PV Energy Communities

Subjects: Energy & Fuels
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Renewable energy sources, in particular those based on solar radiation, are growing rapidly and are planned to play an instrumental role in building power systems to reach the 2030 and 2050 energy and climate mitigation objectives. However, new actors have been introduced into the energy field, highlighting the importance of the role of citizens and communities in building such energy systems.

Keywords: consumer ; literature review local energy communities ; PV ; photovoltaic communities ; renewable energy

1. Introduction

Solar communities are gaining popularity worldwide [1]. This increase in popularity can be explained by a sharp drop in the price of photovoltaic (PV) panels and increase in PV efficiency, reaching 44.5% [2]. This means that PV panels have a strong potential to become one of the main energy generation elements in local energy communities (LECs).

In such an arrangement, PV panels purchased by a residential house or the whole community would be installed on a plot of land or on rooftops, which could supply the electricity needed by the community. It would require both a billing system (to settle with the PV panel owners) and in some cases a connection to the existing electricity infrastructure in order to transfer the remaining generated electricity to the grid or to receive the missing amount of electricity from the grid.

As noted in [3][4], an energy community bonds a variety of collective energy actions (e.g., generation, distribution, supply, aggregation, consumption, sharing, storage of energy, electromobility and provision of energy-related services), involving a group of local members or stakeholders in the decision-making and bringing environmental, economic or social community benefits to their members and/or the local areas. A recent study by [5] stated that energy communities have the potential to become a standard model on the energy markets. However, challenges related to priority dispatching, curtailment, ownership and management of distribution networks need to be considered and thoroughly analysed. There are many additional challenges to the success of PV use for LECs, including policy support, financing, social acceptance and suitable management structure.

Barriers to the deployment of renewable energy are extensively mentioned in article [6]. It lists the main shortcomings and challenges, such as:

- Market failures: underinvestment in market R&D activities, low GHG emission quota prices, energy generation and utility companies' monopoly, RES solution unaffordability and high renewable market risks;
- Informational and awareness barriers: the impact of variables and uncertainties on energy production, lack of reliable energy generation and demand data, lack of modelling solutions, lack of skilled professionals and lack of RES awareness;
- Socio-cultural barriers: inefficient use of land for RES, lack of awareness of the benefits of using RES and weak communication between involved parties;
- Policy barriers: institutional monopoly from existing industry and infrastructure, monopoly-based energy policy, weak intellectual property rights protection and lack of RES support activities.

Looking specifically at energy community-related barriers, the LECo project created PESTLE (political, economic, social, technological, legislative and environmental) analysis [7] for four European countries: Germany, Finland, Sweden and Ireland, identifying existing barriers to energy communities. In addition to barriers described by [6] this analysis also mentioned:

- Social, cultural, political and organizational: lack of experience setting up communities and low trust in the community model;
- Legal, administrative and bureaucratic: complicated legal framework, bureaucratic barriers to grid connections and microgrids operations, lack of authority support and lack of RES support schemes;
- Technical: lack of expert knowledge about energy communities;
- Financial: access to finance, unfair payments for energy produced, weak incentive to use renewable energy in heating and tax and guarantees injustice;
- Challenges in existing communities: membership share value and investments into existing installations.

The aforementioned barrier solutions both from the RES and from the communities' point of view could be addressed through defined and targeted policies and legislative acts. However, the question can be raised: can these barriers be circumvented with the support of research activities, thus stimulating the adoption of relevant policy acts? In order to find an answer to this question, this article reviews the scientific literature of recent years, which will be used to find solutions to the problems related to RES and energy communities. Barriers can be defined in four consumer interest areas: policy, economic, technical and social. In order to perform a more targeted literature analysis on each of these areas, they could be divided into smaller subsections: policy, trading model, economic assessment, business model, energy management, demand response, modelling tools and consumer adoption. Given this division, the literature review seeks for solutions aimed at overcoming such consumer-relevant barriers in the form of these research questions:

- Policy: Does current policy support PV communities and what kinds of policy changes are needed?
- Trading model: What advantages and latest developments does the P2P energy market model have?
- Economic assessment: Are PV communities economically viable?
- Business model: What are the current business models and what changes should be made to improve them?
- Energy management: Is solar power the best solution for local energy production and why?
- Demand response: Does, and how does, demand response affect the effectiveness of PV communities?
- Modelling tools: What technical solutions related to the PV community have been developed in the last five years?
- Consumer adoption: Which factors influence willingness to participate in the PV community?

While four of these consumer interest aspects (i.e., business model, economic assessment, demand response and energy management) can be described as interests for the consumers individually, energy trading and consumer adoption are two of the aspects which unite all community participants. Energy trading and consumer adoption play an important role in connecting all consumers to willingly share their energy with each other without any conflicts of interest, thus making these two aspects a core for energy sharing activities and main driving force to participate in an energy community, additionally increasing share of RES in consumers' final energy consumption. Although related modelling tools and policy directly affects communities' activities and participants' relationships and responsibilities, these two aspects are mainly determined by institutions, policymakers, researchers and other persons or institutions outside the specific community. With that in mind, it can be mentioned that this literature review examines three interest aspect groups: one group affects consumers individually, second group affects consumer mutual relationships and the third group of interests affects the entire energy community from outside of its borders. The link between interest aspects and PV communities in an illustrative form can be seen in **Figure 1**.

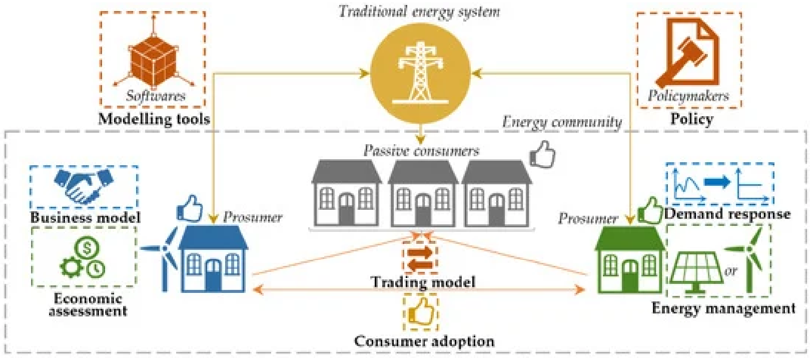

Figure 1. Representation of energy community and consumer interest aspects.

It should be noted that aforementioned research questions are not quite fully covered in any of the literature reviews developed by other authors. This may be due to the low number of overall literature review publications in the field of energy communities. Mostly these reviews do not focus on issue solving; they are concentrating on identifying and analysing the development and prospects of certain parts of the energy community. For example, authors of [8] provided an insight to P2P model implementation perspectives and future research opportunities, such as P2P economics, psychology, industrial engineering and other fields of development. Another review [9] analysed eight energy communities' business models and their impact on energy community development.

