Velik et al., 2014 [83].	74	To find cost-optimal microgrid operation strategies for energy trading with the grid and neighbouring microgrids.	Multi-objective optimization method. Simulation with Visual C studio.	The simulated annealing approach presented striking advantages in terms of computing time in relation to the total state space search approach.	Simple renewable energy data generator was used with 1-h resolution.	ESH
Liu et al., 2017 [84].	231	Energy sharing management inside the microgrid with PV prosumers.	Stackelberg game; introduction of microgrid operator (MGO); dynamical prices model	An hour-ahead optimal pricing model based on Stackelberg game is proposed, where the MGO acts as the leader, and all participating prosumers are considered the followers	Collected data from realistic PV-roofed buildings.	ESH
Liu et al., 2018 [85].	171	Energy sharing among neighbouring PV prosumers.	Battery storage; hybrid approach using stochastic programming and Stackelberg game.	An energy sharing provider using storage can obtain profit during energy sharing, and the PV prosumers can achieve effective cost savings compared with trading with the utility.	Six neighbouring industrial prosumers in a demonstrated PV microgrid project, Foshan, Guangdong Province, China.	ESH
Lüth et al., 2018 [86].	205	Electricity storage in the presence of P2P in local electricity markets with smart grids	Battery storage; peer-to-peer trade; linear optimization.	Electricity bill reduction of up to 31%.	Datasets from London that cover the year 2012 in a time resolution of 30 min.	ESH
Tomin et al., 2022 [87].	12	Unified approach for building and optimally managing community microgrids with an internal markets.	Monte-Carlo tree search algorithm on the bilevel problem.	LCOE reductions from 20% to 40% for a real microgrid.	Real test case of the microgrid community for the settlements located in the Transbaikal National Park (Russia).	ESH
Nizami et al., 2020 [88].	38	Building an energy management system with optimization-based scheduling and a bidding strategy for residential prosumers.	Stochastic bi-level minimization problem solved by MILP using commercial software.	Savings of up to 51% and 22% compared with inflexible and deterministic methods, respectively.	Case studies for a residential prosumer in Sidney.	AO
Hu et al., 2021 [89].	26	Coordinated energy management of prosumers considering network congestion.	Iterative distribution locational marginal prices (iDLMPs) to optimally schedule prosumer resources.	The proposed method can alleviate congestion in the distribution grid, respecting economic interests and private information.	Case studies on a benchmark IEEE 33 bus.	ESH

Table A2. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Pillai et al., 2014 [90].	67	Comparative assessment of the near-term economic benefits of grid-connected residential PV systems.	Techno-economic methodology using prosumer electricity unit cost.	Need for system cost reductions for countries with lower solar resources. Importance of location-specific system planning and load-generation matching.	Case studies from the UK and India.	AO
McKenna et al., 2018 [91].	56	Estimating self-consumption and predicting the resulting electricity bill savings.	Simple regression analysis.	An average UK household can reduce by 24% the average annual electricity demand from the grid.	One-minute electricity monitoring data for 302 households in UK.	ESH
Camilo et al., 2017 [92].	92	Investigating, from an economic point-of-view, the profitability and feasibility of residential PV systems in several contexts.	Techno-economic study.	Self-consumption is already attractive, but storage is not profitable because battery investment is still too high	Typical 15-min annual profiles of consumption and micro generation, made accessible by the Energy Services National Regulatory Authority of Portugal.	ESH
Schopfer et al., 2018 [93].	99	Profitability of PV plus battery storage.	Techno-economic study using machine-learning.	High variability in the profitability and the optimal system configuration. Further storage price decrease is needed toward 250–500 €/kWh.	Smart-meter data from 4190 households in Ireland.	ESH
Barzegkar et al., 2020 [94].	31	Profitability of PV plus battery storage under a pure self-consumption scheme.	Levelized cost of use indicator is introduced.	Self-consumption rate should be considered for evaluating PV. In most cases PV plus storage is not profitable.	Typical generation and consumption profiles for six European countries.	AO
Quoilin et al., 2016 [95].	141	Evaluation of the self-consumption level that can be expected for a household installing a PV system with or without a battery.	Simulating self-consumption in various EU countries for various household profiles, with or without battery.	Achieving 100% self-consumption is not realistic for the studied countries without excessively oversizing the PV system and/or the battery	A database of profiles from monitoring data and a number of additional stochastic-generated profiles.	AO
Gómez-Gonzalez et al., 2020 [96].	52	Methodology for jointly optimizing the sizing and power management of PV household-prosumers	Techno-economic assessment to calculate the total costs and revenue using the teaching–learning-based optimization (TLBO) algorithm.	A battery is a cost-effective way of enhancing PV self-consumption by decreasing the levelized cost of electricity (LCOE).	Two 30-min PV power profiles measured in households at different locations in Jaen (southern Spain).	AO
Tostado-Véliz et al., 2021 [97].	38	Optimal sizing of PV plus storage system form home energy management, considering grid outages and demand response.	Clustering techniques for reducing data to the most characteristic profiles.	A case study has provided guidelines for its universal applicability, with two scenarios with and without grid failures.	Characteristic outages, along with demand, irradiance, and temperature profiles from real data.	AO
Hernández et al., 2020 [98].	35	Methodology to assess the techno-economic performance of PV home prosumers with self-consumption enhancement and frequency containment reserves.	Three charge-level strategies simulated in a 1-ms step.	Frequency containment reserve increases profitability by 14%. The best indicators are found to broaden the storage band (30–90%).	0.5-s PV power profile measured with a smart meter in a household in Jaén (Spain).	AO
Muqeet et al., 2020 [99].	31	Proposes an energy management system (EMS) strategy for an institutional microgrid (µG) to reduce its operational cost and increase its self-consumption	PV modules and diesel generator and storage. Linear problem solved in MILP and simulated in MATLAB.	Grid electricity costs reduction of around 30%. Significant economic and environmental benefits.	Load patterns for typical summer and winter days in Pakistan.	ESH

