energies

MDPI

Review

Prosumer Communities and Relationships in Smart Grids: A Literature Review, Evolution and Future Directions

Eunice Espe [1,*], Vidyasagar Potdar [1] and Elizabeth Chang [2]

1 Discipline of Business Information Systems, School of Management, Curtin University, Perth 6107, Australia; Vidyasagar.Potdar@cbs.curtin.edu.au

2 School of Business, University of New South Wales (UNSW), Canberra 2612, Australia; Elizabeth.Chang@unsw.edu.au

* Correspondence: Eunice.Espe@postgrad.curtin.edu.au

Received: 2 July 2018; Accepted: 20 August 2018; Published: 21 September 2018

check for updates

Abstract: Smart grids are robust, self-healing networks that allow bidirectional propagation of energy and information within the utility grid. This introduces a new type of energy user who consumes, produces, stores and shares energy with other grid users. Such a user is called a "prosumer." Prosumers' participation in the smart grid is critical for the sustainability and long-term efficiency of the energy sharing process. Thus, prosumer management has attracted increasing attention among researchers in recent years. This paper systematically examines the literature on prosumer community based smart grid by reviewing relevant literature published from 2009 to 2018 in reputed energy and technology journals. We specifically focus on two dimensions namely prosumer community groups and prosumer relationships. Based on the evaluated literature, we present eight propositions and thoroughly describe several future research directions.

Keywords: prosumers; prosumer community groups; prosumer relationships; smart grids; energy management systems; energy sharing

---

1. Introduction

Energy demand in the world continues to rise at an alarming rate. The International Energy Outlook 2017 (IEO2017) projects a 28% increase in world energy consumption between 2015 and 2040 [1]. The current demand is largely met by petroleum, coal, and natural gas. However, the exploitation of these non-renewable energy sources results in pollution of the natural ecosystem, global warming, greenhouse gas emissions, and other harmful environmental effects. Thus, the energy usage is shifting from non-renewable to renewable energy sources. Furthermore, to manage the fast-growing demand, the provider-consumer unidirectional model is transforming into a bidirectional energy and information model. To support this transformation, the use of digital communications in the energy network is proliferating, giving rise to the smart grid concept. The smart grid is defined as "an electric system that uses information, two-way, cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable [2]." It is increasingly becoming popular due to its desirable characteristics and potential promise which includes self-healing, improved reliability, enhanced power quality, moderated peak demand, increased asset utilization, reduced transmission congestion costs, increased security, and improved resistance to malicious attacks or unfavorable natural events [3].

Smart grids differ from traditional utility grids, where consumers use energy from the utility provider and are charged based on their consumption. On the other hand, in the smart grid, energy users may generate, store, or trade energy with other users in the grid [4].

The smart grid framework consists of five main elements that enable seamless energy sharing [5]. These include smart energy and information infrastructures, bidirectional communication, advanced management systems, standards and legislation, and sustainable integration with prosumers [5]. This paper revolves around the fifth element, that is, sustainable integration with prosumers, because numerous studies covering the first four elements already exist in the literature.

Reference [6] was one of the first thorough studies in the area of prosumer based smart grids. Hence, we used this reference as a starting point for this systematic literature review. It also introduced the concept of prosumer community groups (PCG) referring to a community of prosumers generating and sharing energy [6]. In the recent literature, a similar concept is described using new terms such as Electricity Prosumer Communities, Integrated Community Energy Systems, and Clean Energy Communities. However, in this paper, we refer to such concepts as PCG.

In this study, we aim to understand how the research on prosumers and PCGs has progressed in recent years. As a starting point, we gathered eleven articles [4–14] on PCGs. We then used Google Scholar to find the citations of these eleven papers, and as a result, we collected 179 papers.

These papers were exported to Endnote software to remove duplicates, which resulted in 113 papers for further screening. We screened these articles to select relevant research focusing on prosumer based smart grid management. While doing this, we first checked the title of the paper. If the title did not appear to be about prosumers or smart grids, we read the abstract to determine if the research was relevant to our study. We evaluated the updated list and noticed two areas of interest namely PCGs and prosumer relationships.

We then searched additional articles that are closely related to these two themes by querying Web of Science, Scopus, and Google Scholar databases. This process ensured the rigorousness of our research. In total, we selected 105 articles for this systematic literature review. Figure 1 shows the distribution of the reviewed articles by year of publication.

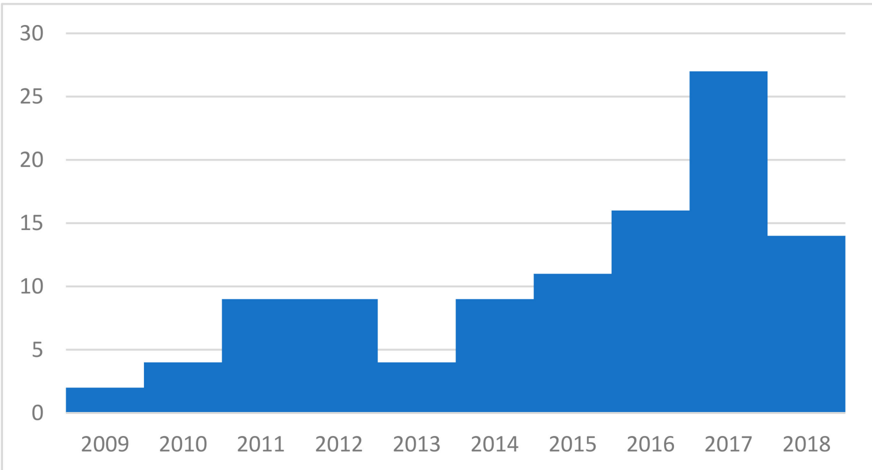

Figure 1. Distribution of Reviewed Articles by Year of Publication.

The objective of this paper is to thoroughly examine the selected research papers and group them based on their research contribution into one of the categories shown in the prosumer smart grid taxonomy in Figure 2. We developed this taxonomy based on the evaluation of the literature reported in this article. Table 1 shows the corresponding list of papers reviewed under each category.

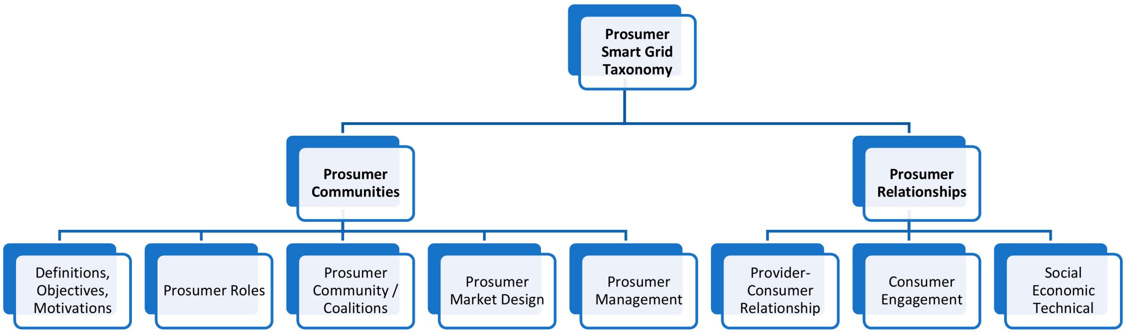

Figure 2. Prosumer Smart Grid Taxonomy.

Table 1. Literature Classification based on Taxonomy.

Literature Area	Relevant Literature
Prosumer communities	
Prosumer definitions, objectives, motivations	[4,7–9,15–36]
Prosumer roles	[7,37–44]
Prosumer community/Coalition formation	[4,7,10–13,17–22,45–51]
Prosumer market design	[16,36,38,49,52–54]
Prosumer management	[5,8,10,11,37,55–59]
Prosumer relationships	
Provider-consumer relationships	[16,36,60–72]
Consumer engagement	[5,14,36,56,73–82]
Socio-Economic-technological aspect	[18,28,46,74,76,80,81,83–107]

This paper is structured as follows: Section 2 discusses the latest progress in the area of prosumer based smart grids focusing on prosumer communities and prosumer relationships. Section 3 outlines the future work and Section 4 concludes the paper. Based on the evaluated literature, prosumer communities sustain efficient energy exchange. Furthermore, effective prosumer relationships enable successful smart grids.

2. Detailed Analysis of the Literature

This section analyses the literature on prosumer community based smart grids and follows the taxonomy shown in Figure 2. We start with prosumer communities followed by prosumer relationships. We present propositions at the end of each category.

2.1. Prosumer Communities

The rapidly growing demand for energy combined with the reduction of conventional energy sources in recent years have led to the transformation of the energy sector. Households and other energy users can now both produce and consume energy. They can also either store the surplus for future use or send it to the grid for sharing with other energy users. As a result of this transformation, the smart grid gave rise to "prosumers" who contribute to the energy supply.

In the following subsections, we elaborate the prosumer concept in further detail by defining the prosumer, then covering prosumer roles, their motivations to be part of a prosumer community, the overall market design mechanisms, and prosumer community formation which enables prosumer based energy sharing and management.

2.1.1. Prosumer Definitions, Objectives, and Motivations

"Prosumer" refers to "an energy user who generates renewable energy in his/her domestic environment and either store the surplus energy for future use or trades to interested energy customers in smart grid [4].” Hence, the objective of these prosumers is to produce and consume energy, as well as share and redistribute excess energy to other users in the grid [15,16]. We can also find other definitions of prosumers in the prosumer literature [15,16]. In general, all these definitions of prosumers refer to energy users who produce energy that are consumed within the grid.

A next related concept is a group of prosumers participating in energy provisioning. PCG refers to “a network of prosumers, having relatively similar energy sharing behaviors, who endeavor to pursue a mutual goal and jointly compete in the energy market [7].” Another closely related concept is Electricity Prosumer Communities (EPCs) which are “groups of people producing, sharing, and consuming electricity locally [17].” Other authors have used terms such as Integrated Community Energy Systems (ICESs) [18–21] and Clean Energy Communities (CECs) [22] to refer to the same concept. The primary difference between PCG’s and other prosumer communities is that in a PCG, the formation of groups or coalitions is based on mutual goals. We discuss further details about PCG in the Prosumer Community subsection.

Prosumers are different from traditional energy consumers. Compared to the traditional consumers who use energy from the grid, prosumers generate, consume and actively transfer or store excess energy [8,23]. Prosumers can also store excess energy using Energy Storage System for future use, or sell the surplus energy to the grid or nearby consumers [24]. Prosumers use smart meters during energy production and integrate these devices with household energy management systems [9,25,26], energy storage systems [27–29], electric vehicles [30–32], and vehicle-to-grid systems [33,34] to efficiently integrate into the smart grid [16].

