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Review

Critical Review on Community-Shared Solar—Advantages, Challenges, and Future Directions

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Abstract: In the last few years, many innovative solutions have been presented to address the climate change crisis. One of the innovative solutions is the participation of community members in the collective production of solar electricity instead of individual production. The current study aims to provide a critical literature review of the collective production of solar electricity, which is called "community-shared solar" (CSS). Sixty-seven peer-reviewed publications were selected based on the setting up of a combination of related keywords. To analyze the concept of CSS in the existing literature, a multi-level perspective (MLP) framework was used to observe the CSS innovation at the niche, regime, and landscape levels. Four aspects, including the technical, economic, socio-political, and regulatory and institutional, were considered to evaluate those three levels. The results revealed that in the technical and economic aspects, CSS has reached maturity and internal momentum that can take it to the next levels. However, a lack of attention to the socio-political aspect and the regulatory and institutional aspect, in particular, is the potential barrier to the emergence of CSS and its potential position as a leading energy system.

Keywords: energy community; solar energy; solar PV; energy transition; literature review; multi-level perspective

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1. Introduction

The issue of climate change in recent years has caused many countries and legislators to look for effective solutions to prevent and overcome this matter. Today, a potential solution in different parts of the world to overcome the climate change crisis is the gradual replacement of large-scale, centralized energy systems with small-scale, decentralized energy systems. A recent concept that is receiving attention with regard to how to use clean energy more efficiently is the "energy communities" (ECs) concept, sometimes called "community energy" [1]. The community term could be multi-dimensional, depending on the concept under consideration. For instance, according to the European Union: "Energy communities organize collective and citizen-driven energy actions that help pave the way for a clean energy transition while moving citizens to the fore" [2]. Bauwens et al. systematically reviewed 183 different definitions of community in relation to energy systems [3]. In this study, they mentioned that the vagueness of the community term could have three aspects: first, the meaning of the community itself; second, the type of energy activities the communities are following; and third, the goals that the communities are aiming for [3]. However, all the different EC definitions emphasize two main characteristics, namely collective action and renewable energy technologies [4].

Among renewable energy technologies, solar PV has third place in electricity production, with 3.6% of global electricity generation [5]. Despite the widespread use of solar energy, all members of society can't use it in the residential sector. For instance, in urban areas, 49% of residents do not have the possibility to use solar energy because they do not own the building or they live in high-rise buildings and do not have direct access to the roof, or because the roofs of their houses do not have suitable spaces to install solar PV systems [6]. Due to the extensive use of solar PV systems and the challenges regarding their adoption for each household, the main focus of this study is on solar PV usage in ECs.

Therefore, this study focuses on the concept of EC based on solar energy applications called "community shared solar" (CSS) as a potential way to give all households a chance to access the benefits of solar PV systems. CSS is defined by the U.S. Department of Energy as "any solar project or purchasing program, within a geographic area, in which the benefits of a solar project flow to multiple customers such as individuals, businesses, non-profits, and other groups" [7].

The involvement of different actors (e.g., individual households, local businesses, local policymakers, etc.) in CSS, as with all other types of EC, could cause many challenges, such as those related to how the benefits would be shared among the members; how energy security could be provided in an EC; the rules according to which the energy should be exchanged between members and the main grid; and so on. Because the concept of CSS is relatively new, answering these types of questions requires a comprehensive investigation to put it under the microscope and to observe it from various perspectives. Apart from reviewing the existing literature and discussing the gaps, the aim is to answer the following three main research questions:

- Why should solar PV CSS be the leading energy system?
- Why is solar PV CSS not the leading energy system?
- What can be done to make solar PV CSS a leading energy system?