Table A2. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Huang et al., 2019 [100].	52	Case study of rehabilitation of a residential cluster in Sweden with PV production and sharing and heat pump thermal generation and storage.	A fitness function based on a genetic algorithm is established to optimize the capacity and positions of PV modules at the cluster level, with the purpose of maximizing self-consumed electricity; simulations in TRNSYS.	The research results reveal how electric vehicle penetration, thermal storage, and energy sharing affect PV system sizing/positions and the performance indicators and thus help to promote PV deployment.	3D model for building geometry and irradiation matrix. Hourly weather data. Fixed prices for electricity taken and returned to the grid.	ESH
Wirtz et al., 2020 [101].	69	Bidirectional low temperature heat networks in energy hubs.	Techno economic performance evaluation. Linear programming.	Cost reduction of 42% with 56% less CO_2 emissions compared with individual HVAC.	Heating and cooling data recorded at sub-hourly resolution for 17 buildings and clustered for 50 design days.	ESH
Keiner et al., 2019 [102].	61	To find the cost optimal mix of the various complementary technologies, such as batteries, electric vehicles, heat pumps, and thermal heat storage, for PV prosumers across the world by exploring 4 different scenarios.	MATLAB	In addition, the research presents the threshold for economical maximum battery capacity per installed PV capacity, along with self-consumption ratios, demand cover ratios, and heat cover ratios for 145 different regions across the world.	Household data from UN database. PV profiles from MENDELEY CITATION PLACEHOLDER 0 Bogdanov and Breyer 2016. Load profiles from MENDELEY CITATION PLACEHOLDER 1 Werner et al. 2012	ESH
Brange et al., 2016 [103].	120	Evaluation of the potential for district heating contribution from small scale prosumers based on excess heat and their environmental impact in an area with diverse building types.	Environmental calculations were performed by simulations in the commercial simulation program NetSim.	The potential for excess heat prosumers is fairly large, in Hyllie around 50–120% of the annual heat demand. Most of the excess heat, however, is produced during the summer months.	Data from property developers and some measured data.	ESH
Li et al., 2022 [104].	12	Storage of prosumers' excess heat in district heating.	Dynamic optimization problem.	Annual costs savings of 9% and investment recovery in less than 10 years.	Full-year measurements from a district heating campus in Norway.	ESH
Brand et al., 2014 [105].	101	Heat prosumers in district heating in Malmö, Sweden.	Simulations in NetSim software (https://www.vitec-energy.com/netsim-grid-simulation/, accesed on 14 May 2023).	Increased fatigue in the pipes due to the reverse flow.	Flow rates, temperatures, pressure maintenance, heat power in solar collectors and heat pumps, supply temperatures, return temperatures, and customer heating demand for 2012.	
Sommer et al., 2020 [106].	42	New topology for simultaneous heating and cooling: the reservoir network.	Modelica simulations.	The reservoir network in a ring layout and single-pipe configuration is more economical.	Hourly profiles based on the Swiss archetypes.	ESH

Table A3. Peer to Peer.