Comparisons between prosumer based smart grids and conventional grids show that prosumers improve efficiency in the energy system through various means. These include enhancing the operation of household appliances through smart devices and communication technologies, offering storage capacity to help manage power fluctuations, and supporting the balance of local demand and supply [16].

The shift from being passive consumers into active prosumers maximizes a variety of economic [34], operational and environmental benefits in the areas of micro-generation, demand reduction, demand response [34], data management [34,35], and energy storage [36]. Various factors influence this transformation such as new technologies (smart meters and advanced metering infrastructure [25,26], energy displays, and smart appliances), implementation of cost-efficient energy saving measures, government incentive schemes to encourage participation in the energy system, and strong public stance to alleviate harmful environmental effects [8,36]. Hence, we propose the following:

Proposition 1. *Prosumer communities aim to transform traditional consumers to become active prosumers thereby improving the efficiency of the smart grid and offering economic, operational and environmental benefits.*

2.1.2. Prosumer Roles

The prosumer is one of the actors operating in the complex energy value network. As an active participant, they drive the sustainability of the energy sharing process in the PCG [7]. Although prosumers are value-adding participants in the evolving energy system, limited research exists on the subject of prosumer roles [37,38]. Recognizing prosumer roles and aligning expectations at the first stages of smart grid implementation are important for better adoption of the technology regarding functionality, processes, business models, and opportunities for innovation [37]. There are three proposed categories of prosumer roles in smart grid based on the perspective of co-creation, or strategy to promote collaboration among different parties to achieve a shared objective. These are the “Engineer” who value new technologies and innovation, the “Green User” who are concerned with environmentally sustainable solutions, and the “Value Seeker” who are interested in the economic benefits and product performance, quality and security [37].

Prosumers can also contribute to the digital energy ecosystem. Aside from being involved in energy production, prosumers can also engage in innovation and value creation processes through digital touch points such as the web, user interfaces, and mobile devices and application [38]. Some examples of such innovation and value creation are energy market processes related to data monitoring, data analytics, and other areas of physical and financial energy flows. Moreover, prosumers can also help in developing innovative solutions through sharing ideas and providing feedback [38].

Prosumers can further participate in supporting distributed flexibility in the power market by managing their energy production and consumption schedules and providing decentralized storage capacity [39]. Different prosumer roles also contribute to the transformation from traditional to future flexible energy systems [40]. An investigation of the evolving energy system elaborates a set of exploratory propositions for six different types of prosumer roles in the smart grid [40]. These roles include participating as an early market actor, testing functionality and relative advantage, testing financial benefits, validating business models, providing feedback on technology, and engaging in co-creation [40]. Several other researchers have independently addressed some of these aspects such as early market actors [41], smart grid business models [42,43], and prosumer co-creation [44]. Consequently, we propose the following:

Proposition 2. *Prosumers role is critical in ensuring sustainable energy provisioning in the early stages as well as ongoing operations of the smart grids. Prosumers are value-adding actors in the complex energy value network and contribute towards innovation, value-creation and distributed flexibility in the energy value network.*

2.1.3. Prosumer Community/Coalition Formation

A group of prosumers collectively selling energy to the grid is more efficient and reliable in providing sustainable energy supply compared to a prosumer acting as an individual entity [4]. Aside from being too small to compete with traditional energy generators, individual prosumer's energy supply is unpredictable due to dependency on climatic conditions [10]. These challenges in efficiency and reliability led to the emergence of PCGs [11], also referred to as EPCs [17], ICESs [18–21], or CECs [22]. In a PCG, the prosumers interact with other prosumers and smart grid via a community gateway. A community gateway is an intelligent component connecting the grid to smart devices within the community [11]. Optimal prosumer communities offer a range of socio-economic benefits namely enhancing prosumers bargaining power, achieving higher sustainability, facilitating efficient energy transfer, reducing energy transfer cost, reducing energy loss, and promoting active involvement of the energy user into the supply chain [11]. However, the challenge lies in grouping prosumers together to achieve long-term sustainability of the PCG.

Several studies addressed this challenge. One such study proposed an algorithm that outputs coalitions of prosumers designed for aggregators who seek to maximize their offer of energy production while minimizing the risk of financial penalty if production falls below contracted amount [45]. Real weather data of a given territory is used to simulate realistic prosumer behaviors. Based on the geographical correlation structure, the algorithm forms coalitions with both high productivity and low variability of energy production. Findings show that the generated coalitions provide more energy to the grid with lower variability, hence use less storage and waste less energy compared to unstable coalitions. The formed coalitions are also more resilient to random prosumer failures [45].

ICESs are designed to deal with the rapidly changing energy landscape [18,19]. It is a socio-technical system consisting of technologies and social systems. The technologies manage the commodities flow from generation to storage and distribution. The social system made up of different actors (aggregators, energy suppliers, prosumers, system operators) handles the operations taking into account the economic efficiency, environmental effects and consumer options [19].

ICES primarily aims to meet the energy requirement of a local community through effective synergies among multiple energy providers [18]. It redesigns local energy systems by integrating distributed energy resources (DERs) and engaging local communities, which ensures self-provisioning of energy. There are several ways to integrate energy systems (such as virtual power plants or VPPs, community grids, energy hubs, PCGs, and community energy systems) and various issues and trends influencing the development of ICESs [18]. Some of these issues are intermittent local energy generation [46], local balancing of supply and demand [47], community engagement [4,10,12], split-incentive problem [48], trust, motivation and continuity [49].

Another form of PCG is CECs that are distributed and decentralized [22]. An exploratory study of CEC discusses its different forms such as peer-to-peer (P2P), VPPs, and microgrids. It also talks about the transition and evolution of communities and grids [22]. The analysis reveals that "low-carbon transition pathways will be varied, driven by social, technological and organizational contexts, and shaped by institutional change processes, and interaction with the existing regime and incumbent actors [22]." The study reported a SWOT (strengths/weaknesses/opportunities/threats) analysis on Current Utility Mode, Centralized CEC, Distributed CEC and, Decentralized CEC. Opportunities for CECs include the intensified use of assets and services, expanded business opportunities, enhanced projects based on lessons learned, and improved regional infrastructure planning aligned with national planning [22].

A prosumer community that is goal-oriented is effective in attaining sustainable energy exchange [4]. Energy networks may have multiple conflicting goals like fulfilling the energy demands for external customers and the prosumer groups, increasing income, and reducing costs. Thus, a framework to manage these goals is necessary.

Formation of prosumer groups based on mutual objectives may be affected by specific factors such as prosumer behavior profiles and geographical structures. A proposed framework describing the formation of PCG classifies the energy-sharing behaviors of prosumers, characterizes PCG, and detects outliers [13]. Another proposed methodology aims to assess and rank prosumers using their energy profiles to select the influential prosumers within the group [7]. The conceptual model includes four processes. First is the definition of assessment criteria namely ability to meet the energy agreement, produce more energy than agreed, trade energy with other prosumers, and the quality of historical provisioning of energy. The next process is criteria prioritization, followed by point allocation, and finally, the prosumer ranking [7].

On a technical front, the implementation of a PCG will be possible by understanding the underlying routing technologies which is especially important when forming PCG with prosumers that are geographically apart from each other. One way to address this problem is to develop intelligent geographic routing protocols [50]. It reduces communication overhead because packet forwarding decision is dependent on node positioning and the location of the end node. A wireless communication technology called geographic GReedy routing with Ant Colony Optimisation (GRACO) based recovery aggregates geographically sparse DERs into a scalable and rapidly deployable VPP. It aggregates geographic greedy forwarding strategy and ant colony optimization (ACO) method for efficient data packet delivery. Simulation results of the proposed routing protocol reveal that the delivery date conforms with the virtual power plant requirements and that the end-to-end delay reduces as paths shorten and increases network density [50].

An investigation of EPCs reveals added information about energy exchanges between prosumers [17]. A rigorous mathematical framework modeled the energy exchanges and formalized several optimization problems based on target objectives. These objectives (such as maximize distributed production, minimize losses, and optimize revenues) aim to improve a community of prosumers [17]. Following the above, we propose the following:

Proposition 3. *A goal-oriented PCG aims to maximize distributed production, optimize electricity consumption, minimize losses, and optimize revenues, thereby sustaining effective energy exchange. Prosumer behavior profiles and geographical structures affect the formation of PCGs.*

2.1.4. Prosumer Market Design

In this section, we discuss prosumer market design. The "prosumer market" is characterized by consumers providing services to the grid and transforming into active prosumers [36]. The platform enables consumers to engage and integrate with other entities in the energy value network using market-based energy prosumption strategies. Prosumers could potentially integrate into the energy markets through three engagement models [16,52]. One is the P2P model which involves a decentralized, autonomous, and flexible P2P network where prosumers interconnect directly with each other. Another is the prosumer-to-grid model that involves prosumers providing services to either an independent microgrid or a microgrid connected to the main grid. The third is the organized prosumer group model which is composed of multiple groups of prosumers. The groups work together and pool resources for community benefit or can become large enough to form a prosumer VPP [16]. VPP and P2P platform can be combined to attain the advantages of each model [49]. The federated power plant is another type of electricity market structure wherein P2P trading of autonomous prosumers forms a VPP [49].

A study on prosumer market introduced and evaluated a direct P2P design and a closed order book design [53]. It also evaluated zero intelligence agents and intelligently bidding agents. It derived four scenarios, i.e., two market designs combined with two agent behaviors. The objective was to determine which parameters are suitable for a local energy trading market that integrates distributed generation at energy prices that are beneficial to the local agents. Based on simulation results, all scenarios offer similar economic advantages regarding self-consumption and energy traded. However, the P2P design with intelligent agent is the most relevant for participating agents because of the resulting lower energy rates.