2. Revealing Multiple Edges of PV Energy Community

2.1. Policy

One of the main aspects that affects the consumer's willingness to get involved in the solar community is policy which has technical, economic and social influence to all community participants. It is policy that plays a key role in the implementation and development of the PV community through the legislation that, in particular, imposes market restrictions, cooperation guidelines between community and grid operators, provision of various investment opportunities from the public sector and other activities. The review described in this subsection examines whether existing policies support the introduction of the PV community and what kind of policy decisions would motivate consumers to become a member of such a community.

During the literature analysis, a policy analysis was observed in [10], in which the authors drew attention to the advantages of implementing various legal acts over other policies. In this publication, authors described how two types of policies affect PV energy communities with batteries installed, resulting in the conclusions that sharing policy is more or ever more important than pricing policy for the sale of energy excess. Furthermore, net metering as a pricing policy does not help to form energy communities, because no savings can be made by relying on energy costs' revenue and it does not encourage demand-related activities. The authors also pointed out that the variation of energy prices forces consumers to install more batteries than sharing or pricing policy, but it would be possible to reduce the amount of these batteries by more advanced sharing policy.

The experience of PV energy communities' implementation policies is widely described in publications dedicated to the United States—several research studies describe analyses that show how the policies developed are holding back the implementation and development of PV energy communities. Specifically, in [11] it is concluded that the electric utility companies lobby and their lack of attention slows down adoption of PV community-related legislation acts. Reference [12] describes that zero energy communities (as well as PV communities) is a relatively undeveloped concept due to the lack of involvement and support from different stakeholders (policymakers, utilities, installers and others). It is pointed out that to achieve zero energy community, the most important factor is coordinated action and communication between utilities and policy makers, and this is the missing piece of the puzzle to implement the community concept on a large scale. In another article [13], it is pointed out that regulatory demand for renewables, revenue and socially oriented mandates for utilities play a greater role for PV energy community implementation than potential infrastructure savings. This publication also mentions the situation in the state of Arizona, where, despite the great solar resource availability, investor-owned utility companies are unwilling to deploy community scale PV panels, but municipal utility companies as well as rural electric cooperatives deploy PV communities only as a premium offer, making an implicit statement that the aforementioned stakeholders are not moving in the direction of extensive deployment of PV. In a publication dedicated to the state of Ohio [14], it is described that local elected officials have control over determination of the energy mix dedicated to the consumers. With a high renewable energy penetration rate, Ohio has established one of the largest PV communities, thus saving consumers more than USD 300 million since its inception in 2001. With this deployment example, other states could take notes from them on how, without municipal electricity utility companies, it would be possible to implement this type of system. This conclusion is also supported by [15], which indicates that when developing and implementing a successful PV energy community policy framework, other countries would have an opportunity to implement such a model, taking into account the different aspects and conditions of that country. This generally points to an overall lack of policy, thus hampering the wider use of renewables.

Continuing on the impact of the policies, article [16] provided an insight into the different policy approaches in the Baltic States (Estonia, Latvia and Lithuania) and their impact on the electricity production from PV panels. Although the three neighbouring countries have similar climatic conditions, in 2017 Estonia's PV panel capacity was about seven times lower than in Lithuania, and Latvia's was120 times lower, but the PV panel payback period in Estonia was almost two times shorter than in Latvia (10 and 6 years, respectively). The authors of this article point out the huge impact of the choice of different policies and support schemes on the attractiveness of installing PV technologies, as well as the positive impact of a net metering system and negative impact of a mandatory electricity procurement component.

However, based on the above conclusion, a comprehensive PV energy communities' policy is not yet fully determined and used, the authors of the scientific articles have developed guidelines and main directions for these policies. In [17], local PV mini-grids implementation guidelines are described stating, for example, that PV mini-grids have to be implemented where main grid connections are not available and rural communities should be involved from the planning phase to the end of the project. Reference [18] states that the Weberian administrative model, which was used for the development of an isolated PV system in Cameroon, was not working properly, and authors offered policy related suggestions which would motivate the establishment of such a system in developing countries, specifically, decentralisation of the institutional structure for policy administration and encouraging interaction among stakeholders and competent authorities.

The authors of several articles point out that the introduction of a general policy model would be difficult due to various climate and consumer-related factors. Reference [19] showed that effectiveness of implementation of PV communities would depend on rules for retail competition, authority for utilities to own distributed generation assets, civil society and elected officials—generally complicating the implementation process. Reference [20] showed that policy implementation depends on consumer reaction from solar community offerings, preventing non-acceptance by a specific target group communication plan. Authors of this article suggest that policymakers should introduce effective models, which would remunerate consumers with solar energy instead of financial benefits. In this way, one of the main tasks of policy makers would be to ensure careful and accurate communication with consumers, thus persuading them to switch to renewable energy communities. The importance of communication between consumers, stakeholders and policy makers is also observed by the authors of [21], concluding that with different communication approaches, there is a different desire to create and get involved in PV energy communities. Cooperation between state and local institutions, as well as a unified approach to energy transition by leaders at all levels, also plays a major role in the implementation of successful PV-related policies.

Several conclusions follow from the literature review dedicated to solar community policy development analysis. The important role of sharing policy was shown in this subsection. For the United States-related publications, we showed that utilities play an essential role in the possibility of creating a solar community. Moreover, they are considered to be the biggest barriers for solar community implementation, but in the Baltic States the policy is responsible for the low PV panel installation rate due to unattractive electricity metering and tariff systems. It has also been shown that many authors draw attention to the benefits of creating a single policy framework, whereas several authors emphasize that a common approach would not work due to the circumstances of different regions and countries. Although the legislation itself is important, the authors highlight the biggest shortcoming in the implementation and successful operation of the policy; specifically, the lack of communication between the parties involved that indirectly creates barriers and slows down large-scale formation of solar communities.

2.2. Trading Model

In the traditional energy system, electricity through utility grids is delivered from the energy source to the consumer. In such an energy supply system, the consumer covers the costs of electricity generation, network maintenance, as well as other components in the final bill, depending on the policy provisions in each country or region. Bearing in mind that in several countries (for example, in Greece and Romania [22]) the consumer has limited access to the electricity market (that is, electricity is at a fixed tariff), the cost of supplied electricity is determined by electricity generation companies and transmission/distribution system operators, with the aim of increasing their profits from produced and supplied electricity. In the solar community, the traditional electricity supply can be replaced with a peer-to-peer (P2P) system, in which the electricity produced from PV panels could be purchased directly from other households through the respective platform, introducing its own electricity tariff system. This means that electricity trade between electricity producers and consumers will be made regardless of the tariffs set by the network operators (except in cases when electricity is transmitted through these utility networks). A more detailed description of the principles of the P2P energy trading model can be found in [8][23].

When introducing a peer-to-peer system, it is necessary to discover whether such a market would work in real life conditions and be beneficial for the consumer, and to determine the advantages from the traditional market. In this subsection, this is clarified through the related scientific literature analysis.

First, we focus on the P2P market-related economic benefits. Reference [24] concludes that, if 40% of all energy communities' customers would have individual PV panels with or without any battery capacity, P2P electricity sharing could reduce energy costs by about 30% (compared to excess energy trading with a traditional grid). Economic benefits are also observed in a case study dedicated to the state of Texas [25], in which a shared solar market of 50 residential houses was created (PV panels were installed on all of them). A conclusion was made that with the help of the PV sharing market, cost savings can be improved for all participants. The authors of [26] conclude that P2P electricity trading is more economically beneficial than trading with the grid, but [27] reports that by using direct current appliances and P2P trading, large economic benefits can be observed.