References	# Citations	Application	Techniques	Results	Data	Revised
Soto et al., 2021 [19].	73	Peer to peer energy trading.	Review	Papers are grouped into six topics: (1) trading platforms; (2) blockchain; (3) game theory; (4) simulations; (5) optimization; and (6) algorithms.		ESH

Table A3. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Tushar et al., 2018 [20].	103	Cooperation among prosumers in peer-to-peer trading.	Canonical coalition game framework.	The coalition is stable among prosumers.	5 residential PV systems. 15-min data recorded in Dec. 2013. Fixed electricity prices.	JPD
Andoni et al., 2019 [21].	934	Blockchain activities in the energy sector.	Systematic review.	Blockchain systems offer novel solutions to empower consumers and small renewable energy generators to play a more active role in the energy market and monetize their assets.	Review of 140 research projects and blockchain start-ups.	JPD, ESH, AO
Thukral, 2021 [22].	20	P2P energy market implementation.	Review and case study.	Comprehensive description of blockchain technology.		ESH
Siano et al., 2019 [80].	175	Transactional energy systems and P2P.	Computational model validated by experiments.	A novel blockchain architecture that uses less than 0.0001% of Bitcoin energy is proposed.		JPD
Ahl et al., 2020 [107].	64	Analysis of challenges with blockchain in energy.	Theoretical study.	Identifies challenges and opportunities in five dimensions.		JPD
Ali et al., 2021 [108].	26	Self-adaptative prosumer grouping.	Python, Ethereum blockchain, solidity.	Blockchain-assisted adaptative model for scalability and decentralization of prosumer grouping.	Hourly energy consumption dataset from renewable energy sources in Spain randomly distributed among 300 participants.	JPD, ESH.
Hwang et al. 2017 [109].	79	New energy prosumer service model applying blockchain technology.	Experimental case studies leading to an architecture of the proposed model	A transaction-based model that can collect, use, and process data more efficiently.		JPD
Park et al., 2018 [110].	76	Energy transaction ecosystem between prosumers and consumers of smart homes.	Simulation inside a smart home that has installed a PV and an ESS using the suggested blockchain-based P2P energy transaction platform.	The suggested P2P platform is more economical while guaranteeing high-quality energy.	Simulation of smart home for July and September 2016.	JPD
Van Leeuwen et al., 2020 [111].	119	Bilateral blockchain platform for microgrid communities.	Bilateral mechanism involving a blockchain-based energy management platform that optimizes a micro-grid's energy flows.	A decrease in the import costs of the whole community, with energy imports reduced by 15%	Real data from a prosumer community in Amsterdam.	JPD
Malik et al., 2022 [113].	10	Cooperative game trading algorithm.	Cooperative game in Nash equilibrium. 100 players, 50/50 community storage, and 15 charging points.	Prosumers have high revenue, and consumers save on electricity bills when using the proposed algorithm.	24-h dataset, fixed electricity rates.	JPD
Zia et al., 2020 [12].	140	Microgrid transactive energy.	Review of existing architectures.	Proposes a seven-layer architecture. Presents the local energy market concept.		JPD
Cui et al., 2020 [115].	33	P2P energy sharing framework for numerous community prosumers.	MATLAB	Two-phase model to derive the optimal energy-savings profiles and energy-sharing prices.	PV profiles of typical day in August in Wuhan, China.	JPD