In another study of prosumer centric digital energy ecosystem, the authors propose a framework consisting of actors and layers [38]. The actors include the natural environment and various organizations such as regulators, academia, business system, energy industry incumbents, new energy industry actors, and new entrants from other sectors. It also comprises digital actors such as hardware and software platforms such as ICT infrastructure, smart grid infrastructure, smart meters, energy storage, home energy management system, data hubs, and other devices. The four layers include the human activity layer (consisting of prosumer activities), the value-adding layer (applications, processes, and activities), the digital layer (ICT infrastructure, fog computing, data analytics in the cloud), and the energy layer that involves energy production, transmission, distribution, and consumption. All these actors and layers link together the various processes (human activity, value creation, digitization, and energy process) that contribute to the digital energy ecosystem success [38]. Based on the above, we propose the following:

Proposition 4. *The prosumer market is a platform which enables integration between prosumers and other entities to enable an efficient and sustainable energy exchange within the energy value network. Prosumer engagement can either be P2P, prosumer-to-grid, organized prosumer group, or combination of P2P and organized prosumer group. A prosumer centric digital energy ecosystem integrates different actors and layers to link various processes essential to the ecosystem's success.*

2.1.5. Prosumer Management

Effective management of prosumers is essential for sustainable energy sharing within the smart grid. Two management approaches are individual integration method and simple-group integration forming a VPP or microgrid [10,11]. Due to the shortcomings of these approaches, the authors introduced a framework to manage prosumers as goal-based virtual PCGs [10,11]. Prosumers across various geographies demonstrating same energy sharing patterns virtually connect with one another to form a community and achieve a common goal such as provisioning a fixed amount of energy every week [10]. In this approach, having similar behaviors and interests lead to stronger ties and reduced disagreements among members [5]. Furthermore, sharing a common goal motivates the members to fulfill this goal and guarantees the quantity of energy supply to the grid, which consequently reinforces their bargaining power and enables long-term sustainability [11].

The organization, motivation, and overall control of prosumers are the three most essential components of the prosumer management domain [5]. Prosumer organization requires a comprehensive analysis of prosumers' behaviors and preferences. Their behavior profiles help in selecting the appropriate prosumers to participate in the energy sharing program and form the PCG. Prosumer motivation aims to positively influence the prosumers' attitude to enable consistent energy sharing behavior within the smart grid. It involves encouraging active prosumers to improve their contribution and attracting passive prosumers (i.e., prosumers who do not share energy), to participate in the energy sharing.

Prosumer overall control consists of five aspects: (i) communication/negotiation to build trust and develop mutual understanding among the prosumers, (ii) standard/ethics definition to ensure compliance when joining the energy sharing process, (iii) prosumer assessment to identify influential prosumers and members who do not meet expectations, (iv) incentive/penalty distribution to motivate positive contribution from prosumers, and (v) risk assessment to identify negative prosumer behaviors, evaluate vulnerability and prevent long term negative effects to the energy sharing process [5].

In managing prosumers, understanding their energy behavior profiles, activities, and processes is critical. The prosumer profile is the set of characteristics of the user that may influence their energy demand. This data may include various aspects such as the demographic and family information, type of real estate the user lives in, occupancy status, style of work and hobbies, usage budget limit, and devices utilized including their usage patterns [5,55].

One study analyzed the energy generation, consumption and sharing behaviors of Australian solar PV users [8]. The analysis generated summer and winter energy patterns of prosumers. Results show that the profiles vary over day and month of the year. Therefore, the authors recommend putting into consideration the variable nature of energy profiles when investigating prosumers [8].

Furthermore, examining prosumer behavior profiles is vital during energy system planning. Analysis of all the factors that dominate prosumers' behaviors and interactions within the smart grid helps in shaping the system load profile and forecasting the energy demand [56]. To illustrate this principle, a proposed methodology models car drivers' behavior to assess how charging of electric vehicles influence the utility grid in Dutch residential areas [56]. Findings reveal that a rise in electric vehicles requires a corresponding increase in communication between electric vehicles and utilities [56].

Consequently, based on prosumer behavior profiles, energy system planning identifies appropriate energy consumption optimization techniques. The literature suggests various techniques. One of these is to follow an optimal schedule to use household appliances. For example, an analysis of the prosumer behavior led to a prototype of an informatics solution that assists in decision-making and selecting optimal use of non-controllable appliances [57]. Likewise, another proposed energy scheduling model for residential consumers aims to optimize the timing of their consumption, generation, and storage [58]. Other similar smart scheduling of electric appliances are also found in the literature [59].

As active participants in energy co-creation, we also discuss prosumers' co-creation activities. These four activities include ideation, development, testing and giving feedback, and providing validation through new functionalities and innovative services [37]. Co-creation is a critical component in ensuring sustainable energy supply to the community grid. Therefore, we propose the following:

Proposition 5. *Understanding prosumers' energy behavior profile, their organization, and their motivation is an essential building block for effective prosumer management and energy system planning. A goal-oriented PCG builds stronger ties among members, motivates members, reinforces their bargaining power, and sustains the energy sharing process.*

2.2. Prosumer Relationships

This section outlines the latest research related to managing the prosumer relationship. This includes a number of aspects such as provider-consumer relationship [16,36,60–72], consumer engagement [5,14,36,56,73–82], and socio-economic-technological aspect [18,28,46,74,76,80,81,83–107]. We will elaborate each of these aspects in further detail in the subsequent sections.

2.2.1. Provider-Consumer Relationship

The provider-consumer relationship is an essential element of the smart grid technology because it influences the efficiency of energy production and consumption as well as the proper balance of energy demand and supply. Thus, its management must be given sufficient attention so that both parties can work together harmoniously and achieve long-term sustainability of energy exchange. However, this relationship presents multiple complexities as observed in the related literature [60–62,71].

In exploring the complexities of the provider-consumer relationship, system models were used to illustrate the entities, actors, processes, actions, and associations within the smart grid [60]. Their model has four phases—registration phase, request phase, delivery phase and confirmation phase. A central authority handles operational control within the system and also plays the role of a broker agent that enables communication among providers and consumers. Network control agents and smart meters provide control of the end users' connections to the grid [60].

A study investigated the relationship among energy prosumers and energy companies, by gathering data through interviews and participant observations of Finnish private solar power owners and energy company representatives [61]. Findings reveal that the relationship is a co-producing stakeholder relation where the key element is reciprocity. Prosumers strongly expect to be acknowledged by the energy companies as being co-producers. Failure to do so may result in prosumers' refusal to sell surplus energy to the grid. As a result, the perception of other stakeholders or the society towards energy companies is affected particularly from a corporate social responsibility perspective. On the other hand, since co-production entails working together, prosumers receive support from their energy company as part of the company's community involvement. Several related studies also support this line of thought [16,36,72].

In a reciprocal relationship, both parties should ideally benefit by working together. The energy provider and customer relationship transforms into a "bilateral monopoly" relationship, or a situation where a single producer faces a single consumer, and where each party negotiates to maximize gain whenever the other party makes an effort to adapt [62]. The conflicting interests between the customer and the provider, where the customer wants cheaper energy whereas the provider is interested in maximizing economic return, may lead to ineffective management of microgrids. Resolving this fundamental challenge involves aligning these interests through various mechanisms [62] such as long-term contracting [63–65], performance-based contract design [65,66], profit and risk sharing [65,67], and incentive strategies [65,68–70].

Long-term contracting is an efficient governance approach which aims to ensure that the objectives between two parties are aligned and that the agreed expectations from one another are realized [62]. In the area of prosumer relationship management, long-term contracting can be beneficial to both generators and consumers. Such contracts enable the generators to avoid low wholesale prices and protect them from the cost of uncertain future production while allowing the consumers to avoid high prices and safeguard against the cost of uncertain future demand [63]. Due to uncertainty in future supply and demand, the contract aims to provide a proper balance. One method to address this challenge is to introduce a model for long-term contracting for competing utility providers [64]. In the proposed model, a Recursive Genetic Annealing algorithm could be used to determine the Nash-Equilibrium or the best energy combination of cost and uncertainty, so as not to compromise the adherence of the utility company to the contract. Results of testing on ten utility companies show that the algorithm outperformed the traditional scheme in terms of speed and quality [64].

Another approach for prosumer relationship management is performance-based contract design [65,66] which can also be a long-term contract or service agreement contract that may include two components—a fixed fee and a variable fee based on output and performance [65]. Energy Performance Contracting is an example of performance-based contract design which is a contractual arrangement between the energy service provider and its client where demonstrated performance determines remuneration [66]. It traditionally binds partnership agreements between the public sector and the private energy service company, but there are challenges regarding its adoption such as difficulties in ensuring win-win condition for both parties based on net benefits and selecting the suitable schema. One model aims to address this challenge by evaluating the net economic benefits for each party and measuring the schema using net present value (NPV) method [66]. The contract with the least NPV difference results in a win-win. The proposed model was applied in a project in Southern Italy to demonstrate its applicability. The study has several contributions. First, the study considers both technical and economic perspectives when assessing contract efficiency. Also, the study highlights the importance of benchmarking the contract schemes. Results also show that extending the contract period increases uncertainty and affects contract selection based on the win-win condition [66].

Profit and risk sharing is another form of prosumer relationship management [67]. Examining the risk-sharing processes between aggregators and prosumers reveals a dynamic contract problem. While the risk-averse prosumers can control their energy supply and intend to minimize the exponential type cost function, the risk-neutral aggregator will select an incentive strategy to control prosumers' energy generation indirectly [67]. Resolution of this problem can be through an optimal dynamic contract mechanism where prosumers and aggregators share the financial risk and the uncertainty of energy generation. The prosumers optimal control can be expressed as a solution of the Linear Exponential Quadratic Gaussian dynamic games, while the aggregator's optimal solution is determined analytically by using a standard global optimization algorithm. Simulation results show that the incentive-based mechanism effectively leads to risk-sharing between the aggregator and prosumers under moral hazard [67].

Another method to manage prosumer relationship is through implemented incentive strategies [11,68–70]. A study investigated the incentive policies in China, identified effects and problems, and provided advice on how to improve these mechanisms [68]. One of these existing policies is the market development incentive strategy which leads to remarkable improvements in the renewable energy sector including the behaviors of its participants. However, it gives rise to complex issues such as grid connection difficulties. Addressing this challenge involves proper coordination of development plans [68].

A proposed multi-stage incentive model aims to motivate different stakeholders such as government, utility company, energy and equipment supplier, and the user [69]. Results reveal that social benefits and costs positively influence microgrid subsidy, enhance the technical competency of the supplier, and improve equipment quality. Such an incentive model can motivate prosumers to become more active. Similarly, prosumer incentives and penalty strategies can motivate existing passive prosumers to become active [70]. Thus, one approach to promote motivation is a performance-based penalty framework that influences prosumers' energy sharing behaviors [70].