To constructively study CSS and address the research questions, from among the available frameworks, such as the techno-economic paradigm (TEP) [8] and the institutional analysis and development (IAD) [9] frameworks, the multi-level perspective (MLP) [10] was chosen. The MLP provides an opportunity to study CSS as an innovative niche for the energy transition and to explore its different socio-technical aspects. The advantage of the MLP over the other frameworks is that the transition in the energy system can be observed multi-dimensionally; therefore, the MLP can provide a better overview of how the transition can be carried out. However, the disadvantages are its ambiguity, the unclear boundaries between the different dimensions of the MLP, and the geographical space inclusion [11]. Various studies by Geels (e.g., [10,12,13]) have also applied the MLP to study different ECs, while [11,14] used the MLP to structure and analyze the literature. Following such studies, four main aspects, i.e., the technical, economic, socio-political, and regulatory and institutional aspects, are included in this analysis.

The rest of the paper is organized as follows. In Section 2, the research approach is elaborated with a description of the process of the selection of papers for review and the theoretical background of the MLP framework. Section 3 provides a general overview of the reviewed papers in terms of historical overview, associated disciplines, VOSviewer results, etc. Section 4 presents an analysis of past studies based on the MLP framework. Section 5 discusses the findings from the literature and provides the limitations of the current study. Finally, Section 6 presents the conclusions, addresses the three main questions, and provides the knowledge gaps and recommendations for future studies.

2. Research Approach

2.1. Collecting the Literature

An extensive and systematic literature review was conducted on collective solar-shared energy systems. This literature review was based on material published up to the end of February 2023. The material was collected from www.webofknowledge.com and www.scopus.com, using the combinations of keywords as presented in Table 1.

Table 1. Keywords and the number of papers.

Combinations of the Keywords	Number of Articles
"solar" AND "photovoltaic" AND "energy community"	97
"solar" "photovoltaic" AND "energy cooperative"	11
"solar" "photovoltaic" AND "energy initiative"	58
"solar" "PV" AND "energy community"	82
"solar" "PV" AND "energy cooperative"	5
"solar" "PV" AND "energy initiative"	47
"solar" "panel" AND "energy community"	22
"solar" "panel" AND "energy cooperative"	1
"solar" "panel" AND "energy initiative"	16
"solar" "module" AND "energy community"	11
"solar" "module" AND "energy cooperative"	2
"solar" "module" AND "energy initiative"	9
"shared solar" "photovoltaic"	11
"shared solar" AND "PV"	9
"shared solar" AND "panel"	4
"shared solar" AND "module"	0
Total (excluding the duplicated documents)	232

The choice of keywords was made to cover all the research on solar PV systems (i.e., "photovoltaic", "PV", "panels") and the collective organizational structures (i.e., "energy community", "energy cooperative", "energy initiative"). The collected documents only covered the peer-reviewed articles; the conference proceedings and articles that were not peer-reviewed were deliberately left out, leading to 156 peer-reviewed articles written in English. This setting provided an opportunity to conduct a critical review and propose a research agenda for studying collective solar-shared energy systems.

Among these 156 peer-reviewed articles, only 67 of them were actually within the scope of the review. For instance, in some of these 156 English documents, "energy initiative" referred to an official part of the government (energy initiative office/plan) but not to community-based energy initiatives. "EU energy community", "international energy community", "atomic energy community", and "East Asia energy community" are other examples of the use of the "energy community" keyword with a meaning other than collective action for local renewable energy generation and distribution. Moreover, some studies (e.g., [15,16]) did not address the collective action nature of CSS and were therefore excluded. Figure 1 elaborates on the processes of including and selecting articles.

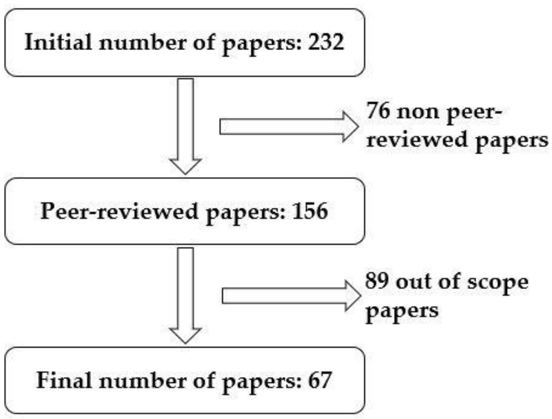

Figure 1. Prisma flow diagram literature search.