Table A3. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Morstyn et al., 2018 [116].	374	Federated power plants.	Theoretical work.	The concept of a federated power plant is proposed as a virtual power plant formed through P2P transactions between self-organized prosumers.		JPD
Hayes et al., 2020 [117].	76	Local energy trading	Methodology for the co-simulation of power distribution networks and a local peer-to-peer energy trading platform using OpenDSS.	A moderate level of peer-to-peer trading does not have sig- Voltage Test Feeder.		ESH
Luo et al., 2019 [118].	157	Distributed energy trading system.	Java.	Proposes a two-layer distributed electricity trading system to facilitate peer-to-peer electricity sharing among prosumers.	Load curves from the Australian "Smart Grid, Smart City" dataset. One-day meteorological data. Fixed retail prices.	ESH
Anoh et al., 2020 [119].	129	Clustering virtual microgrids (VMGs) using relevant telecommunication systems.	Stackelberg game; MATLAB.	P2P energy prosumers make 47% more profit.	MATLAB-generated data sets as uniformly distributed random variables.	JPD
Tushar et al., 2020 [120].	105	P2P scheme for reducing total electricity demand at peak hours.	Cooperative Stackelberg game.	There is a unique and stable Stackelberg equilibrium.	Residential network with 12 prosumers; datasets from an Australian company; fixed retail prices.	JPD
Zhou et al., 2018 [121].	224	Application in the evaluation of the existing proposed P2P energy sharing mechanisms, i.e., supply and demand ratio (SDR), average market tariff (MMR), and bill sharing (BS).	Simulation.	In terms of overall performance, the SDR mechanism outperforms the other mechanisms. The MMR mechanism performs well with moderate levels of photovoltaic penetration.	Cardiff University data catalogue at "http://doi.org/10.17035/d.2018.0046405003 (accessed on 26 June 2023)".	JPD
Morstyn et al., 2019 [123].	96	Decentralized market design that allows a DSO to obtain flexibility from competing aggregators.	Simulation cases using the IEEE European Low Voltage Test Feeder.	Through the market, the distribution system operator, aggregators, and prosumers reach agreement on a stable outcome.	Smart meter data from the UK Customer-Led Network Revo-lution project. NREL data for electric vehicle charging.	ESH
Chen et al., 2019 [124].	88	The optimal functioning and profit maximization of price creation by prosumers in the electricity market, acting as price creators.	Market prediction model based on an extreme learning machine (ELM) and a novel prediction-integration strategy optimization (PISO) model.	The proposed methods successfully realize high market transaction rates and improve the prosumer profits in different market situations.	15-min data from 374 participants for 3 weeks in 2016.	JPD
Davatgaran et al., 2018 [125].	88	Profit maximization in the energy hub. Participation in the day-ahead market is allowed by submitting bids to maximize profits.	Use of energy input and output vectors that make the energy concentrator unique. MILP.	The model takes advantage of the multiple input vector of the energy hub to present the optimal bids, including the sale/purchase of electricity and cost optimization.	Forecasted data are electrical and thermal loads, wind generation, and day-ahead and real-time market prices.	JPD
Morstyn et al., 2019 [126].	218	The new concept of energy classes is introduced, allowing energy to be treated as a heterogeneous product, based on attributes of its source.	Distributed price- directed optimization mechanism using ADMM.	The operation of the proposed P2P energy market platform is verified for the IEEE European Low Voltage Test Feeder, with 55 subscribed prosumers.	One minute resolution load data from the IEEE European Low Voltage Test Feeder	ESH
Qiu et al., 2021 [127].	24	The incorporation of prosumers' heterogeneous characteristics into the P2P trading problem.	Multi-agent deep reinforcement learning (MADRL).	The proposed MADRL method exhibits a strong generalization capability in the test data-set and outperforms the state-of-the-art MADRL methods	Real-world dataset involving 300 residential households	JPD

Table A3. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Tushar et al., 2019 [128].	168	Direct application of behavioural sciences in the study of prosumer activation to act as a prosumer.	Literature review of peer-to-peer energy trading. A motivational framework is introduced and validated thorough numerical experiments.	The proposed framework is capable of reducing both the CO_2 emissions and the price of electricity.	Actual publicly available data on solar generation and the energy demand of residential consumers.	JPD
Paudel et al., 2019 [129].	311	Application of P2P in a small community micro-grid with photovoltaic and energy storage systems.	Simulation using mainly Stackelberg games and their application for buyers and sellers.	P2P energy trading provides significant financial and technical benefits to the community, emerging as an alternative to high-cost energy storage systems.	Actual data from a demonstration project of the China Southern Grid. Fixed electricity prices.	JPD
Hahnel et al., 2020 [130].	76	Investigation of customer preferences related to P2P energy trading.	Analysis of homeowners' trading decisions in simulated P2P electricity trading scenarios.	Four target groups of consumers are identified: from price-focused to non-trading.	A sample of 301 German homeowners.	JPD
Mehdinejad et al., 2022 [112].	12	Decentralized P2P energy trading between retailers and prosumers.	Numerical simulation of several case studies.	Retailers increase their revenue by participating in local and wholesale markets. Conversely, the local players maximize their welfare through energy trading with each other and with the retailers.		ESH
Jamil et al., 2021 [122].	63	Predictive energy trading platform to provide real-time support, day-ahead controlling, and generation scheduling of distributed energy resources.	Blockchain, machine learning.	The proposed model is effectively used for energy crowdsourcing between the prosumer and consumer to attain service quality.	Real energy consumption data for the Re-public of Korea.	ESH
Wu et al., 2021 [27].	46	Transactive energy Internet.	Systematic overview.			AO