A closer look at production and consumption in the energy system shows the existence of an expanded symbiotic relationship between production and consumption [71]. This perspective shifts from a linear flow of production to a circular process. It demonstrates that the integrated relationships among nature, industry, and prosumers may lead to synergistic activities such that each actor involved provides benefits to the others and thus, fostering sustainability. Accordingly, we propose the following:

Proposition 6. *(a) A positive reciprocal relationship between prosumers and energy providers motivates prosumers to reduce energy consumption leading to an efficient smart grid; (b) Contracting, profit or risk sharing and incentives are approaches to manage relationship conflicts; (c) Maintaining an authentic relationship with the prosumers positively affects the impact of corporate social responsibility initiative from the energy providers' perspective.*

2.2.2. Consumer Engagement

The energy value network enables consumers to transform into active prosumers and build strong relationships with other entities in the network [36]. The existing literature presents several methods that drive customer acceptance and engagement [36,73,75–79,82]. Enablers of customer participation include—added comfort, energy independence, extended chance for electricity market participation, innovative control of appliances and devices, environmental benefits, economic incentives, energy bill reduction, clear and periodic billing, detailed information of energy consumption, enhanced energy supply reliability, and other social engagement factors [73].

Other researchers also address these aspects [5,56,74] and suggest techniques for customer engagement in the smart grid. Recommendations given include: providing access to usage, pricing, data for energy monitoring, implementing privacy policies, offering access to smart grid devices, instilling consumer awareness, and providing information about smart grid technologies [73]. Also, mobile social media technologies can help promote customer engagement by enhancing their digital experience [75]. Through mobile applications, social media can be a platform where energy utilities can transform from being energy suppliers to energy service advisors, thereby promoting customer loyalty [75].

A study investigated the factors that enhance customer engagement through a survey of energy consumers in Korea [76]. A key contribution of the study is the inclusion of the perceived risk during testing of the acceptance model. This perceived risk involves the uncertainty resulting from a purchase and the expectation about the loss due to the purchase. The authors recommend that customer anxiety about the risks in using smart grid technology should be mitigated to promote customer engagement [76].

Despite the importance of the active engagement of industrial consumers for energy system transformation, the majority of empirical studies focus on residential and commercial consumers [77]. In one study, two Danish industrial consumers, one energy retailer, and one energy consulting firm were investigated to determine various factors influencing industrial consumers' participation [77]. Results show eleven influential factors which impact four phases of smart grid adoption namely *inscription*, *translation*, *framing and stabilization*. Inscription stage includes three activities namely problem assessment, concept generation, and concept specification. Translation stage involves role delegation or product outsourcing to third parties, and alignment of interests. The framing stage is the development of the technology into useful physical products and involves testing and modifications. Finally, the stabilization stage involves adaptation and product redefinition which may also include ICT organizational change. The eleven influential factors include "awareness of multiple contexts, shared support, return-on-investment, ease of use, flexibility and dynamic pricing, liberalization and energy tariff structure, customer focus, solution integration, process improvement, service quality, and company's green image [77]."

A noteworthy facet of the transformation of the energy value network is that, as with any radical change, it draws resistance from involved participants. This resistance which is due to the associated increased responsibilities of all stakeholders needs to be urgently managed [78]. The urgency led to the introduction of a framework for stakeholders' analysis which examines the interplay between key energy stakeholders [78]. The analysis aims to encourage active involvement in the smart grid technology deployment, apply suitable treatment to areas of resistance, and achieve synergy among all players. Although the framework was in the European Union context, it may also apply to other regions. The socio-psychological aspect of the integration of the new technologies should garner more attention to manage the resistance from involved participants. One approach is to adopt a communication strategy through campaigns, advertising, and education for instilling public awareness of the significant benefits of the smart grid deployment [78].

Another fundamental building block to address stakeholder resistance and develop a sustainable prosumer engagement is to have mechanisms for trust management and consumer confidence. Trust management must adapt to the continuous progress of the smart grid considering the smart grid's dynamic nature [79]. However, very limited research exists in this area. Studies on trust in social network and online engagement can be a starting point for investigation. Experiments on a dataset from real social networks examined two types of trust measures, i.e., reliability based on the direct interaction from experience, and local reputation or suggestions by friends and friends of friends based on their past experiences [80,81]. Results reveal that reliability and local reputation strengthens group cohesion and homogeneity in the social network setting.

A study compared online social network versus smart grid network to understand how prosumer based smart grids can grow and flourish [14]. The comparison involved three dimensions, i.e., community formation, community growth, and overall community management, and highlights the need for investigating trust and loyalty in a prosumer network. Two ideas are proposed here, firstly implementing mechanisms for management of breach of trust within the community, and secondly, investigating policy-based solutions to prevent disloyal behaviors. No significant work on trust exists since the publication of the article in 2012. Only one paper discussed trust in the smart grid [82]. The authors argue that trust and confidence, including lack of it, can affect sustainability in energy systems. Based on the above, we propose the following:

Proposition 7. *(a) Consumer engagement enhances the dynamics within the prosumer market, and facilitates prosumer market objectives, resulting in the sustainable deployment of smart grid; (b) Drivers of consumer acceptance and engagement include comfort, control of innovative devices, environmental benefits, financial incentives, information on billing and electricity use, security, and other social aspects, including social media technologies; (c) Mitigating consumer's anxiety towards risks attributed to smart grid deployment can increase consumer engagement; (d) Stakeholder resistance can be managed through communication strategies to uphold public awareness of the smart grid benefits; (e) Trust management is essential to improve consumer engagement.*

2.2.3. Socio-Economic-Technological Aspect

Prosumer management has three important dimensions—social, economic, and technological. Factors under all three aspects may affect demand response in smart grid either as a barrier or as an enabler [84]. A smart grid involves different stakeholders and components in an interconnected world of these three dimensions [85].

There are different types of studies on smart grid, e.g., some cover only one aspect such as social [80,81,86–89] or economic [46,90,91], or technological, while others cover multiple aspects such as socio-economic [85,92], or socio-technical [93], or techno-economic [28], or all three aspects [74,83]. Although this paper does not cover the technological aspect in detail, other existing research examines this technological aspect spanning various areas such as PV systems, VPPs, storage, DERs, and demand-side management. However, research integrating all the three aspects is limited.

We now evaluate the research on the social aspect of prosumer groups and smart grids. There is a need for understanding social interactions in social networks because social interactions are critical for smart grid adoption [80,81]. An ethnographic study examined the exchanges of energy between households in rural India for three months [86]. The concept of "circle of mutual energy exchange" is introduced and describes "mutual energy sharing" and "mutual energy trading" as co-existing modes of energy exchanges. The analysis shows that "social relations and cultural values influence energy exchanges between households" [86].

Similarly, other existing research covers the social aspect of the effective implementation of smart energy in households [87]. Social context drives energy-related behavior, and pro-environmental social norms highly influence energy conservation [88]. Likewise, in the human collaboration aspect, human and social dimensions in an energy system should not be ignored [89]. Consequently, in one research work, the authors incorporate the social domain aspect in their proposed consumer-centered energy system architecture [89].

The economic aspect covers elements such as investment costs, maintenance and operational costs, and energy management in wind energy systems in the smart grid [90]. Along with security, economic viability is a major challenge in the adaptability and sustainability of wind turbines [90]. One research discusses the economic aspect of pooling small local prosumers in the UK market context [46]. It focuses on two elements namely Levelized cost of electricity (LCOE) and self-consumption. Findings reveal that pooling of prosumers associated with lower load profile volatility improved self-consumption levels indicating that effective coordination among prosumers leads to economic benefits. Also, LCOE reached grid parity. These results suggest the viability of electricity prosumer models for economic gains [46].

Another study arrived at similar findings regarding the economic operations of the future retail energy system with high prosumer participation [91]. Using novel game-theoretic algorithms this study investigated several case studies, and the results reveal that prosumer group coalitions cleared the retail electricity market price.

Based on a literature review of related journal articles, categories for the socio-economic aspects include costs, consumers' perception, privacy, cybersecurity, and regulation that influence smart grid technologies and public acceptance [92]. Analysis revealed that majority of the literature addresses costs issues [96–98], cyber security [76,99,100], regulatory aspects [97,101,102], customer privacy [3,103,104], and consumers' perception [105–107]. Furthermore, it is recommended to acquire support from information science and engineering to devise methods for automated operational monitoring, assessment, control, and decision-making to meet social, economic and environmental needs [85].

Examining both social and technological aspects led to a four-layered framework to study the interactive prosumer behaviors in the emerging distribution system [93]. Using a multi-agent based simulation, results of the study show that technical interactions and social interactions affect the operational performance of the power systems wherein social values may dominate the impact of price signals. Although a prosumer's energy generation and demand can be price-responsive, social interactions may have a significant influence on their attitudes [93].

The technical and economic feasibility of both Household Energy Storage (HES) and Community Energy Storage (CES) technologies is investigated using real data of 39 households in a pilot project in the Netherlands [28]. Results reveal that PV self-consumption significantly contributes to savings achieved by storage and influences the payback period. Using both HES and CES systems reduce costs by 22–30% while increases PV self-consumption by 23–29%. Furthermore, considering current storage costs, both HES and CES are economically infeasible.

The analysis of different aspects of literature related to the effective existence of community renewable energy networks (CREN) reveals that although there is abundant information on the technology components, the social aspects have not received the same level of attention [83]. These social aspects include human infrastructure or collaboration [89], economics [85,90,92], and governance [94,95]. Adopting a holistic approach is significant, and hence, both technological and social aspects should incorporate into a working solution for successful implementation of CREN [83]. An investigation on the key issues shaping ICES also reveals a similar line of thought. Attention is needed in all aspects including technical, socio-economic, environmental and institutional to support the emergence of ICES [18].

Other studies also study this holistic approach and discuss the sociological, economic and technological drivers for the energy turnaround along with the environmental and political drivers [74]. Findings reveal that although technological development promotes energy turnaround, the other four factors also drive the evolution of the energy system. Therefore, it is critical to analyze all these factors for a sustainable deployment of the smart grid [74]. Following the above, we propose the following:

Proposition 8. *(a) A holistic approach spanning social, economic and technological dimensions is essential when examining smart grids; (b) Social values are impactful in bringing a change in prosumer behavior; (c) Social interactions and cultural values influence energy exchanges between households, and attitudes on benefit and comfort.*

3. Future Work

This section will elaborate the potential areas for future research in the prosumer communities and prosumer relationships space. Section 2 of this paper thoroughly reviewed the existing literature to propose eight propositions. We now outline future research opportunities in the prosumers management space. The structure of this section follows the taxonomy shown in Figure 2.

3.1. Prosumer Communities

3.1.1. Prosumer Definitions, Objectives, and Motivations

This section outlines the need for further research in the area of prosumers' objectives and motivations. Such studies would need to be interdisciplinary or multi-disciplinary covering social, political, technological and economic perspectives. For example, understanding prosumer psychology would be critical in understanding what motivates their behavior. Motivation can be triggered using economic incentives or penalties. Technological advances may be required to realize such social and economic objectives. To achieve this, we need to understand several elements at a conceptual level before developing detailed solutions. This understanding will enable us to grasp the big picture and attain a wider perspective of the opportunities, issues, and challenges surrounding a given field of interest.