By studying the range of scientific publications, it can be noted that new models and simulations are being developed that can accurately display the solar energy market conditions. Reference [28] describes the Perturb and Observe methods' implementation in the MATLAB/SIMULINK environment for a controlled power flow model with a battery storage system between residential houses and the utility grid. Probabilistic optimisation using solar generation statistical properties is described in [29], which compares the optimisation method developed by the authors with forecasting and Monte Carlo Simulation—in this way the model they have developed has additional advantages, such as fine tuning long-term power purchase agreements, market exposure risk analysis and solar generation prognosis. Authors of [30] have developed a solar community investment model that reflects a dynamic network charge mechanism with inclusive uncertainties. The development of such a model allows participants to choose the optimal amount of investment for the development of the PV system, thus optimising the necessary cash flow. Discriminatory continuous double auction market mechanism is proposed in [31], where the simulation mechanism proved its effectiveness for profit allocation in P2P market system, thus improving energy welfare. In [32], interesting results can be observed; for example, in the model of 500 residential houses with a P2P market and battery storage, a maximum of 28% economic savings from such a system was reached. It is also noted that, if a household is only equipped with battery storage, it will receive fewer benefits compared to households without any renewable energy in the P2P market, which once again proves the advantage of the P2P energy trading system.

Although the comprehensive list of P2P market descriptions and innovations in this field is quite extensive, there are no national experiences described under different circumstances using our proposed literature selection methodology. Considering that research studies support P2P market implementation, it can be concluded that the lack of national real life experience possibly indicates a conflict of interest between energy system participants and the need for related policy changes in favour of such a market design.

A literature review on the PV communities' P2P market, as well as related conclusions discussed in this subsection, shows that in the past five years P2P system development increased, creating innovative market modelling tools and simulations, thus determining power flow between participants, and also developing useful forecasting methods for solar-made energy generation and investment flow. In the light of the developments mentioned earlier, the market and trading system for the solar community may be suitable and usable for real life energy communities. Furthermore, the use of such market conditions and gained experience could represent added value for other consumer communities, which would like to reap the maximum benefits from the use of solar energy. These conclusions are also supported by case studies and pilot projects, in which P2P energy trading models were successfully implemented in real-life energy communities—a more detailed description of these successful examples can be found in [23].

2.3. Economic Assessment

Any system put in a place in which the consumer is expected to participate must be able to pay off itself over time. In other words, in order to motivate the consumer to participate in the solar community, it would be necessary to find out how beneficial such a system would be from an economic and payback point of view. An example of the benefits of implementing such an idea is described in [33], in which simulation in the HOMER environment shows that total net, energy and annual operational costs are reduced when the consumer operates in the solar community (when compared with the existing consumer-utility grid system). However, this is not enough to determine which aspects affect the economic benefits of this kind of system. Therefore, a deeper analysis of the various scientific publications was carried out in this subsection in order to identify precisely these aspects.

Remuneration and self-consumption can be mentioned as one of the factors positively influencing the payback period of the PV community. Reference [34] states that market remuneration plays an important role in the terms of profitability—without any additional subsidies, large PV systems with high full load and market remuneration are profitable. Market remuneration impact is also described in [20], which concludes that willingness to buy community PV panels depends on the design of such a remuneration scheme. In addition, self-consumption would increase this measure. Authors of [34] also point out that further electricity costs in the PV energy community can be reduced by community investments, high energy procurement prices, load aggregation and load shifting, thus indirectly increasing self-consumption. The role of self-consumption in economic assessment is also proved in [35], in which a PV community self-consumption simulation was developed; it is stated that PV panels can reduce energy bills by 30%.

Several authors point out that in covering self-consumption, excess electricity would help to make the PV community a profitable system. The optimisation analysis provided in [10] concludes that energy price variation stimulates deployment of such a system, rather than sharing or pricing policy. This conclusion is also implicitly supported by the authors of [36], who used the Mean-Variance Portfolio Theory and Monte-Carlo method to develop an optimisation model. As a result, a portfolio with a maximum electricity output offered the highest return of investments and shortest payback period, indicating that tariff policy plays the main role in determining economic aspects, but other circumstances (such as physical, environmental and financial uncertainties) are less decisive as tariffs.

To determine the impact and interaction of the above aspects on the payback period, advanced modelling tools are needed that could be used in the development phase of the PV community. Some reviewed publications suggested optimisation methods and models that could increase a community's profitability. According to [37], authors used a linear and quadratic service pricing model (thereby increasing the fairness index), but [38] reviewed how cooperative game theory and the cost causation principle could help to decrease a PV community's net total costs. Authors of [26] showed that by using a storage-equipped energy sharing model, PV panel owners can obtain profit when energy is shared between the members; furthermore, prosumers in this model can achieve cost savings compared to trading with the utility grid.

Continuing on consumers, reference [39] indicates that the economic feasibility of a PV community is directly influenced by the energy consumers and nature of consumption of community members. Large consumers can increase profitability (due to large roofs and facades on which PV panels could be installed; this paper concludes that the biggest beneficiaries are single-family houses and multi-apartment buildings—heterogeneous load profiles gain more cost saving potential, and the system eventually becomes profitable.

The abovementioned aspects influencing economic benefits and payback time of LEC are summarised in **Table 1**.

Table 1. Aspects influencing economic benefits and payback time of LEC.

Aspect	Impact	Sources
Remuneration scheme and self-consumption	**Reduce the payback period (in some cases even without additional subsidies); Load flexibility directly impacts self-consumption; The optimised proportion between generation and self-consumption decreases costs.**	[20][34][35]
Energy price and tariffs	**Decisive role, directly/significantly influence payback period.**	[10][36]
Load profile	**Heterogeneous load profiles gain more cost saving potential, and the system eventually becomes profitable.**	[39]
Optimized scheduling and costs	**Improve profitability, decrease net total costs; Storage equipped energy sharing model achieve cost savings compared with trading with utility grid.**	[10][26][36][37][38]
Climatic conditions and other aspects	**LEC could be beneficial not only in the regions with high solar radiation; Technical solutions (e.g., sun tracking, location/angle, storage use, etc) could improve efficiency and decrease costs; There are cost-effective solutions on a small and large scale.**	[36][39][40]

Although the aforementioned publications theoretically support the implementation of solar communities from the economic and payback side, it is important to find out whether these benefits and advantages are reflected in real life or under different climatic conditions. In terms of the specific approach of different countries, reference [40] shows that the PV energy community model in the Hungarian energy market is more profitable than the centralised PV model with lower levelised costs of energy and higher net present value. It is also mentioned that even under the inclusion of different negative outcome variables, a community would be cost-effective if different tax deductions were introduced. In a publication dedicated to Austria [41], a model of cost-optimal economic potential was developed; as a result, recommendations were made on how the European Union should implement solar communities as effectively as possible. In addition, authors concluded that the introduction of such a system is cost-effective on both a small and large scale. A study examining the use of solar community in two Palestinian villages [42] concluded that the use of the authors' developed two-axis solar tracking system reduced the size of PV panels needed by up to 50%, thus reducing the initial investment for the purchase of PV panels and reducing the payback period for this system. In [43], authors optimise the design and develop dispatch control strategies of a standalone PV community with a fuel cell power system to meet the desired electric load of a residential community of 150 houses in a desert region of Sharjah (United Arab Emirates), as a result lowering the cost of energy and also producing no carbon dioxide emissions while electricity is generated.