Table A4. Prosumer.

References	# Citations	Application	Techniques	Results	Data	Revised
Di Silvestre et al., 2021 [28].	22	Renewable energy communities (RECs).	Review of the legal framework.	Identification of aspects that need to be addressed for a complete implementation of REC and their integration with the power system.		ESH
Bauwens et al., 2022 [29].	15	Energy communities.	Systematic review of 183 definitions of communities in energy systems coded across three dimensions: meanings, activities, and objectives of communities.	Weakening of scholars' attention to "transformative" notions of community, emphasizing collective and grassroots processes of participation in energy transitions for the benefit of "instrumental" notions.	405 articles	ESH
de Sâo José et al., 2021 [31].	32	Smart energy community	Systematic Review. PRISMA.	Need to analyse synergistic improvement in multi-purpose energy communities and to research energy islands as smart communities.	2306 records identified through database searching. 103 references in the final sample.	ESH

Table A4. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Ceglia et al., 2022 [32].	14	Smart energy community	Systematic Review. PRISMA.	111 scientific references.		ESH
Gržanić et al., 2022 [34].	14	Prosumers as active market participants. Demand response.	Systematic review. Analysis of the response to dynamic prices and aggregation, i.e., communities or microgrids.	Easy to understand models and results for several reviewed cases.		ESH
Zhou et al., 2016 [131].	213	Systematic study of the energy Internet from a business perspective.	Review	Four stages of energy system evolution are proposed. Business value and research are analysed.		ESH
Grijalva et al., 2011 [133].	146	Prosumer smart-grid architecture.	A prosumer-based, service-oriented layered architecture, flexible and scalable, is proposed for grid interaction.	Any electric power system, from large interconnections to homes and appliances, can be modelled as a prosumer.		ESH
Li et al., 2021 [134].	45	Energy management in the energy Internet.	Energy bodies. Double-Newton descent algorithm.	Each participant can locally obtain its optimal operation, and each energy router can locally obtain the optimal exchanged energy.		ESH
Goncalves et al., 2014 [135].	154	Forecasting local consumption and production to help ensure the operational stability of the power system.	Based on the NOBEL CDA market. Simulation of 1897 participants at 15-min intervals for the month of September 2012.	Grouping consumers (and prosumers) diminishes forecasting errors. Higher PV penetration leads to erroneous trading and uncapitalized generation.	1897 items from a dataset simulated from real smart-metering. Generation profile is simulated.	ESH
Qiu et al., 2018 [136].	80	Integrating various distributed energy resources for optimal scheduling of prosumers in coupled energy systems.	Transactional approach. Autoregressive integrated moving averages (ARIMAs). Artificial neural network (ANN) models.	Hierarchical and coordinated power and gas scheduling can identify more accurate operating plans for coupled transactional power systems.	Modelled from the Australian energy market operator's publicly available 2015 historical data.	ESH
Yin et al., 2020 [137].	59	Day-ahead energy management for aggregate prosumers considering the uncertainty of intermittent renewable energy output and market prices.	Virtual power plant (VPP). Two-stage robust Stackelberg game. Clustering of prosumers by adaptive K-means algorithm.	Operating mechanism of a VPP aggregated only by prosumers.		ESH
Zhou et al., 2021 [138].	22	Multi-energy net load forecasting.	Deep learning.	The methodology is capable of managing the multi-prosumer prediction problem with multi-energy carriers.	1-h interval multi-energy net load data from Jan 2019.	ESH
Zafar et al., 2018 [10].	246	Prosumer-based energy management and sharing in smart grid (PEMS).	Theoretical conceptualization. Literature review.	PEMS has enormous potential for cost savings, energy conservation, and peak load balancing		ESH
Zepter et al., 2019 [139].	119	Prosumer integration into wholesale electricity markets.	Two-stage stochastic programming approach. P2P trading. Autoregressive moving average (ARMA).	P2P trade and battery storage by themselves each induces a reduction in electricity bills by 20% to 30%. Combined, P2P trade and battery storage may lead to savings of almost 60%.	Half-hourly demand profiles of single households, meteorological data, prices for seven representative days of each season.	ESH