As the prosumer community based smart grids continues to evolve at an accelerated pace, it is essential to gain a conceptual understanding of the new technologies, the emergence of related institutions, the different actors and systems involved in the energy sharing dynamics, and their shifting of roles and responsibilities [19]. Once we acquire this conceptual understanding, we will be equipped with the necessary knowledge and awareness to evaluate the impact of these elements towards the deployment and advancement of sustainable PCGs and other similar concepts such as ICESs, EPCs, and CECs.

Quantitative evaluation of empirical data would pave the way for a deeper understanding of the value of PCGs and ICESs, how they contribute to an efficient energy value network, and how they affect different actors and the wider energy system [18]. The tools identified for the planning and analysis of ICES are helpful for further development of ICES and design sustainability models and deployment options for ICES [21].

Moreover, ICESs need to adapt and enable further technological and social innovation as the energy landscape continues to change alongside the emergence of new technologies [19]. Two emerging technologies that will greatly impact the society are blockchain and big data. Although several studies already exist which examined how these technologies will transform the future of smart grids, these topics could be further investigated. One study presented a simple local energy market running on a private blockchain and recommended to further examine the suitability and technological limitations of blockchain-based energy market design [108]. Another study found that the use of blockchain technology in demand side management is suitable for matching energy demand and supply within the smart grid [109]. A separate study proposed a system using blockchain based smart contracts to allow secure energy exchange between prosumers [110]. Furthermore, we explored big energy data management in smart grids which include the different steps to process the heterogeneous data [34]. The study presented various challenges such as secure data communication, bad data detection, cost optimization, quality of service, data reliability, visualization, and integration [34]. These challenges could provide guidance for future research directions in this field.

Consequently, these quantitative outcomes and clear understanding of the changing energy landscape can help establish suitable governance structures, policies, incentive strategies, and support schemes (drivers for adoption and success) to overcome challenges and difficulties in the planning, operation, and advancement of ICESs [18,19]. Therefore, another future research direction is examining and identifying the suitable policy recommendations that will lead to effective and sustainable energy exchanges within the smart grids.

Likewise, a closer examination of various cultural, economic, political, social, infrastructural aspects among different actors and institutions is necessary for future energy planning [22].

Field trials are equally critical to evaluate the effectiveness of proposed techniques and methodologies. For example, field trials could utilize MATCH, a real-time algorithm based on the theory of Lyapunov optimization, to assess its functions in the daily operations of the smart grid [23]. Furthermore, as future work, the proposed framework and methodologies in managing PCGs could be tested using a larger dataset in the real world to evaluate system performance in real time [4,7,8].

In addition, energy management strategies could take into account the technology aspect. For example, in the future, a prosumer energy management system with central storage and fair priority allocation could be further examined for improved peak load management and system reliability [24].

3.1.2. Prosumer Roles

This section outlines the need for further research for a deeper understanding of the role of prosumers in achieving sustainable PCGs.

Studies like [37,40] mentioned several propositions for prosumer roles. However, these need quantitative validation and empirical testing to develop hypotheses. For testing various factors such as the amount of prosumers' price reduction resulting from policy actions, the percentage of current vs. potential adopters, the percentage of prosumers involved in testing, and the percentage of early prosumers engaged in co-creation [40].

The literature also indicates prosumers as actors engaging in innovation and value creation processes, but research is limited in this area. The innovative aspects of their role as prosumers as well as their motivations for co-creational activities require further attention in the future [38]. Co-creation is the building block for sustainable operation of prosumer communities, and hence understanding co-creation from different perspectives such as motivation, finance, and relationships will be critical.

The differences between early market and late market prosumers can be further examined to understand prosumer behavior their requirements and best management approaches for a sustainable prosumer grid [37]. The literature also discusses prosumers' role in providing flexibility. However, the extent to which they are willing to provide flexibility and the different factors affecting their preference of flexibility option are areas for further investigation [39].

There are several independent technical and social studies published in the literature. However, holistic studies that cover socio-technical aspects are possible areas to be explored in the future. Such interdisciplinary research would result in highly practical and useful solutions for the society.

Furthermore, new roles or entities have emerged in the energy system. One of these is the "prosumager" which is defined in literature as a prosumer who engages in storing excess energy for later use [111]. In the future, these new entities could be explored further to examine the transformations of prosumer roles and investigate how these new roles may potentially drive advancements of energy management within the smart grids.

3.1.3. Prosumer Community/Coalition Formation

This section outlines the need for further research on the formation of prosumer communities. Although this area has progressed, we believe there is room for improvement to enhance the proposals or come up with novel and innovative approaches.

One promising direction of research could be to plan and implement new methodologies in the formation of PCGs. The concept of goal-oriented virtual prosumer communities had been introduced [10], but novel, smart techniques and strategies could be designed to optimize the formation, growth, and management of prosumer communities [11].

The objectives of these new techniques could be to make way for a more robust formation of sustainable PCG's that encourage active participation among prosumers for a more sustainable energy sharing.

Trust and local reputation of prosumers can be used to study prosumer behavior and form cohesive prosumer groups [81]. One interesting direction of research would be to assess the degree of effectiveness of trust and reputation in building sustainable PCGs. Further, a comparative study of trust based and profile based systems could be undertaken to understand the superiority of these approaches.

Due to high implementation and maintenance costs of centralized schemes for energy exchanges in prosumer communities, another future work would be to design decentralized energy exchange strategies using other data-based approaches. One recommendation is through agent-based modeling approach using Reinforcement Learning [17]. Since agents can intrinsically self-improve over time with newly acquired data, this approach could be an effective decentralized strategy for decision management and control in smart grids [51].

In evaluating these new methodologies, actual data extracted from energy markets and aggregators' records could be used for testing to mimic closer to real-life scenarios [45]. Doing so will yield more realistic results. Additionally, research efforts could be directed towards understanding switching of prosumers from one PCG to another.

Another interesting future research area is to explore the different communities that exist in the energy market. We mentioned about other communities that are closely related to PCGs used across the literature such as EPCs, ICESs and CECs. These communities, including microgrids and virtual power plants and other emerging energy communities, could be compared and contrasted to gain a deeper understanding of the strengths, weaknesses, and effectiveness of each towards developing a sustainable energy exchange.

3.1.4. Prosumer Market Design

This section presents several possible future works in the prosumer market design area. Future research areas and directions include prosumer behavior, design issues, deployment and enforcement issues, distributive impact, regulatory and policy issues, economic factors, business opportunities, environmental effects, and public view and opinions [36].

A closer examination of these socio-techno-economic elements could help in improving the design and development of prosumer markets.

The proposed prosumer market models have their primary roles and functions as well as challenges. A poorly designed prosumer market may lead to failure of these markets which may have a serious impact on consumer empowerment, sustainability, and continuous improvement initiatives. Thus, future work could cover additional studies for a more informed technological perspective and sufficient awareness of the strengths and challenges of the various approaches [16].

Further, different market designs also cater to different market objectives. Thus, future research could cover the multiple interdependencies between social, economic, and political market objectives [53]. A deeper understanding of the correlation of these objectives is essential for the suitable consideration and evaluation of the energy market.

Concerning the federated power plant (FPP) market structure, further research could also cover several areas of interest [49]. First is to identify new methods that determine complementary prosumer capabilities that will provide efficient grid services. Second research area is about trust, knowledge and skill development towards participating in FPPs. Another research area is about the P2P energy trading and how it could be affected by prosumer locations and DER characteristics such as flexibility, variability, and capacity. Finally, the necessary regulatory changes brought about by new business models also need to be examined [49].

Appropriate ICT for the local energy market should also be determined, which should be able to link the prosumer market participants for them to work together effectively [53].

Furthermore, large-scale advanced prosumer markets would involve stronger participation and more meaningful contributions from researchers, vendors and energy providers, policy makers, regulatory bodies, and other overall industry-wide participants [16].

Additionally, as the prosumer network grows, it will become more challenging to manage groups as different prosumers may be part of more than one group. For example, a prosumer may be selling energy to two different suppliers. In this case, there will be an emerging need to identify/detect communities as well as methods to allocate energy supply to different suppliers. This is a new and emerging area for smart grid research. However, existing investigations of this area were from an online social networks perspective [54].

3.1.5. Prosumer Management

The prosumer management area attracts significant attention among researchers and several existing research projects address critical challenges such as energy sharing approaches, prosumer groupings, prosumer motivations, and incentive strategies. However, there is a need to discover and develop novel and innovative approaches that address these challenges more effectively and efficiently.

Rathnayaka's published articles cover significant areas which are helpful in gaining a firm understanding of prosumer communities and their management schemes. These include an analysis of prosumers' energy behavior profiles [8], a framework to manage multiple goals [4], and a methodology to form PCGs [4,7,10], among others. However, a thorough examination of the related challenges involved in managing PCGs is limited. Rathnayaka enumerated six open challenges which need to be further investigated namely: "lack of approaches that take energy sharing between prosumers and consumers into account; lack of systematic methods for grouping of prosumers; lack of prosumer inspiration; limited approaches to identify and attract more dynamic prosumers; lack of approaches to identify risks associated with negative behaviors of prosumers; and lack of comprehensive prosumer rewarding schemes, including non-financial aspects" [5]. These are areas to be explored for future work which can contribute to developing sustainable PCGs.

Existing research on prosumer management strategies is focused primarily on residential consumers. In the future, the proposed methods could be explored and optimized for different business types and industries such as restaurants, hotels, universities, and factories [55]. In the future, actual dataset obtained from Future Energy Management System or other available dataset from existing energy systems could also be used for testing the general usability of the proposed methods [55].

3.2. Prosumer Relationships

3.2.1. Provider-Consumer Relationship

This section outlines the need for further research in this area of provider-consumer relationship in different settings. The systematic representation of the entities, actors, processes, actions, and associations within the energy system is beneficial to analyze the prosumers' behaviors and relationships further. The system models could enable designers and architects to examine new characteristics of the system and study the different associated challenges in advancing to a more resilient and flexible system [60].

The study on provider-consumer relationship based on retrospective interviews may have had biased interviewees' reflections on their behaviors and decisions, hence, more suitable extensive methods such as participatory approaches could be investigated in the future [61]. Additional empirical studies could also be conducted in the future to examine the implications of various ownership and governance structures to prosumer relationships [62]. With these in-depth methods, we could further investigate the underlying prosumers' behaviors and motivations and gain a deeper understanding of prosumer relations [61].