As can be seen from this review of publications, the introduction of PV communities is economically viable and additional modelling and optimisation measures are being carried out, within which this viability is being increased. In the light of the review, a conclusion can be drawn that the solar community's economic assessment depends on various variables, i.e., market remuneration, self-consumption measures, climatic conditions, used optimisation methods, consumers' demand profile and tariffs for solar and utility-provided electricity.

2.4. Business Model

Although solar communities are designed to benefit consumers as well as increase the use of environmentally friendly energy resources in final energy consumption, new ideas also form new business plans and the desire to obtain financial benefits for those who have created this type of community. With the analysis in this subsection, we want to provide insight into whether PV community owners (including PV panel owners) have established new business models and what factors affect their revenue from a business perspective.

While reviewing the literature, several publications were found which describe and analyse the existing business models. In [44], a business model, which was proven to be successful for the German PV community, was tested as to whether it would be applicable under Austrian conditions. Authors conclude that using the German business model, profitability of Austrian PV communities is quite marginal (using a PV community scheme in multi apartment buildings, the profitability gap can reach only 40 euros per apartment and a cost saving potential of 90 euros for the whole building), but significant profitability can be achieved in German PV communities due to high retail energy prices. In [13], authors describe the results obtained when they analysed the situation in the United States—in the current utility business model, utilities are bigger winners if solar customers function as usual consumers, but consumers lean towards using local energy generation for their own energy consumption, ultimately creating a lose-lose situation.

The solution to a problem described in [13] can be found in [45]. This paper describes a novel business model which used a Nash bargaining solution and neural network-based method to increase payoff rate. As the authors point out, their developed business model can improve financial relationships between solar community participants and utilities, and their solution leads to a good surplus allocation, as well as a win-win outcome for all participants involved.

The authors of [46] proposed a P2P business model for a small PV community in Sweden, including different energy use behaviour, energy and cash flows, as well as different market rules. In this article, the authors conclude that PV energy prices can generate various business opportunities:

- If an energy provider sets the price of electricity in the range of 0% to 10% from the levelised cost of energy, it will generate a strong drive to self-consume as much PV generated energy as possible, but there would be a risk for least-consuming customers;
- If an energy provider sets the price of electricity in the range of 10% to 100% from the levelised cost of energy, financial benefits to building owners and stakeholders can be observed;
- If an energy provider sets the price of electricity more than 100% from the levelised cost of energy, this will encourage third party energy providers to become involved in the solar community.

Reference [47] offers three different business models for PV communities: a private limited company, market-based model and village energy committee model. Although in these business models the authors have developed an innovative approach, they once again indicate a lack of policy—both from a financial point of view and from a government support point of view. Reference [48] describes the business models of PV communities in Brazil, but in [49] authors have provided an extensive overview of the business models of England PV communities. In [49], authors point out that existing PV communities have very complex business models due to the interests of too many stakeholders being included, indirectly complicating the pace of introduction of new PV communities. Therefore, authors recommend that inexperienced consumers create or participate in new solar communities, thus creating much simpler business models.

Two publications used innovative business model approaches aimed to indirectly promote PV communities. The first of them [50] checked if the business model for conventional solar PV could be usable for the further adoption of building-integrated PV. As a result, no difference between these two concepts was observed and authors concluded that solar communities can be a great way to promote building-integrated PV. In the second publication [51] the authors conducted a study which proved that a low-utility independent solar PV business model had an up to 20% higher welfare rate than a higher-utility cooperative solar business model. In addition, the authors conducted an experiment—in a group of stakeholders they involved a "catalyst" (dominant player for onboarding community solar in that region). Thanks to the "catalyst", cooperation behaviour among stakeholders was formed, which increased the effectiveness of ongoing solar projects by 2/3—thus indirectly influencing the business model.

With the help of the review provided in this subsection, we examined the current state of PV community business models and solutions, as well as innovative approaches on how to optimise the establishment of PV communities. As a result of the analysis, we determined the factors influencing business models, for example, utility involvement, energy prices and other aspects. Although the authors point out that it is important to involve all stakeholders in the structure of PV communities, this can be argued by other authors, who indicate that in some cases stakeholder-wide involvement can result in quite complex business models, thus slowing down the establishment of other PV communities. In some cases, though, experienced stakeholder involvement in PV community management can be a good practice, creating a cooperative approach between stakeholders.

2.5. Energy Management

Nowadays, consumers have a wide choice of how to supply their home with the energy they need from renewable energy —from wind turbines and heat pumps to biomass stations and other generation elements. Therefore, with the scientific literature review discussed in this subsection, we want to give an idea of whether solar power is the best solution for local energy production and whether the inclusion of other generating elements in such a community would increase its efficiency and benefits for the consumer.

In many of their articles, the authors had analysed whether the implementation of solar communities could be more beneficial than energy communities containing other energy-generating elements. Authors of [52] developed a methodology for hybrid energy generation to create an isolated energy island. As a result, a case study was developed for a remote Shanghai (China) energy island, concluding that wind turbines with almost 90% wind energy saturation are the most viable option (compared to PV only), because of higher wind energy density as compared to solar radiation density in that specific region. A similar idea was implemented in Vermont (United States) where researchers analysed the possibilities and the best option for local energy generation, solar radiation and wind capabilities [53]. As a result, the PV performed least effectively at covering the required energy consumption and also covered a larger area of land than wind turbines. However, covering the energy consumption with the help of wind turbines was not the best solution possible, so the authors concluded that the best choice between PV community and wind energy community would be to combine them in one hybrid system, thus achieving the highest results possible. Authors also concluded that such a hybrid system is a better solution than receiving energy from utilities. The efficiency of a hybrid wind and solar energy system was also demonstrated in [54], in which the possibility of PV and wind minigrid with energy storage for an isolated system with a 21 possible configurations was studied. In 18 of those configurations, the hybrid system had a significant impact on environmental sustainability. Compared to the system with PV panels only, wind generators occupied a smaller land area, and by using them with PV panels and battery storage, renewable penetration in the final energy consumption can be achieved up to 100%. The need for energy storage in PV energy communities is also mentioned in [55], where authors concluded that PV panels can generate up to eight times more energy than the amount of electricity that can be consumed. This means that by using batteries to store this energy, it can be used in cases when PV panels are unable to generate electricity (for example, at night). Continuing on hybrid systems, authors of [56] compared in their study PV-wind (PV-W) system with PV, wind and biomass (PV-W-B) system; as a result, PV-W-B system achieved up to three times lower cost of energy and net present cost compared to PV-W. Their developed simulations showed that using 69% PV-W-B-generated energy along with 31% natural gas could be more environmentally sustainable than using 100% natural gas-generated energy.