Next, to provide a descriptive analysis of these articles, the dominant topics (i.e., common repeating words) in these 67 articles were explored using Vosviewer [17] with a co-occurrence analysis of all the keywords with a minimum co-occurrence of 5. Vosviewer is a software tool for creating, visualizing, and exploring maps based on network data (e.g., scientific publications), where these networks can be connected by co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation links [17]. Therefore, in our study, any of the suggested keywords in the abstracts, titles, and articles that were repeated in at least five different articles were reported. These keywords could be used for the further study and structuring of the literature.

2.2. Structuring and Analyzing the Literature: Multi-Level Perspective Framework

In the realm of transition literature, the multi-level perspective (MLP) framework focuses on how innovation niches take place and evolve in complex systems such as the energy system [12]. The MLP framework explores the dynamics of the innovative niches on the transition journey [18], where it tends to argue for the non-linear process of system innovation [19]. The internal tension and dynamics related to niches, along with the external pressure and trends, reinforce changes in the dominant practices, policies, cultural norms, infrastructures, and business models [20]. Therefore, the importance of niches in the transition processes, as their growth and implementation drive the transition, is highlighted in the MLP framework [10,21]. As explained in studies such as those of [10,12,13], the MLP framework constructively analyzes these dynamics and reinforcements at the following three levels:

- Niche level: Innovative projects that individual actors have developed are at this level. Such innovative niches might not have enough power to form and influence the higher levels, namely the 'regime' and 'landscape' levels. Specifically, the regime blocks their diffusion if they conflict with the status quo. Energy communities, such as solar-shared energy communities, are considered innovative niches within the energy system context.
- Socio-technical regime level: Institutions and social networks orient the configuration of infrastructures and technologies. Thus, the dominant actors, elements, and resources of systems at the regime level can facilitate infrastructure improvements and organizational change. Therefore, they could block or facilitate the niche's evolution.
- Landscape level: The natural environment, material, infrastructure, political culture, macro-economy, and social demography, which construct the system as a whole, are discussed here. The societal trends, policy choices, and available technologies that stimulate the economic and regulatory instruments at the macro-level and can support a change are related to the landscape level.

Following studies such as those of [11,14], to constructively study these three levels and the possible dominance of CSS, the following four aspects were chosen: (i) technical, (ii) economic, (iii) socio-political, and (iv) regulatory and institutional. These four aspects facilitate the study and analysis of CSS through the MLP framework lens while considering the various socio-technical aspects. Along with [11,14], other studies have also used the same approach to study the energy communities (e.g., [22,23]) and energy transition as a whole (e.g., [24–26]). However, none of these studies is focused on CSS.

3. Overview of the Community-Shared Solar Literature

This section presents an overview and the quantified data of 67 articles on CSS. As presented in Figure 2, although CSS is a relatively emerging topic, the number of studies related to CSS has grown rapidly in recent years. The fact that it is receiving such growing attention highlights the potential of CSS to become one of the dominating energy systems.

Although this branch of literature is growing fast and various disciplines are being explored, the majority of the studies were focused on the technical and economic disciplines. As Figure 3 demonstrates, the technical and economic disciplines covered 70% of the published articles. In these disciplines, indicators such as efficiency (e.g., [27,28]), self-consumption (e.g., [29,30]), and yearly costs per household (e.g., [31]) were discussed in detail. On the other hand, the other 30% of the articles discussed topics related to the environment (e.g., environmental impact and CO_2 emissions), social aspects and behavior (e.g., willingness to participate in a community), and policy and institutions (e.g., feed-in tariffs).