The interaction between compensation and retaliation appears to influence the prosumers' energy sharing behavior unfavorably and could also be an interesting area to further explore in the future [61].

Based on the hypothesis that greater symbiotic integration directly correlates to greater sustainability, another area for future research would be to evaluate the degree of impact of symbiotic insertion and its effects on sustainability [71]. Furthermore, since reciprocity is a vital element in prosumer relationships, business models for co-production could also be an interesting topic of investigation [61].

In the context of performance-based contract design, another area for future research would be to develop a framework for improved risk evaluation between the provider and the consumer when entering into new contracts [66]. The objective would be to fairly allocate the incentives and risks to guarantee a win-win situation for both parties. For example, further evaluation of the current incentive strategies implemented in China could be a future work and reviewed if similar policies for renewable energy industry could be adopted by other countries [68]. Moreover, research in understanding the impact of negotiations with powerful suppliers to obtain strong bargaining power in a challenging area of research.

3.2.2. Consumer Engagement

This section outlines the need for further research in the area of consumer engagement. Suggested research areas include the identification of socio-economic motivations for consumer engagement, regulatory measures, and sustainable funding policies to support the crowd energy concept [74]. Further study is also needed to design and implement mechanisms to handle the automation and control in support of the decentralization [74]. These mechanisms would involve the use of information and communications technologies to integrate the decentralized production, storage and load, business relationships and prosumers.

A comparative study to determine the factors influencing smart grid acceptance among current and potential consumers is another area for investigation [76]. The results would lead to more reasonable suggestions for policies and measures for smart grid participation. Future studies could also consider exogenous and endogenous variables [76].

The factors influencing industrial consumers' smart grid participation were derived based on a qualitative approach using data from four Danish companies [77]. Denmark is an emerging nation in the field of the future intelligent grid, and the research findings apply to Danish smart grid context. Thus, it is recommended to extend the study of this topic through cross-national comparisons. Also, the study used a qualitative approach. Hence, further qualitative or quantitative approaches could be used to validate the research findings [77].

Trust management is essential in customer engagement, but there is limited work that relates trust in the smart grids. Therefore, future work could include investigating the process of trust and distrust attribution in the smart grid [82]. This could be further extended by analyzing or simulating dataset extracted from a real social network, to understand trust measures that can do profile matching to strengthen community cohesion [80].

3.2.3. Socio-Economic-Technological Aspect

Prosumer management covers social, economic, and technological dimensions. This section outlines different areas for future research concerning these three dimensions.

A significant topic for future research is the emerging forms of mutuality in upcoming energy initiatives where digital platforms enable energy exchanges [86]. For example, this could include exploring how Facebook and other social media platforms can act as an enabling platform for energy sharing initiatives such as Vandebron in The Netherlands and Brooklyn Micro-grid in the USA [86]. A future study could also cover the different challenges encountered when using these digital platforms.

Another future work could be to investigate energy management methods based on the consumer-centered energy system architecture aimed at achieving various optimization targets in an electric vehicle integrated smart grid [89].

Being a major stakeholder in the energy sharing process, the role of utilities is also essential. Future research direction could be to investigate the different functionalities of utilities further as these would significantly affect business decisions [15,91]. The developed game-theoretic framework could be enhanced to consider uncertainties such as customer behaviors which are becoming more difficult to predict [91]. Another line for future research would be to examine the optimal sizing of energy cells for strategic planning. Furthermore, the framework could be extended to apply to large smart grids that could operate in real-world scenarios [91].

Analyzing the socio-economic setting is essential to gain a deeper level of acceptability for smart grid development among consumers [92]. Therefore, the socio-economic investigations are an essential aspect of future research. Resolving the engineering and the socio-economic research gap could also be another research direction. Another area would be business applications, security, policy, and organizational approaches [92]. Even with the rapid advancement of technology, the development of new technologies alone does not guarantee acceptance from consumers because consumers perceive that this comes at high costs.

Instead of investigating the various elements from the technical or social science perspectives separately, it is recommended to focus on bringing together all these contributions from different perspectives and adopt a holistic approach [83]. The suitable business model would incorporate features such as a combination of technologies to optimize system implementation, cost structures to enhance funding and ongoing operations, defined management and governance structures to allow meaningful collaboration, and necessary relationships to provide a convincing value proposition for the adoption of PCGs [83].

4. Conclusions

Prosumers are new entities in the smart grid that produce, consume, store, and share energy with other users in the grid. They play a vital role in the energy value network by contributing towards flexibility, innovation, and value creation. Prosumer communities help enable an efficient and sustainable energy sharing process. Due to its significant relevance, this field of research is rapidly progressing, and hence there is a need to identify the key issues, challenges, and opportunities in this area. Therefore, this paper systematically evaluated the progress in prosumer communities and relationships by investigating 105 articles published between 2009 to 2018. We presented eight propositions based on our findings of the evaluated literature. We also observed that although there is significant research growth on this topic, there are still numerous research gaps and open issues. Thus, we outlined several research questions that require further investigation. These questions would steer the research direction in the future.

Author Contributions: Conceptualization, E.C. and V.P.; Invastigation and research directions, E.E., E.C. and V.P.

Funding: This research received no external funding.

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

References

1. EIA. International Energy Outlook 2017. Available online: https://www.eia.gov/outlooks/ieo/index.php (accessed on 27 March 2018).
2. Gharavi, H.; Ghafurian, R. Smart Grid: The Electric Energy System of the Future. *Proc. IEEE* **2011**, *99*, 917–921. [CrossRef]
3. El-hawary, M.E. The Smart Grid—State-of-the-art and Future Trends. *Electr. Power Compon. Syst.* **2014**, *42*, 239–250. [CrossRef]

4. Rathnayaka, A.D.; Potdar, V.M.; Dillon, T.; Kuruppu, S. Framework to manage multiple goals in community-based energy sharing network in smart grid. *Int. J. Electr. Power Energy Syst.* **2015**, *73*, 615–624. [CrossRef]
5. Rathnayaka, A.J.D.; Potdar, V.; Ou, M.H. Prosumer Management in Socio-technical Smart Grid. In Proceedings of the CUBE International Information Technology Conference, Pune, India, 3–5 September 2012; pp. 483–489.
6. Rathnayaka, A.J.D. Development of a Community-Based Framework to Manage Prosumers in Smart Grid. Ph.D. Thesis, Curtin University, Perth, Australia, 2014.
7. Rathnayaka, A.J.D.; Potdar, V.M.; Dillon, T.S.; Hussain, O.K.; Chang, E. A Methodology to Find Influential Prosumers in Prosumer Community Groups. *IEEE Trans. Ind. Inform.* **2014**, *10*, 706–713. [CrossRef]
8. Rathnayaka, A.J.D.; Potdar, V.M.; Dillon, T.; Hussain, O.; Kuruppu, S. Analysis of energy behaviour profiles of prosumers. In Proceedings of the IEEE 10th International Conference on Industrial Informatics (INDIN), Beijing, China, 25–27 July 2012; pp. 236–241.
9. Rathnayaka, A.D.; Potdar, V.M.; Kuruppu, S.J. Evaluation of wireless home automation technologies. In Proceedings of the IEEE 5th International Conference on Digital Ecosystems and Technologies (DEST), Daejeon, Korea, 31 May–3 June 2011; pp. 76–81.
10. Rathnayaka, A.D.; Potdar, V.M.; Dillon, T.; Hussain, O.; Kuruppu, S. Goal-oriented prosumer community groups for the smart grid. *IEEE Technol. Soc. Mag.* **2014**, *33*, 41–48. [CrossRef]
11. Rathnayaka, A.D.; Potdar, V.M.; Kuruppu, S.J. An innovative approach to manage prosumers in Smart Grid. In Proceedings of the IEEE World Congress on Sustainable Technologies (WCST), London, UK, 7–10 November 2011; pp. 141–146.
12. Rathnayaka, A.D.; Potdar, V.M.; Hussain, O.; Dillon, T. Identifying prosumer's energy sharing behaviours for forming optimal prosumer-communities. In Proceedings of the IEEE International Conference on Cloud and Service Computing (CSC), Hong Kong, China, 12–14 December 2011; pp. 199–206.
13. Rathnayaka, A.D.; Potdar, V.M.; Dillon, T.S.; Kuruppu, S. Formation of virtual community groups to manage prosumers in smart grids. *Int. J. Grid Util. Comput.* **2014**, *6*, 47–56. [CrossRef]
14. Rathnayaka, A.; Potdar, V.; Kuruppu, S. Design of smart grid prosumer communities via online social networking communities. *Int. J. Infonomics* **2012**, *5*, 544–556. [CrossRef]
15. Zafar, R.; Mahmood, A.; Razzaq, S.; Ali, W.; Naeem, U.; Shehzad, K. Prosumer based energy management and sharing in smart grid. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1675–1684. [CrossRef]
16. Parag, Y.; Sovacool, B.K. Electricity market design for the prosumer era. *Nat. Energy* **2016**, *1*, 1–6. [CrossRef]
17. Olivier, F.; Marulli, D.; Ernst, D.; Fonteneau, R. Foreseeing New Control Challenges in Electricity Prosumer Communities. In Proceedings of the 10th Bulk Power Systems Dynamics and Control Symposium—IREP'2017, Espinho, Portugal, 21 August–1 September 2017.
18. Koirala, B.P.; Koliou, E.; Friege, J.; Hakvoort, R.A.; Herder, P.M. Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. *Renew. Sustain. Energy Rev.* **2016**, *56*, 722–744. [CrossRef]
19. Koirala, B.; Hakvoort, R. Integrated Community-Based Energy Systems: Aligning Technology, Incentives, and Regulations. In *Innovation and Disruption at the Grid's Edge*; Academic Press: Cambridge, MA, USA, 2017; pp. 363–387.
20. Xu, X.; Jin, X.; Jia, H.; Yu, X.; Li, K. Hierarchical management for integrated community energy systems. *Appl. Energy* **2015**, *160*, 231–243. [CrossRef]
21. Mendes, G.; Ioakimidis, C.; Ferrão, P. On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4836–4854. [CrossRef]
22. Gui, E.M.; Macgill, I. Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. *Energy Res. Soc. Sci.* **2018**, *35*, 94–107. [CrossRef]
23. Pal, R.; Chelmis, C.; Frincu, M.; Prasanna, V. Match for the prosumer smart grid the algorithmics of real-time power balance. *IEEE Trans. Parallel Distrib. Syst.* **2016**, *27*, 3532–3546. [CrossRef]
24. Mahmood, A.; Butt, A.R.; Mussadiq, U.; Nawaz, R.; Zafar, R.; Razzaq, S. Energy sharing and management for prosumers in smart grid with integration of storage system. In Proceedings of the 5th International Istanbul Smart Grid and Cities Congress and Fair (ICSG), Istanbul, Turkey, 19–21 April 2017; pp. 153–156.
25. Tejani, D.; Al-Kuwari, A.M.A.; Potdar, V. Energy conservation in a smart home. In Proceedings of the 5th IEEE International Conference on Digital Ecosystems and Technologies (DEST), Daejeon, Korea, 31 May–3 June 2011; pp. 241–246.