In addition to all factors mentioned earlier, the reviewed scientific publications also provide information on whether hybrid local energy communities with PV panels are the best option for community-level provision of heat supply. Reference [57] describes how a hybrid PV and heat pump (PV-HP) system energy community would help to meet the European Union's emission reduction targets for heating, concluding that switching to a PV-HP system could reduce emissions by up to 91%

in heating supply. However, the authors of [58] came to a completely different result. In a simulation for a pilot community in Calgary (Canada), PV generation in the neighbourhood was not sufficient to offset the environmental impacts of energy use due to limited roof area for PV panels and climatic conditions in this specific area of the Northern Hemisphere. Simulations also showed that natural gas and a domestic hot water system could be a better option for heating supply for this region, with some environmental benefits. Reference [59] indicated that in the Canadian cold climate, PV panels for community heating purposes can be a better alternative than heat pumps, with a significantly lower climate impact.

Although the use of PV panels in the Northern Hemisphere would not be as effective as other alternatives, solar energy could help northern regions' remote communities to reduce energy resources needed for covering the electricity demand, for example, diesel. This is proved by [60], where authors concluded that by adopting PV generation in Canada's largest rural community, electric consumption and losses can be reduced significantly, thus reducing the amount of diesel required for electricity generation.

So, what can we conclude about solar advantages over other alternatives? According to our review, PV energy community is not the greatest alternative available—the best option for a local energy community would be to use hybrid power generation, including solar as one of the sources of energy generation. The same could be concluded by considering different heat generation options. Disadvantages of using solar communities against other systems could be justified by the information available in [32], which explains that energy savings from PV generation largely depend on the area of the installed PV panels, climatic conditions, P2P market rules, battery storage capacity and energy trading time. Some of these shortcomings are also described in our literature review—a PV energy community is not the best alternative available due to limited rooftop area, low PV penetration in some areas (for example, in the Northern Hemisphere) and climatic condition effects, for example, a higher wind density or greater availability of other energy sources than solar energy.

2.6. Demand Response

As regards solar energy communities, it is necessary to examine consumer behaviour from a demand response perspective. In this kind of energy community, electricity will be generated in the time of broad daylight—this means that without any external electricity generation elements or energy storage, energy would be available to consumers during electricity generation only. Thus, the main question raised in this subsection is: Would the implementation of a demand response would be relevant in such an energy system?

Unfortunately, a review of scientific publications immediately leads to a conclusion that demand response in solar communities is described insufficiently, because, according to our methodology, only four scientific publications describe the effect of consumption behaviour changes. In [25], authors concluded that 50 PV-equipped houses in Texas can achieve cost savings if all houses introduce PV sharing and demand response-related activities. In [61], a demand response model is offered, in which PV panel holders would have an opportunity to use PV panel-generated electricity for self-consumption and surplus energy could be distributed to the remaining participants, thus increasing their demand response and using PV-generated electricity as efficiently as possible. Meanwhile, ref. [62] focused on creating more efficient P2P electricity trading with the help of a demand response system, thus resulting in energy cost optimisation (lowering total energy costs for prosumers). The impact of consumption management on economic benefits is also shown in [63], in which authors explain that demand aggregation can reduce the use of energy storage and required battery capacity, thus saving the necessary funds for the purchase of a storage system. In addition, by optimising the orientation and tilt of PV panels, solar communities with electricity storage show positive profitability value in all cases described in this study.

An analysis of the scientific publications on the impact of demand response suggests that demand response can lower energy costs as well as optimise energy use for self-consumption purposes. However, due to the lack of literature sources about demand response effects on solar communities, these findings can be questionable and additional research activities are needed to clearly determine the related benefits.

2.7. Modelling Tools

Although various techniques have been developed that enable making an economic assessment of the energy system easily adaptable to LEC conditions, it is not yet fully understood what tools should be used to develop the PV community from a technical point of view. This refers to the application of various new and innovative modelling techniques able to provide the best design and planning options for PV communities (depending on effects of multiple variables, such as cash flows, solar irradiation, price fluctuations and other factors). It is the technical tools and improvement of existing ideas that are responsible for further development of PV communities, and a related scientific publication review could give us a vision for the direction in which the greatest use of technically innovative ideas takes place, both in modelling environment and in real life case studies. As such, with this subsection we are trying to answer the question: What kind of technical tools, solutions and innovations were developed in the solar energy community over the past five years?

First, we can look at the latest innovations in improving the planning and design of solar communities. Reference [64] describes an effective design to electrify a remote community in South Africa with the help of PV panels, using PVSYST software simulations, thus decreasing expenses for infrastructure needs. The author of [65], who created the optimal design for rural villages in Palestine, pursued a similar goal. By using PV*SOL software, a new design was provided for a remote village's electrification, where the buildings are far apart, but without the use of PV generation on each of the buildings. Reference [66] describes another new design for solar communities, including guidelines and technical aspects (location, energy demand, PV panel size, controllers, cables, etc.) for an isolated PV community, but authors of [67] presented a new design for a PV power plant for use in a small community in Poland, thus fulfilling the energy demand needed and also reducing emissions in this studied region. In [68], a framework for planning PV energy communities using metadata-assisted clustering techniques is described. In addition, an energy storage system model was developed to further increase the effectiveness of the community's planning. In [1], a framework is described for solar community optimisation and planning using the Monte-Carlo method to ensure diversity between simulated energy users. With the help of this innovative modelling technique, authors discovered that PV communities are a better alternative to individual rooftop PV installation due to more uniform electricity distribution between consumers. Next, we can focus on innovations in community modelling using different variables and uncertainties. In [69], a comparison between the mixed integer linear programming technique and model-predicted control to simulate PV generated power flow is described, including fluctuations in electricity price and energy demand, and other uncertainties. Both techniques presented energy savings, but the use of model-predicted control turned out to be more effective, reaching up to 9% energy savings when compared to normal energy consumption operations. Another comparison between modelling techniques was described in [70], in which the PV array output power forecasting accuracy in the solar community was analysed between three models—a deep recurrent neural network with long short-term memory unit (or DRNN-LSTM, which was created by authors), a multi-layer perception network and a support vector machine. DRNN-LSTM showed the best results with only 7.43% mean absolute percentage error due to the advanced technique of nonlinear problem limitation circumvention.

What is discussed in this subsection suggests that the development of technical solutions for solar communities is still ongoing—improving both design and planning of the solar communities and also developing more advanced models, in which the best layouts, models and optimisation methods are determined, including real-life occurring variables and uncertainties. This shows that the idea of solar communities is still active and can be improved, thus indicating that this type of system will become more efficient and developed over time. Although this subsection examined modelling and application possibilities of various modelling techniques for PV energy communities, additional information on how other modelling solutions have been used for particular problems, as well as their results, can also be found in previous subsections.