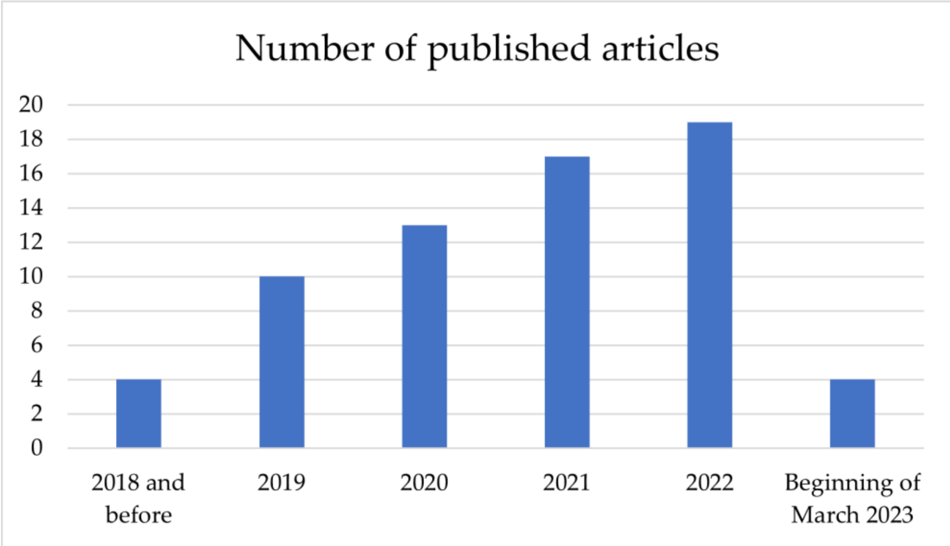

Figure 2. Timeline of published articles.

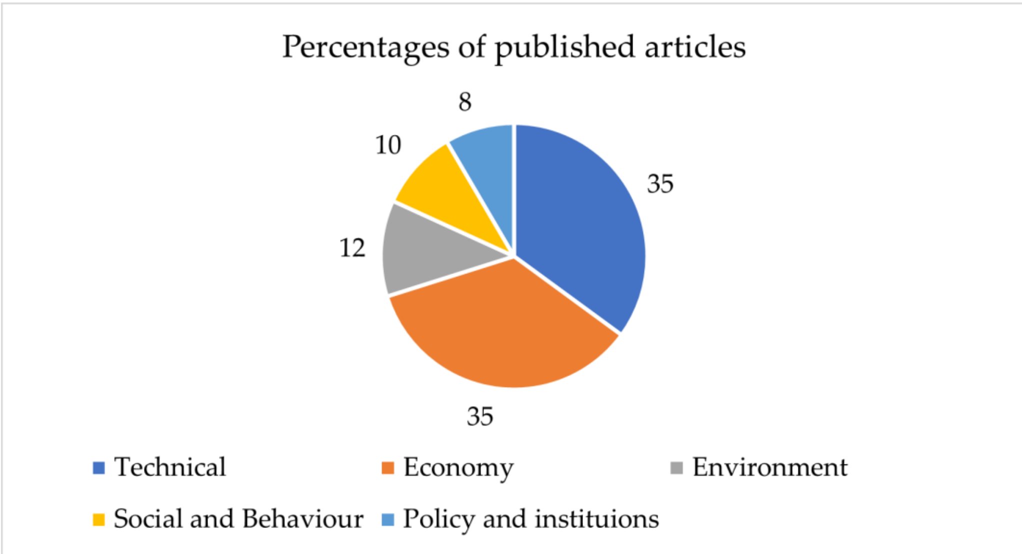

Figure 3. Percentages of published articles in terms of disciplines.

As presented in Figure 4, the majority of these 67 articles, approximately 80% (53 articles), used modeling and simulation approaches (i.e., optimization, input/output, and agent-based modeling) as their research approach, while the other 20% (14 articles) adopted theoretical and empirical approaches such as questionnaires and interviews to study CSS.