26. Al-Kuwari, A.M.A.; Ortega-Sanchez, C.; Sharif, A.; Potdar, V. User friendly smart home infrastructure: BeeHouse. In Proceedings of the 5th IEEE International Conference on Digital Ecosystems and Technologies (DEST), Daejeon, Korea, 31 May–3 June 2011; pp. 257–262.
27. Jarnut, M.; Wermiński, S.; Waśkowicz, B. Comparative analysis of selected energy storage technologies for prosumer-owned microgrids. *Renew. Sustain. Energy Rev.* **2017**, *74*, 925–937. [CrossRef]
28. Van der Stelt, S.; AlSkaif, T.; van Sark, W. Techno-economic analysis of household and community energy storage for residential prosumers with smart appliances. *Appl. Energy* **2018**, *209*, 266–276. [CrossRef]
29. Wongwut, K.; Nuchprayoon, S. Optimum hourly operation of a prosumer with battery energy storage system under time-of-use pricing. In Proceedings of the PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Bangalore, India, 8–10 November 2017; pp. 1–6.
30. Nefedov, E.; Sierla, S.; Vyatkin, V. Towards electric vehicles integration to distributed energy resources of prosumer. In Proceedings of the 15th International Conference on Industrial Informatics (INDIN), Emden, Germany, 24–26 July 2017; pp. 769–772.
31. Mahmud, K.; Town, G.E.; Morsalin, S.; Hossain, M. Integration of electric vehicles and management in the internet of energy. *Renew. Sustain. Energy Rev.* **2018**, *82*, 4179–4203. [CrossRef]
32. El-Batawy, S.; Morsi, W.G. Optimal Design of Community Battery Energy Storage Systems with Prosumers Owning Electric Vehicles. *IEEE Trans. Ind. Inform.* **2017**. [CrossRef]
33. Mumtaz, S.; Ali, S.; Ahmad, S.; Khan, L.; Hassan, S.Z.; Kamal, T. Energy Management and Control of Plug-In Hybrid Electric Vehicle Charging Stations in a Grid-Connected Hybrid Power System. *Energies* **2017**, *10*, 1923. [CrossRef]
34. Potdar, V.; Chandan, A.; Batol, S.; Patel, N. Big Energy Data Management for Smart Grids—Issues, Challenges and Recent Developments. In *Smart Cities*; Springer: Cham, Switzerland, 2018; pp. 177–205.
35. Wongthongtham, P.; Kaur, J.; Potdar, V.; Das, A. Big Data Challenges for the Internet of Things (IoT) Paradigm. In *Connected Environments for the Internet of Things*; Springer: Berlin, Germany, 2017; pp. 41–62.
36. Parag, Y. Beyond energy efficiency: A 'prosumer market'as an integrated platform for consumer engagement with the energy system. *Eur. Counc. Energy Effic. Econ. Summer Study* **2015**, *1*, 15–23.
37. Kotilainen, K.; Järventausta, P.; Aalto, P. Prosumer centric co-creation in Smart Grid innovation ecosystem. In Proceedings of the Innovative Smart Grid Technologies-Asia (ISGT-Asia), Melbourne, Australia, 28 November–1 December 2016; pp. 884–889.
38. Kotilainen, K.; Sommarberg, M.; Järventausta, P.; Aalto, P. Prosumer centric digital energy ecosystem framework. In Proceedings of the 8th International Conference on Management of Digital EcoSystems, Biarritz, France, 1–4 November 2016; pp. 47–51.
39. Kubli, M.; Loock, M.; Wüstenhagen, R. The flexible prosumer: Measuring the willingness to co-create distributed flexibility. *Energy Policy* **2018**, *114*, 540–548. [CrossRef]
40. Kotilainen, K.; Mäkinen, S.J.; Järvetausta, P.; Antti, R.; Markkula, J. The role of residential prosumers initiating the energy innovation ecosystem to future flexible energy system. In Proceedings of the 13th International Conference on the European Energy Market (EEM), Porto, Portugal, 6–9 June 2016; pp. 1–5.
41. Kotilainen, K.; Mäkinen, S.J.; Järventausta, P. Understanding prosumers' intrinsic and extrinsic motivations to become active participants in smart grid innovation ecosystem. In Proceedings of the PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Ljubljana, Slovenia, 9–12 October 2016; pp. 1–6.
42. Venkatachary, S.K.; Prasad, J.; Samikannu, R. Challenges, Opportunities and Profitability in Virtual Power Plant Business Models in Sub Saharan Africa-Botswana. *Int. J. Energy Econ. Policy* **2017**, *7*, 48–58.
43. Rodríguez-Molina, J.; Martínez-Núñez, M.; Martínez, J.-F.; Pérez-Aguiar, W. Business models in the smart grid: Challenges, opportunities and proposals for prosumer profitability. *Energies* **2014**, *7*, 6142–6171. [CrossRef]
44. Wüstenhagen, R.; Kubli, M.; Loock, M. The Flexible Prosumer: Customer Co-Creation of Ancillary Services in Smart Grids. In *Heading Towards Sustainable Energy Systems: Evolution or Revolution? Proceedings of the 15th IAEE European Conference, Vienna, Austria, 3–6 September 2017*; International Association for Energy Economics: Vienna, Austria, 2017.
45. Gensollen, N.; Gauthier, V.; Becker, M.; Marot, M. Stability and Performance of Coalitions of Prosumers Through Diversification in the Smart Grid. *IEEE Trans. Smart Grid* **2018**, *9*, 963–970. [CrossRef]
46. Kästel, P.; Gilroy-Scott, B. Economics of pooling small local electricity prosumers—LCOE & self-consumption. *Renew. Sustain. Energy Rev.* **2015**, *51*, 718–729.

47. Chandan, A.; Potdar, V.; Nandi, C. Pricing Mechanisms for Energy Management in Smart Cities. In *Smart Cities*; Springer: Cham, Switzerland, 2018; pp. 71–103.
48. Bird, S.; Hernández, D. Policy options for the split incentive: Increasing energy efficiency for low-income renters. *Energy Policy* **2012**, *48*, 506–514. [CrossRef] [PubMed]
49. Morstyn, T.; Farrell, N.; Darby, S.J.; McCulloch, M.D. Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. *Nat. Energy* **2018**, *3*, 94–101. [CrossRef]
50. Rekik, M.; Chtourou, Z.; Mitton, N.; Atieh, A. Geographic routing protocol for the deployment of virtual power plant within the smart grid. *Sustain. Cities Soc.* **2016**, *25*, 39–48. [CrossRef]
51. Glavic, M.; Fonteneau, R.; Ernst, D. Reinforcement Learning for Electric Power System Decision and Control: Past Considerations and Perspectives. *IFAC-PapersOnLine* **2017**, *50*, 6918–6927. [CrossRef]
52. Chen, T.; Alsafasfeh, Q.; Pourbabak, H.; Su, W. The Next-Generation US Retail Electricity Market with Customers and Prosumers—A Bibliographical Survey. *Energies* **2017**, *11*, 8. [CrossRef]
53. Mengelkamp, E.; Staudt, P.; Garttner, J.; Weinhardt, C. Trading on local energy markets: A comparison of market designs and bidding strategies. In Proceedings of the 14th International Conference on the European Energy Market (EEM), Dresden, Germany, 6–9 June 2017; pp. 1–6.
54. Sharma, R.; Oliveira, S. Community Detection Algorithm for Big Social Networks Using Hybrid Architecture. *Big Data Res.* **2017**, *10*, 44–52. [CrossRef]
55. Fabisz, K.; Filipowska, A.; Hossa, T. Profiling of Prosumers for the Needs of Electric Energy Demand Estimation in Microgrids. *Int. J. Energy Optim. Eng.* **2015**, *4*, 29–45. [CrossRef]
56. Lampropoulos, I.; Vanalme, G.M.; Kling, W.L. A methodology for modeling the behavior of electricity prosumers within the smart grid. In Proceedings of the PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe), Gothenberg, Sweden, 11–13 October 2010; pp. 1–8.
57. Oprea, S.V. Informatics Solutions for Prosumers connected to Smart Grids. *Database Syst. J.* **2015**, *5*, 12–20.
58. Hubert, T.; Grijalva, S. Modeling for residential electricity optimization in dynamic pricing environments. *IEEE Trans. Smart Grid* **2012**, *3*, 2224–2231. [CrossRef]
59. Adika, C.O.; Wang, L. Autonomous appliance scheduling for household energy management. *IEEE Trans. Smart Grid* **2014**, *5*, 673–682. [CrossRef]
60. Alriyami, O.; Suleiman, H.; Svetinovic, D.; Zeineldin, H. Smart grid consumer-provider relationship analysis using system modeling approach. In Proceedings of the International Conference on Green Computing and Communications (GreenCom), Besancon, France, 20–23 November 2012; pp. 603–606.
61. Olkkonen, L.; Korjonen-Kuusipuro, K.; Grönberg, I. Redefining a stakeholder relation: Finnish energy "prosumers" as co-producers. *Environ. Innov. Soc. Transit.* **2017**, *24*, 57–66. [CrossRef]
62. Gui, E.M.; Diesendorf, M.; MacGill, I. Distributed energy infrastructure paradigm: Community microgrids in a new institutional economics context. *Renew. Sustain. Energy Rev.* **2017**, *72*, 1355–1365. [CrossRef]
63. Neuhoff, K.; Wolter, S.; Schwenen, S. Power Markets with Renewables: New Perspectives for the European Target Model. *Energy J.* **2016**, *37*, 23–38. [CrossRef]
64. Longoria, G.; Shi, L. Nash-equilibrium electricity portfolios in the smart grid: A genetic annealing solution. In Proceedings of the 5th International Istanbul Smart Grid and Cities Congress and Fair (ICSG), Istanbul, Turkey, 19–21 April 2017; pp. 56–59.
65. Gui, E.; Diesendorf, M. Quasi-Market Design for Community Microgrids. In *Meeting Asia's Energy Challenges, Proceedings of the 5th IAEE Asian Conference, Perth, Australia, 14–17 February 2016*; International Association for Energy Economics: Perth, Australia, 2016.
66. Carbonara, N.; Pellegrino, R. Public-private partnerships for energy efficiency projects: A win-win model to choose the energy performance contracting structure. *J. Clean. Prod.* **2018**, *170*, 1064–1075. [CrossRef]
67. Wasa, Y.; Hirata, K.; Uchida, K. A dynamic contract mechanism for risk-sharing management on interdependent electric power and gas supply networks. In Proceedings of the 11th Asian Control Conference (ASCC), Gold Coast, QLD, Australia, 17–20 December 2017; pp. 1222–1227.
68. Zhao, Z.-Y.; Chen, Y.-L.; Chang, R.-D. How to stimulate renewable energy power generation effectively?–China's incentive approaches and lessons. *Renew. Energy* **2016**, *92*, 147–156. [CrossRef]
69. Long, Y.; Wang, Y.; Pan, C. Incentive Mechanism of Micro-grid Project Development. *Sustainability* **2018**, *10*, 163. [CrossRef]
70. Sumesh, S.; Potdar, V.; Krishna, A. Clustered Prosumer Penalty Framework on Smart Grid. In *Advances in Smart Grid and Renewable Energy*; Springer: Berlin, Germany, 2018; pp. 1–12.