2.8. Consumer Adoption

Although the introduction of the concept of PV communities requires an analysis of various aspects and solutions, we cannot forget about the main component—the consumer. The further prevalence of PV communities depends on the consumer's willingness to participate—the more consumers will want to get involved, the more such opportunities will be available. By this, we want to say that it is necessary to determine what factors influence consumer willingness to get involved in solar communities and what kind of activities would help them to adopt such an energy supply model.

First, on the current consumer knowledge in the field of solar communities: In [71], researchers described their study in which they developed a mobile app to simulate PV energy generation in a community setting, including the ability to regulate demand response, compare electricity consumption with other households and to determine electricity self-consumption from PV panels. Observing the results described in this paper, an assumption was made that there are various factors which affect consumers' awareness and knowledge about PV communities, because distributed results did not indicate a uniform trend.

A similar assumption was observed by other authors when describing the various influencing factors inferred from their research. In [50], authors, with the help of a survey, tried to ascertain Swiss customers' willingness to buy either community solar-associated and building-integrated PV offers or a conventional rooftop solar community offer; as a result, there was no difference in participation rates between those two offers. Their data analysis showed that pro-environmental and pro-social behaviour, age (younger people are more willing to get involved than older people), income (higher income—higher participation rate) and political attitude (more conservative attitude means lower interest in solar communities) have significant impacts on the willingness to participate in solar communities. This is also supported by [72], but business model, i.e., different forms of technology within a community solar offer, is not considered as decisive as the aforementioned factors. A similar conclusion was described in [15], which was aimed at Pakistanian energy consumers—energy costs, income per household, education and information availability are the key factors which are affecting social acceptance and adoption rate. The authors of this article have also mentioned suggestions on how to encourage consumers to participate in PV communities—for example, by introducing subsidies for poor households and wider information dissemination activities, including peer (mouth-to-mouth) information and experience dissemination. The importance of disseminating information locally is also supported by the information provided in [73], describing the ineffectiveness of large-scale awareness-raising campaigns (electronic and print media, subsidies, etc.) in rural areas of India, concluding that the best method of disseminating information would be the mouth-to-mouth method. Authors emphasised that locally targeted, organised and delivered dissemination campaigns are needed to better inform consumers about opportunities to participate in the solar community, at the same time providing more efficiently targeted subsidies.

Willingness to buy community PV panels depends on the level of remuneration [20], but authors also pointed out that there are different approaches possible, such as how to encourage consumers to participate. According to the study described in this paper, consumers who are involved or interested in the use of green energy and environmentally friendly solutions should be motivated to become a solar community member by non-financial means, because money is not their main motivation to use renewables for their energy consumption, but the group of consumers who do not care to use environmentally friendly solutions should be motivated by financial remuneration. With this observation, the authors draw attention to the fact that in order to attract as many consumers as possible, first, such an opportunity should be offered to a group of society supporting environmental protection, and only after some time should it be offered to those who would be interested in financial remuneration.

Literature analysis showed that the level of participation in solar communities goes hand-in-hand with the implementation of relevant policy. In Switzerland, adopting the Zero Emission Vehicle regulation led to a 23% higher district PV adoption level than before the introduction of such a regulation [74]. In several papers [12][15][72], authors have indicated that policy makers with their actions and measures can influence consumers to participate in solar communities and inform them about the benefits and advantages, thus increasing adoption level. They also pointed out that policymakers should analyse their research results and make changes to the relevant legislation in order to move forward with the implementation of solar panels, thus further developing the community model as a consumer- and environment-friendly energy system. Unfortunately, such a conclusion once again demonstrates the signs of energy legislation stagnation and maladaptation to new ideas from the policymakers' side.

With the help of a literature review, it was clarified that adoption of solar communities mainly depends on the following consumer-related factors:

- Remuneration (financial or environmental);
- Age;
- Financial aspects (income, cost of energy);
- Political views;
- Education and information availability.

Authors pointed out the need to change the current information dissemination model in order to encourage wider consumer participation through various methods. Authors recommend financial support for low income households and those who are not interested in the use of renewable energy sources for their final energy consumption; but to households supporting renewable energy sources, authors recommend addressing them with emphasis on the benefits of using solar energy (as a clean energy source). Through an analysis of publications, it was determined that the best method for information dissemination and reaching out to consumers could be mouth-to-mouth communication. The analysis also pointed to the lack of policy, and policymakers' stagnation can be mentioned as one of the reasons why consumers do not widely participate in solar communities.

References

1. Awad, H.; Gül, M. Optimisation of community shared solar application in energy efficient communities. Sustain. Cities Soc. 2018, 43, 221–237.