Specifically, optimization (e.g., [32,33]) and input/output modeling (e.g., [34,35]) covered the majority of the research approaches. Such approaches were mainly used for studying the techno-economic design and the feasibility of CSS, which could potentially be related to the exploration of CSS as an innovative niche or a socio-technical regime. There were a few studies (e.g., [36,37]) that used agent-based modeling as their research approach. Qualitative and quantitative data gathering and analysis (e.g., questionnaires and interviews) were the main approaches for the empirical and theoretical studies; however, their total share was approximately 12%.

The geographical locations of the published articles were also studied. The geographical location of the case studies could potentially influence the research results, as different countries and regions have their conditions (e.g., technical and policy settings). Figure 5 presents the geographical distribution of the case studies within the literature.

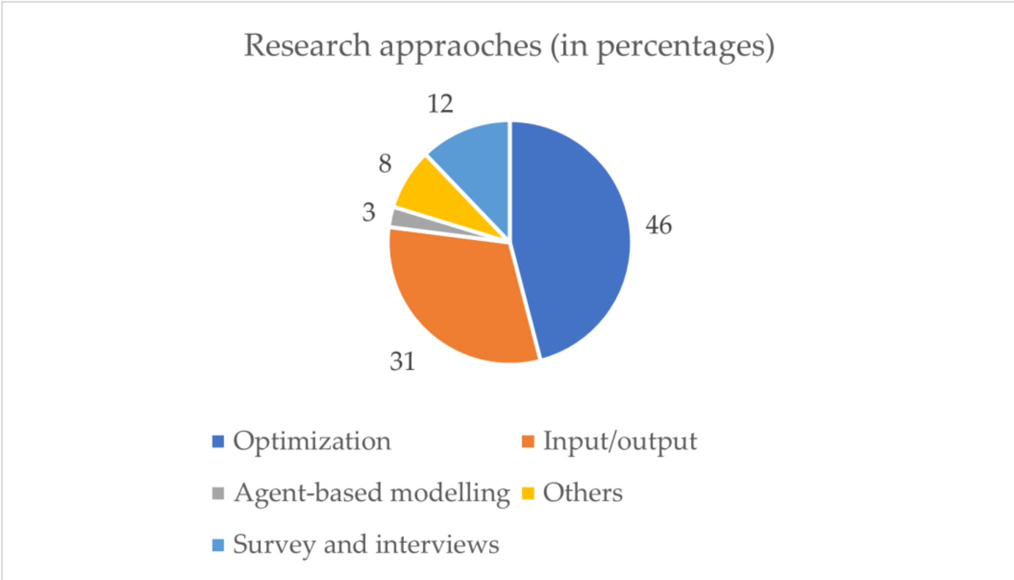

Figure 4. Research approaches (in percentages).