71. Silva, L.; Guevara, A.; Oliveira, P.; Fernandes, K. Homo Sustentabilis: Symbiotic Open Collaborative Possibilities among Nature, Industry and Consumers. In Proceedings of the 14th International Conference on Innovation & Management (ICIM); Wuhan University of Technology Press: London, UK, 2017; pp. 816–824.
72. Mah, D.N.; van der Vleuten, J.M.; Hills, P.; Tao, J. Consumer perceptions of smart grid development: Results of a Hong Kong survey and policy implications. *Energy Policy* **2012**, *49*, 204–216. [CrossRef]
73. Ellabban, O.; Abu-Rub, H. Smart grid customers' acceptance and engagement: An overview. *Renew. Sustain. Energy Rev.* **2016**, *65*, 1285–1298. [CrossRef]
74. Teufel, S.; Teufel, B. The crowd energy concept. *J. Electr. Sci. Technol.* **2014**, *12*, 263–269.
75. Moreno-Munoz, A.; Bellido-Outeirino, F.; Siano, P.; Gomez-Nieto, M. Mobile social media for smart grids customer engagement: Emerging trends and challenges. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1611–1616. [CrossRef]
76. Park, C.-K.; Kim, H.-J.; Kim, Y.-S. A study of factors enhancing smart grid consumer engagement. *Energy Policy* **2014**, *72*, 211–218. [CrossRef]
77. Ma, Z.; Asmussen, A.; Jørgensen, B.N. Industrial Consumers' Smart Grid Adoption: Influential Factors and Participation Phases. *Energies* **2018**, *11*, 182. [CrossRef]
78. Vereshchagina, V.; Gstrein, M.; Teufel, B. Analysis of the Stakeholder Engagement in the Deployment of Renewables and Smart Grid Technologies. *J. Electr. Sci. Technol.* **2015**, *13*, 221–228.
79. Dumitrache, I.; Constantin, N.; Stoica, O. Some Challenges for the Cyber—Physical Energy System. *IFAC Proc. Vol.* **2013**, *46*, 1–6. [CrossRef]
80. Fotia, L.; Messina, F.; Rosaci, D.; Sarné, G.M.L. On the impact of trust relationships on social network group formation. *CEUR Workshop Proc.* **2017**, *1867*, 25–30.
81. Fotia, L.; Messina, F.; Rosaci, D.; Sarné, G.M. Using Local Trust for Forming Cohesive Social Structures in Virtual Communities. *Comput. J.* **2017**, *60*, 1717–1727. [CrossRef]
82. Büscher, C.; Sumpf, P. "Trust" and "confidence" as socio-technical problems in the transformation of energy systems. *Energy Sustain. Soc.* **2015**, *5*, 34. [CrossRef]
83. Tomc, E.; Vassallo, A.M. Community Renewable Energy Networks in urban contexts: The need for a holistic approach. *Int. J. Sustain. Energy Plan. Manag.* **2015**, *8*, 31–42.
84. Good, N.; Ellis, K.A.; Mancarella, P. Review and classification of barriers and enablers of demand response in the smart grid. *Renew. Sustain. Energy Rev.* **2017**, *72*, 57–72. [CrossRef]
85. Yu, X.; Xue, Y. Smart grids: A cyber-physical systems perspective. *Proc. IEEE* **2016**, *104*, 1058–1070. [CrossRef]
86. Singh, A.; Strating, A.T.; Herrera, N.R.; van Dijk, H.W.; Keyson, D.V. Towards an ethnography of electrification in rural India: Social relations and values in household energy exchanges. *Energy Res. Soc. Sci.* **2017**, *30*, 103–115. [CrossRef]
87. Kowalski, J.; Biele, C.; Mlodozeniec, M.; Geers, M. Significance of Social Factors for Effective Implementation of Smart Energy Management Systems in End-User Households. In Proceedings of the International Conference on Intelligent Human Systems Integration, Dubai, UAE, 7–9 January 2018; pp. 119–124.
88. Nowak, A.; Rychwalska, A.; Szamrej, J. Social, psychological and technological determinants of energy use. *IEEE Technol. Soc. Mag.* **2014**, *33*, 42–47. [CrossRef]
89. Cheng, X.; Zhang, R.; Yang, L. Consumer-centered energy system for electric vehicles and the smart grid. *IEEE Intell. Syst.* **2016**, *31*, 97–101. [CrossRef]
90. Colak, I.; Fulli, G.; Bayhan, S.; Chondrogiannis, S.; Demirbas, S. Critical aspects of wind energy systems in smart grid applications. *Renew. Sustain. Energy Rev.* **2015**, *52*, 155–171. [CrossRef]
91. Zhang, N.; Yan, Y.; Su, W. A game-theoretic economic operation of residential distribution system with high participation of distributed electricity prosumers. *Appl. Energy* **2015**, *154*, 471–479. [CrossRef]
92. Bigerna, S.; Bollino, C.A.; Micheli, S. Socio-economic acceptability for smart grid development—A comprehensive review. *J. Clean. Prod.* **2016**, *131*, 399–409. [CrossRef]
93. Cai, Y.; Huang, T.; Bompard, E.; Cao, Y.; Li, Y. Self-sustainable community of electricity prosumers in the emerging distribution system. *IEEE Trans. Smart Grid* **2017**, *8*, 2207–2216. [CrossRef]
94. Buchmann, M. Governance of data and information management in smart distribution grids: Increase efficiency by balancing coordination and competition. *Util. Policy* **2017**, *44*, 63–72. [CrossRef]
95. Buchmann, M. The need for competition between decentralized governance approaches for data exchange in smart electricity grids—Fiscal federalism vs. polycentric governance. *J. Econ. Behav. Organ.* **2017**, *139*, 106–117. [CrossRef]

96. Dupont, B.; de Jonghe, C.; Kessels, K.; Belmans, R. Short-term consumer benefits of dynamic pricing. In Proceedings of the 8th International Conference on the European Energy Market (EEM), Zagreb, Croatia, 25–27 May 2011; pp. 216–221.
97. Clastres, C. Smart grids: Another step towards competition, energy security and climate change objectives. *Energy Policy* **2011**, *39*, 5399–5408. [CrossRef]
98. McHenry, M.P. Technical and governance considerations for advanced metering infrastructure/smart meters: Technology, security, uncertainty, costs, benefits, and risks. *Energy Policy* **2013**, *59*, 834–842. [CrossRef]
99. McDaniel, P.; McLaughlin, S. Security and Privacy Challenges in the Smart Grid. *IEEE Secur. Priv.* **2009**, *7*, 75–77. [CrossRef]
100. Ericsson, G.N. Cyber Security and Power System Communication—Essential Parts of a Smart Grid Infrastructure. *IEEE Trans. Power Deliv.* **2010**, *25*, 1501–1507. [CrossRef]
101. Glachant, J.-M. Regulating networks in the new economy. *Rev. Econ. Inst.* **2012**, *3*, 1–27. [CrossRef]
102. Hledik, R. How Green Is the Smart Grid? *Electr. J.* **2009**, *22*, 29–41. [CrossRef]
103. Cavoukian, A.; Polonetsky, J.; Wolf, C. SmartPrivacy for the Smart Grid: Embedding privacy into the design of electricity conservation. *Identity Inf. Soc.* **2010**, *3*, 275–294. [CrossRef]
104. McKenna, E.; Richardson, I.; Thomson, M. Smart meter data: Balancing consumer privacy concerns with legitimate applications. *Energy Policy* **2012**, *41*, 807–814. [CrossRef]
105. Gangale, F.; Mengolini, A.; Onyeji, I. Consumer engagement: An insight from smart grid projects in Europe. *Energy Policy* **2013**, *60*, 621–628. [CrossRef]
106. Stragier, J.; Hauttekeete, L.; de Marez, L. Introducing Smart grids in residential contexts: Consumers' perception of smart household appliances. In Proceedings of the Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES), Waltham, MA, USA, 27–29 September 2010; pp. 135–142.
107. Verbong, G.P.J.; Beemsterboer, S.; Sengers, F. Smart grids or smart users? Involving users in developing a low carbon electricity economy. *Energy Policy* **2013**, *52*, 117–125. [CrossRef]
108. Mengelkamp, E.; Notheisen, B.; Beer, C.; Dauer, D.; Weinhardt, C. A blockchain-based smart grid: Towards sustainable local energy markets. *Comput. Sci.-Res. Dev.* **2018**, *33*, 207–214. [CrossRef]
109. Pop, C.; Cioara, T.; Antal, M.; Anghel, I.; Salomie, I.; Bertoncini, M. Blockchain based decentralized management of demand response programs in smart energy grids. *Sensors* **2018**, *18*, 162. [CrossRef] [PubMed]
110. Shuaib, K.; Abdella, J.A.; Sallabi, F.; Abdel-Hafez, M. Using Blockchains to Secure Distributed Energy Exchange. In Proceedings of the 5th International Conference on Control, Decision and Information Technologies (CoDIT), Thessaloniki, Greece, 10–13 April 2018; pp. 622–627.
111. Sioshansi, F.P. Chapter 1—Innovation and Disruption at the Grid's Edge. In *Innovation and Disruption at the Grid's Edge*; Sioshansi, F.P., Ed.; Academic Press: Cambridge, MA, USA, 2017; pp. 1–22. ISBN 978-0-12-811758-3.