2. How Solar Panel Cost and Efficiency Have Changed over Time. Available online: https://news.energysage.com/solar-panel-efficiency-cost-over-time/ (accessed on 4 January 2021).
3. Walker, G.; Devine-Wright, P. Community renewable energy: What should it mean? Energy Policy 2008, 36, 497–500.
4. Energy Communities: An Overview of Energy and Social Innovation. Available online: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC119433/energy_communities_report_final.pdf (accessed on 4 January 2021).
5. Lowitzsch, J.; Hoicka, C.E.; Van Tulder, F.J. Renewable energy communities under the 2019 European Clean Energy Package—Governance model for the energy clusters of the future? Renew. Sustain. Energy Rev. 2020, 122, 109489.
6. Sen, S.; Ganguly, S. Opportunities, barriers and issues with renewable energy development—A discussion. Renew. Sustain. Energy Rev. 2017, 69, 1170–1181.
7. PESTLE Analysis of Barriers to Community Energy Development. Available online: http://leco.interreg-npa.eu/subsites/leco/PESTLE_Analysis_LECO_A4_190110-singlepages.pdf (accessed on 4 January 2021).
8. Soto, E.A.; Bosman, L.B.; Wollega, E.; Leon-Salas, W.D. Peer-to-peer energy trading: A review of the literature. Appl. Energy 2021, 283, 116268.
9. Reis, I.F.; Gonçalves, I.; Lopes, M.A.; Antunes, C.H. Business models for energy communities: A review of key issues and trends. Renew. Sustain. Energy Rev. 2021, 144, 111013.
10. Alvaro-Hermana, R.; Merino, J.; Fraile-Ardanuy, J.; Castano-Solis, S.; Jimenez, D. Shared Self-Consumption Economic Analysis for a Residential Energy Community. In Proceedings of the 2nd International Conference on Smart Energy Systems and Technologies, Porto, Portugal, 9–11 September 2019.
11. Michaud, G. Perspectives on community solar policy adoption across the United States. Renew. Energy Focus 2020, 33, 1–15.
12. Mittal, A.; Krejci, C.C.; Dorneich, M.C.; Fickes, D. An agent-based approach to modeling zero energy communities. Sol. Energy 2019, 191, 193–204.
13. Funkhouser, E.; Blackburn, G.; Magee, C.; Rai, V. Business model innovations for deploying distributed generation: The emerging landscape of community solar in the U.S. Energy Res. Soc. Sci. 2015, 10, 90–101.
14. Michaud, G. Deploying solar energy with community choice aggregation: A carbon fee model. Electr. J. 2018, 31, 32–38.
15. Jan, I.; Ullah, W.; Ashfaq, M. Social acceptability of solar photovoltaic system in Pakistan: Key determinants and policy implications. J. Clean. Prod. 2020, 274, 123140.
16. Petrichenko, L.; Zemite, L.; Sauhats, A.; Klementavicius, A.; Grickevics, K. A Comparative Analysis of Supporting Policies for Solar PV systems in the Baltic Countries. In Proceedings of the 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe, Genova, Italy, 11–14 June 2019.
17. Suryani, A.; Dolle, P. The Sustainability Dilemma of Solar Photovoltaic Mini-grids for Rural Electrification. In Sustainable Energy Solutions for Remote Areas in the Tropics. Green Energy and Technology; Gandhi, O., Srinivasan, D., Eds.; Springer: Cham, Switzerland, 2020; pp. 81–107.
18. Njoh, A.J.; Etta, S.; Essia, U.; Ngyah-Etchutambe, I.; Enomah, L.E.; Tabrey, H.T.; Tarke, M.O. Implications of institutional frameworks for renewable energy policy administration: Case study of the Esaghem, Cameroon community PV solar electrification project. Energy Policy 2019, 128, 17–24.
19. Hess, D.J.; Lee, D. Energy decentralization in California and New York: Conflicts in the politics of shared solar and community choice. Renew. Sustain. Energy Rev. 2020, 121, 109716.
20. Stauch, A.; Gamma, K. Cash vs. solar power: An experimental investigation of the remuneration-related design of community solar offerings. Energy Policy 2020, 138, 111216.
21. Mah, D.N.-Y. Community solar energy initiatives in urban energy transitions: A comparative study of Foshan, China and Seoul, South Korea. Energy Res. Soc. Sci. 2019, 50, 129–142.
22. Report on Regulations, Codes and Standards in EU-28. Available online: https://pantera-platform.eu/wp-content/uploads/2021/01/D3.2_Report-on-Regulations-Codes-and-Standards-in-EU-28.pdf (accessed on 8 April 2021).
23. IRENA. Innovation Landscape Brief: Peer-to-Peer Electricity Trading; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2020; pp. 1–20. ISBN 978-92-9260-174-4.
24. Long, C.; Wu, J.; Zhou, Y.; Jenkins, N. Aggregated battery control for peer-to-peer energy sharing in a community Microgrid with PV battery systems. Energy Procedia 2018, 145, 522–527.

25. He, L.; Zhang, J. Distributed Solar Energy Sharing within Connected Communities: A Coalition Game Approach. In Proceedings of the 2019 IEEE Power and Energy Society General Meeting, Atlanta, GA, USA, 4–8 August 2019.
26. Liu, N.; Cheng, M.; Yu, X.; Zhong, J.; Lei, J. Energy-Sharing Provider for PV Prosumer Clusters: A Hybrid Approach Using Stochastic Programming and Stackelberg Game. IEEE Trans. Ind. Electron. 2018, 65, 6740–6750.
27. Kuruseelan, S.; Vaithilingam, C. Peer-to-peer energy trading of a community connected with an AC and DC microgrid. Energies 2019, 12, 3709.
28. Soni, J.M.; Patel, D.V.; Patel, R.V.; Modha, H.P. A Strategic Community Control-Based Power Flow between Grid-Integrated PV House. In Electronic Systems and Intelligent Computing; Springer: Singapore, 2020; Volume 686, pp. 1061–1071.
29. van der Heijden, N.C.; Alpcan, T.; Martinez-Cesena, E.A.; Suits, F. Optimal power purchase agreements in PV-rich communities. In Proceedings of the 2017 Australasian Universities Power Engineering Conference, Melbourne, Australia, 19–22 November 2018; pp. 1–6.
30. Maleki Delarestaghi, J.; Arefi, A.; Ledwich, G.; Borghetti, A. A distribution network planning model considering neighborhood energy trading. Electr. Power Syst. Res. 2021, 191, 106894.
31. Li, Z.; Ma, T. Peer-to-peer electricity trading in grid-connected residential communities with household distributed photovoltaic. Appl. Energy 2020, 278, 115670.
32. Nguyen, S.; Peng, W.; Sokolowski, P.; Alahakoon, D.; Yu, X. Optimizing rooftop photovoltaic distributed generation with battery storage for peer-to-peer energy trading. Appl. Energy 2018, 228, 2567–2580.
33. Yadav, R.K.; Bhadoria, V.S.; Hrisheekesha, P.N. Technical and Financial Assessment of a Grid Connected Solar PV Net Metering System for Residential Community. In Proceedings of the 2019 2nd International Conference on Power Energy Environment and Intelligent Control, Greater Noida, India, 18–19 October 2019; pp. 299–303.
34. Radl, J.; Fleischhacker, A.; Revheim, F.H.; Lettner, G.; Auer, H. Comparison of profitability of PV electricity sharing in renewable energy communities in selected European countries. Energies 2020, 13, 5007.
35. Garrido-Lucero, F.; Beaude, O.; Wan, C. Analysis and design of a self-consumption community: A game-theoretic approach. In Proceedings of the 19th IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe, Genoa, Italy, 11–14 June 2019.
36. Shakouri, M.; Lee, H.W.; Kim, Y.-W. A probabilistic portfolio-based model for financial valuation of community solar. Appl. Energy 2017, 191, 709–726.
37. Oh, E.; Son, S.-Y. Community solar photovoltaic service strategy for commercial buildings considering profit balancing and fairness. Energy Build. 2020, 229, 110513.
38. Chakraborty, P.; Baeyens, E.; Khargonekar, P.P.; Poolla, K.; Varaiya, P. Analysis of Solar Energy Aggregation under Various Billing Mechanisms. IEEE Trans. Smart Grid 2019, 10, 4175–4187.
39. Fina, B.; Auer, H.; Friedl, W. Profitability of PV sharing in energy communities: Use cases for different settlement patterns. Energy 2019, 189, 116148.
40. Deutsch, N.; Berényi, L. Economic potentials of community-shared solar plants from the utility-side of the meter—A Hungarian case. Electr. J. 2020, 33, 106826.
41. Fina, B.; Auer, H.; Friedl, W. Cost-optimal economic potential of shared rooftop PV in energy communities: Evidence from Austria. Renew. Energy 2020, 152, 217–228.
42. Odeh, S.; Ibrik, I. Performance assessment of standalone PV systems for rural communities. In Proceedings of the World Engineers Convention 2019, Melbourne, Australia, 20–22 November 2019; pp. 912–926.
43. Ghenai, C.; Salameh, T.; Merabet, A. Technico-economic analysis of off grid solar PV/Fuel cell energy system for residential community in desert region. Int. J. Hydrog. Energy 2020, 45, 11460–11470.
44. Fina, B.; Fleischhacker, A.; Auer, H.; Lettner, G. Economic Assessment and Business Models of Rooftop Photovoltaic Systems in Multiapartment Buildings: Case Studies for Austria and Germany. J. Renew. Energy 2018, 2018, 9759680.
45. Liang, J.; Shirsat, A.; Tang, W. Sustainable community based PV-storage planning using the Nash bargaining solution. Int. J. Electr. Power Energy Syst. 2020, 118, 105759.
46. Lovati, M.; Zhang, X.; Huang, P.; Olsmats, C.; Maturi, L. Optimal simulation of three peer to peer (P2P) business models for individual PV prosumers in a local electricity market using agent-based modelling. Buildings 2020, 10, 138.
47. Joshi, G.; Yenneti, K. Community solar energy initiatives in India: A pathway for addressing energy poverty and sustainability? Energy Build. 2020, 210, 109736.