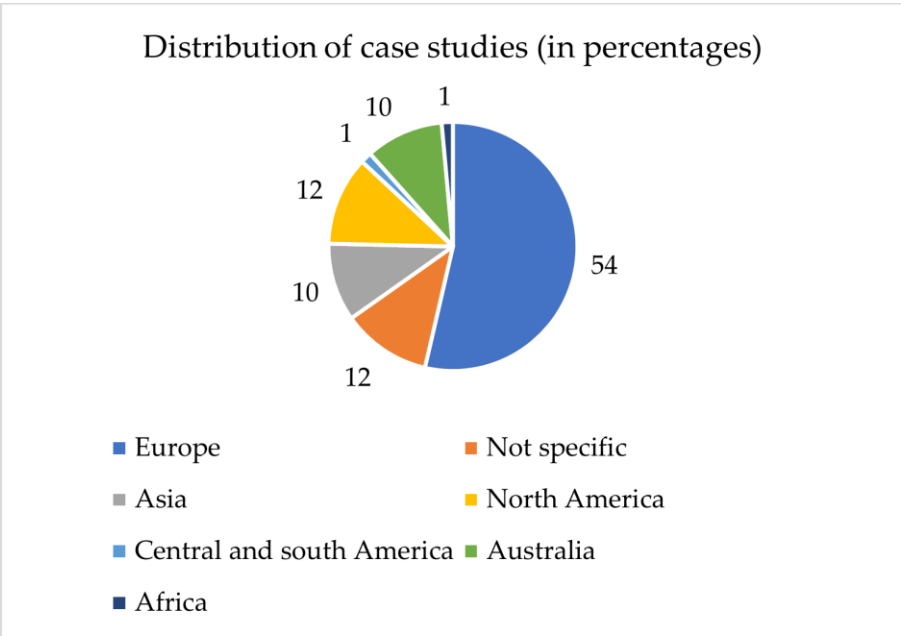

Figure 5. Distribution of case studies (in percentages).

European countries dominated the studies' geographical locations. Countries such as Italy, Spain, Germany, and the United Kingdom were the main case studies in this branch of literature. Australia, the United States, and Canada were the next countries that were studied the most. Asian countries (e.g., Hong Kong and Japan) were also used as case studies. Only one study explored CSS in the context of an African country (i.e., [38]). There were also a few studies (e.g., [39,40]) that did not specify the location of their case study. The studies which were focused on European and North American countries were dominated by modeling and simulation approaches.

As a final part of the overview, the commonly repeated keywords within the 67 articles were extracted by VOSviewer [17], i.e., the words with a minimum co-occurrence of 5 in all the articles. In total, the results led to 49 keywords, which are presented and categorized in Table 2. Moreover, the VOSviewer graph is provided in Appendix A. The suggested categories emerged from the commonly repeated words themselves when considering studies such as [41–43]. Such categories (and the keywords) could potentially bring more constructive insights into the literature, as extensively discussed in [41]. For instance, from the actor analysis perspective, the demand side, infrastructure, and organization were the important categories.

Table 2. Suggested categories and keywords extracted from VOSviewer.

Suggested Categories	Keyword
Solar electricity	Photovoltaic system, Solar power generation, Photovoltaic cells, Solar photovoltaics, Photovoltaics, Photovoltaic systems, Power generation, Electricity
Resources	Solar energy, Solar power, Renewable energy resources, Energy resources, Renewable energies, Alternative energy
Organization	Energy community, Energy communities, Renewable energy community
Storage	Electric batteries, Battery storage, Energy storage, Digital storage, Electric energy storage
Demand-side	Self-consumption, Prosumer, Self-sufficiency, Peer to peer
Building types	Apartment houses, Building, Residential buildings, Housing
Infrastructure	Smart power grid, Electric vehicles, Electric power transmission networks
Research approaches	Optimization, Economic analysis, Game theory, Optimizations
Economic	Costs, Investments, Power markets, Profitability
Other topics	Energy utilization, Energy policy, Energy efficiency, Sustainable development, Energy, Zero energies

4. Detailed Analysis of the Literature Using MLP Framework

To look at the CSS concept, four main aspects, i.e., technical, economic, socio-political, and regulatory and institutional were considered to analyze the literature. The following subsections explain these four aspects in detail.

4.1. Technical

To evaluate the technical aspect of CSS and how it is related to the MLP framework, five subcategories were utilized based on the literature review, including (i) a CSS performance analysis; (ii) combining CSS with other technologies and renewable resources; (iii) integrating with storage systems; (iv) designing CSS; and (v) combining with thermal systems. Each subcategory is analyzed in detail in the following subsections.