Table A4. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Vergados et al., 2016 [140].	78	Prosumer clustering in virtual microgrids.	Six clustering algorithms are compared.	Significant cost reduction achieved through the association of prosumers into groups.	Real 15-min dataset of 33 prosumers located in Greece: residential, commercial, and industrial.	ESH
Yang et al., 2016 [141].	141	Regional multi-energy prosumers (RMEPs) served by energy hubs.	Non-convex optimization problem with multi decision variables and complementarity constraints.	Prosumers can play an important role in responding to time-of-use electricity and gas tariffs, shaving the regional peak loads.	Regional natural gas and renewable energy project in an industrial zone in Changsha, Hunan, China	ESH
Cao et al., 2019 [142].	114	Prosumer-community group detection (PCG).	Dynamic game model. PGC detection as a multiobjective optimization problem; partially visible multiagent system (PVNAS).	Generalized definition of individual prosumer's energy density.	Four power grid networks, generated by the IEEE standard model system, and three synthetic networks.	JPD
Ma et al., 2019 [143].	95	Energy management for energy hubs and PV prosumers with shiftable loads.	Cooperative and non-cooperative trading modes. MILP. MATLAB.	The cooperative model can promote local consumption of PV energy, increase the profits of the manager, and reduce the costs for prosumers.	Data from smart-meters in two office buildings and four residential buildings.	ESH
Han et al., 2019 [144].	106	Prosumer coalitions with energy management.	Cooperative game theory and energy management.	The cooperative approach not only financially rewards all the participating prosumers but also benefits the electricity distribution network by reducing the reverse power flow and flattening the local energy profile.	Customer-Led Network Revolution trials, a UK smart grid demonstration project.	JPD
Espe et al., 2018 [145].	95	Examines the literature on the prosumer community-based smart grid.	Review	Eight propositions are presented based on the findings from the literature on smart grids based on prosumer communities.	105 articles published between 2009 and 2018.	ESH
Pena-Bello et al., 2021 [146].	12	Study of prosumer P2P decisions in an energy community.	Interdisciplinary approach, bridging psychology with the engineering sciences. Online experimental study with 251 German homeowners willing to participate in a P2P community.	P2P energy trading based on human decision-making may lead to financial benefits for prosumers and traditional consumers and reduced stress for the grid.	Detailed description of the sample and P2P experimental design in the Methods section.	ESH
Rathnayaka et al., 2014 [147].	62	Key issues and challenges associated with the development of community prosumer groups	Goal-oriented community groups of prosumers are formed.	The social impact of this concept leads to a more symmetrical interaction between community prosumer groups and utilities.	Use of prosumers' historical energy sharing profiles.	JPD
Rathnayaka et al., 2014 [148].	62	Methodology for assessing and ranking prosumers to build a base of influential members.	Multiple-criteria decision-making techniques (MCDMs).	The higher-ranked prosumers are deemed to be more influential in enhancing the long-term sustenance of the group.	Synthetically generated dataset following realistic energy consumption, generation, and sharing models in Australian conditions.	JPD
Kloppenburg et al., 2019 [149].	63	Digital platforms to drive changes in the energy system	Theoretical study of platforms.	Platformization of energy opens up new possibilities for consumers and prosumers while making questions of energy justice and energy democracy all the more urgent		JPD