48. Schneider, K.; de Oliveira, M.O.M.; Japp, C.; Manoel, P.S.; Rüther, R. Community solar in Brazil: The cooperative model context and the existing shared solar cooperatives up to date. In Proceedings of the ISES Solar World Congress 2019 and IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2019, Santiago, Chile, 4–7 November 2019; pp. 1594–1605.

49. Nolden, C.; Barnes, J.; Nicholls, J. Community energy business model evolution: A review of solar photovoltaic developments in England. Renew. Sustain. Energy Rev. 2020, 122, 109722.

50. Stauch, A.; Vuichard, P. Community solar as an innovative business model for building-integrated photovoltaics: An experimental analysis with Swiss electricity consumers. Energy Build. 2019, 204, 109526.

51. Ferster, B.; Brownson, J.R.S.; Macht, G.A. Catalyzing community-led solar development by enabling cooperative behavior: Insights from an experimental game in the United States. Energy Res. Soc. Sci. 2020, 63, 101408.

52. Ma, T.; Javed, M.S. Integrated sizing of hybrid PV-wind-battery system for remote island considering the saturation of each renewable energy resource. Energy Convers. Manag. 2019, 182, 178–190.

53. Thomas, A.; Racherla, P. Constructing statutory energy goal compliant wind and solar PV infrastructure pathways. Renew. Energy 2020, 161, 1–19.

54. Aberilla, J.M.; Gallego-Schmid, A.; Stamford, L.; Azapagic, A. Design and environmental sustainability assessment of small-scale off-grid energy systems for remote rural communities. Appl. Energy 2020, 258, 114004.

55. Üçtuğ, F.G.; Azapagic, A. Environmental impacts of small-scale hybrid energy systems: Coupling solar photovoltaics and lithium-ion batteries. Sci. Total Environ. 2018, 643, 1579–1589.

56. Bagheri, M.; Delbari, S.H.; Pakzadmanesh, M.; Kennedy, C.A. City-integrated renewable energy design for low-carbon and climate-resilient communities. Appl. Energy 2019, 239, 1212–1225.

57. Rehman, H.U.; Hirvonen, J.; Jokisalo, J.; Kosonen, R.; Sirén, K. EU emission targets of 2050: Costs and CO2 emissions comparison of three different solar and heat pump-based community-level district heating systems in nordic conditions. Energies 2020, 13, 4167.

58. Hachem-Vermette, C.; Cubi, E.; Bergerson, J. Energy performance of a solar mixed-use community. Sustain. Cities Soc. 2016, 27, 145–151.

59. Guarino, F.; Longo, S.; Hachem Vermette, C.; Cellura, M.; La Rocca, V. Life cycle assessment of solar communities. Sol. Energy 2020, 207, 209–217.

60. Nassif, A.B.; Anderson, R. Diesel reduction opportunities in a remote isolated community. In Proceedings of the 2019 IEEE Electrical Power and Energy Conference, Montreal, QC, Canada, 16–18 October 2019.

61. Faria, P.; Barreto, R.; Vale, Z. Demand Response in Energy Communities Considering the Share of Photovoltaic Generation from Public Buildings. In Proceedings of the 2nd International Conference on Smart Energy Systems and Technologies, Porto, Portugal, 9–11 September 2019.

62. Alam, M.R.; St-Hilaire, M.; Kunz, T. Peer-to-peer energy trading among smart homes. Appl. Energy 2019, 238, 1434–1443.

63. Freitas, S.; Reinhart, C.; Brito, M.C. Minimizing storage needs for large scale photovoltaics in the urban environment. Sol. Energy 2018, 159, 375–389.

64. Molotsi, C.; Puati Zau, A.T.; Daniel Chowdhury, S.P.; Ngobeni, A. Design of a solar photovoltaic system to power the community of Riverton in Droogfontein. In Proceedings of the 10th International Renewable Energy Congress, Sousse, Tunisia, 26–28 March 2019.

65. Ibrik, I. Design and verification the results of electrification small communities in Palestine by using decentralized off-grid PV systems. Int. J. Innov. Technol. Explor. Eng. 2019, 8, 983–987.

66. Ali, W.; Farooq, H.; Rehman, A.U.; Awais, Q.; Jamil, M.; Noman, A. Design considerations of stand-alone solar photovoltaic systems. In Proceedings of the 2018 International Conference on Computing, Electronic and Electrical Engineering, Quetta, Pakistan, 12–13 November 2018.

67. Krawczak, E. Studies on PV power plant designing to fulfil the energy demand of small community in Poland. E3S Web Conf. 2019, 116, 00040.

68. Poursanidis, I.; Rancilio, G.; Kotsakis, E.; Fulli, G.; Masera, M.; Merlo, M. A design framework for Citizen Energy Communities in Cities: Exploring PV-storage synergies. In Proceedings of the 2019 IEEE PES Asia-Pacific Power and Energy Engineering Conference, Macao, Macau, 1–4 December 2019.

69. Yu, D.; Brookson, A.; Fung, A.S.; Raahemifar, K.; Mohammadi, F. Transactive control of a residential community with solar photovoltaic and battery storage systems. In Proceedings of the 4th Asia Conference of International Building Performance Simulation Association, Hong Kong, China, 3–5 December 2018.

70. Wen, L.; Zhou, K.; Yang, S.; Lu, X. Optimal load dispatch of community microgrid with deep learning based solar power and load forecasting. Energy 2019, 171, 1053–1065.
71. Griego, D.; Catunda, N.; Schmitt, G. Pilot study of 'Our Energy', an app designed to facilitate self-consumption of community solar photovoltaic systems. J. Phys. Conf. Ser. 2019, 1343, 012153.
72. Schunder, T.; Yin, D.; Bagchi-Sen, S.; Rajan, K. A spatial analysis of the development potential of rooftop and community solar energy. Remote Sens. Appl. Soc. Environ. 2020, 19, 100355.
73. Yadav, P.; Davies, P.J.; Khan, S. Breaking into the photovoltaic energy transition for rural and remote communities: Challenging the impact of awareness norms and subsidy schemes. Clean Technol. Environ. Policy 2020, 22, 817–834.
74. Mehta, P.; Griego, D.; Nunez-Jimenez, A.; Schlueter, A. The Impact of self-consumption regulation on individual and community solar PV adoption in Switzerland: An agent-based model. J. Phys. Conf. Ser. 2019, 1343, 012143.