Table A4. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Moreno-Munoz et al., 2016 [150].	57	The social role of the prosumer within the strategy of public entities in their communication through social media and mobile apps to improve customer engagement.	Theoretical work.	Critical reflection on how companies need to move from energy suppliers to energy service advisors.		JPD
Parag and Sovacool, 2016 [151].	624	Conceptual study that establishes the basis for differentiation between groups of prosumers.	Theoretical work.	It establishes consistency in classification into three potential prosumer markets by differentiating among peer-to-peer models, prosumer-to-grid models, and organized prosumer groups.		JPD
Rodríguez-Molina et al., 2014 [152].	100	New business models for prosumers.	Theoretical work.	Different examples of business models have been suggested as ways to prove that businesses based on a prosumer integrated into a smart grid are feasible.		JPD
Brown et al., 2019 [153].	73	Study based on UK regulatory framework of barriers to new prosumer business models.	Qualitative mixed methods approach involving a baseline documentary analysis and in-depth semi-structured interviews.	Recent technological developments are opening up several new value propositions, which in turn are starting to be exploited by some new business models.		JPD
Tang and Yang, 2019 [154].	64	Robust optimization of VPPs by considering the influence on the markets.	Algorithm is developed using the CPLEX MILP model in MATLAB.	The results also verify the effectiveness of the proposed VP method with various combinations of renewable energy sources, energy storage systems, and loads.	Data from Elia and Taipower system.	JPD
Bryant et al., 2018 [155].	51	Utility business models.	Content analysis.	Findings identified 4 emerging energy utility and utility equivalent business model typologies.	50 Australasian and European energy utilities were analysed.	JPD
Szulecki, 2018 [156].	172	'Energy democracy' is positioned in relation to similar normatively derived concepts: environmental, climate, and energy justice; and environmental democracy.	Essay using political theory and political sociology.	'Energy democracy' is conceptualized as an analytical and decision-making tool, defined along three dimensions.		ESH
Campos et al., 2020 [157].	42	Prosumer movement.	Review of social movements theory Thematic analysis.	Active energy citizens are co-creating a new socially valuable energy model.	46 prosumer initiatives in Europe.	ESH
Brown et al., 2020 [158].	48	Normative dimensions of prosumer business models, modes of governance, and understandings of value.	Semi-structured interviews, focus groups, and documentary analysis.	A more explicit recognition of competing theories of value, agency, and change is needed in future discussions of prosumerism.	Case study of Bristol in the UK.	ESH
Wilkinson et al., 2020 [159].	40	Who are the users interested in P2P electricity market and what role can they play?.	Early trial of a blockchain-based P2P trading model in real-world conditions in Fremantle, Western Australia (RENeW Nexus)	The users who joined the P2P trial were typically financially secure households with great interest in social equity and cleaner energy systems	50 participants in total: 40 prosumers and 10 consumers	ESH

Table A4. *Cont.*

References	# Citations	Application	Techniques	Results	Data	Revised
Palm, 2018 [160].	97	To compare what homeowners identify as motives for and barriers to installing photovoltaic panels	Two rounds of interviews with PV homeowners in Sweden in the periods of 2008–2009 and 2014–2016.	First wave, early adopters motivated by environmental reasons. Second wave, the rise of economic motivations.	2008–2009, 20 households. 2014–2016, 43 households.	ESH
Horstink et al., 2020 [161].	32	Identification of key aspects of collective prosumers.	Documentary study and an online survey in nine EU countries.	Identification of several internal and external obstacles, highlighting a mismatch of policies, organizational weaknesses, and slow reforms.	Average response rate of 21.8%. 198 initiatives concluded the questionnaire.	ESH
Hackbarth et al., 2020 [162].	30	To identify the most prospective customer segments and their preferences and motivations for participating in P2P electricity trading.	Principal component analysis was used as a method for data reduction for the attitudinal and behavioural items (all measured based on five-point Likert scales). Theory of planned behaviour.	Rather than current prosumers, planners willing to install microgeneration are considered to be the most promising target group for P2P.	Survey in April and May 2017 among 100,756 customers of seven municipal utilities in southwest Germany. 7006 participants.	ESH
Scholten et al., 2016 [163].	86	Potential political implications of the geographic and technical characteristics of renewable energy systems.	A thought experiment that imagines a purely renewable based energy system, keeping all else equal.	Extends the prosumer concept at the continental and national level, the latter leading to the concept of 'prosumer country'.		ESH
Scholten et al., 2020 [164].	33	Study of the political implications of renewable energy systems for interstate energy relations.	Policy perspective.	One possible outcome is a world of continental-sized grid communities consisting of prosumer countries		ESH
Gautier et al., 2018 [58].	46	Comparison between net metering and net purchasing (net billing).	Mathematical model to compare the two metering systems.	Net metering leads to too many prosumers, a decrease in the bills of prosumers compensated via higher bills for traditional consumers, and a lack of incentives to synchronize local production and consumption.		ESH

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