4.1.1. CSS Performance Analysis

To analyze the performance of CSS, Caballero et al. [44] investigated the solar PV generation potential of sustainable CSS using digital twin simulation. Their study included urban regions and an industrial area. They showed that the industrial park could be the location of solar PV installations and could provide electricity to the nearby urban area. Public spaces could also be used for solar PV installation, with systems to supply electricity to those dwellings without an opportunity to install solar PV panels. Generally, adding more solar PV systems and storage systems improves self-sufficiency (i.e., the energy demand portion met by on-site electricity generation) and self-consumption (i.e., electricity generated proportion through local generation resources used on site). Nykyri et al. [45] suggested a blockchain-based balance settlement ledger to provide the opportunity for CSS members to participate in an open electricity market instead of using an energy aggregator to manage CSS. The advantage of this technology is that after providing common energy between the co-owned solar PV system in CSS, instead of selling excess electricity to the network that energy can be automatically exchanged between the participating prosumers. Moreover, the blockchain method could increase self-sufficiency from 4.03% to 9.61% compared to the conventional solar PV system. Ascione et al. [46] considered many energy efficiency parameters to carry out an extensive energy performance analysis of CSS. They reported a considerable decrease in energy consumption and cost of CSS if Italian public policy was applied. To evaluate the common property energy consumption in CSS, Syed et al. [47] developed an empirical model to investigate the grid energy usage mitigation of common property. The common property was connected to a shared solar PV system and battery system. Three different strategies were considered, including instantaneous consumption, surplus allocation, and consumption-based allocation. The last two schemes allocated surplus solar PV electricity for common property demand instead of selling the excess electricity to the grid. The surplus allocation strategies showed the maximum reduction in grid usage, while the consumption-based allocation scheme was the best strategy in terms of economics. Therefore, enhancement within those key parameters, such as the self-consumption and self-sufficiency of communities, could push CSS from an innovation niche to the regime level.

Many studies have attempted to show that the CSS niche has more potential to reach the regime level compared to the other competitor niche, i.e., individually installed solar PV systems. For instance, Diahovchenko and Petrichenko [48] used an optimization model to compare the hosting capacity (the highest quantity of distributed generation that can be incorporated into the power distribution system without breaking its limitations or requiring alterations to its infrastructure) of CSS prosumers when they were playing an individual role in a low-power distributed generation (DG) community and when they were members of a medium-capacity energy community. The results revealed an improvement in technical and economical hosting capacity when the prosumers participated in CSS compared to only being members of DG. Borràs et al. [49] considered different building types (i.e., various load profiles) with three energy interaction approaches, including out-of-CSS individual self-consumption and collective self-consumption with (and without) battery systems. In terms of self-sufficiency, the results demonstrated improvement when considering collective action and a mix of different load patterns. Furthermore, the storage system could achieve more self-sufficiency, resulting in less economic feasibility. Similarly, Norbu et al. [50] developed a techno-economic analysis to compare community-owned and individually-owned solar PV, wind turbines, and battery systems. The result confirmed that the grid constraints had a larger impact on the performance of CSS in comparison to the individually owned solar PVs. This could be a withholding factor with regard to the technical regime. However, from an economic view, individually owned solar PVs have fewer benefits than CSS systems. Schram et al. [51] also reported the environmental benefit of prosumers participating in CSS rather than acting as individual units. Syed et al. [52] and Awad and Gül [27] also mentioned the benefit of shared energy microgrids over separate connections to the grid.

Mazzeo et al. [53] developed two-stage artificial neural networks (ANNs) to size and evaluate the energy performance and grid energy interactions of clean energy communities in 48 locations worldwide. They suggested that their framework could be a useful and user-friendly tool for working with limited input data, and it could eliminate the need for transient simulation software for evaluating clean energy communities. Wen et al. [31] developed a two-level optimization model to carry out secure day-ahead operational planning while considering solar PV's uncertain generation. Comparing the results with deterministic-based operational planning demonstrated a 15% improvement in the operational and ecological costs. Liang et al. [54] developed a convolutional neural network to consider the uncertainty that could affect the generation of a community, such as the uncertainty caused by meteorological and geographical parameters. In this study, a business model was developed to evaluate the cooperative formation of a solar community according to the households and utilities. Liu et al. [55] and Naware et al. [56] also used machine learning algorithms to decrease the uncertainty in estimating future solar generation, which resulted in a more accurate evaluation of the energy performance of CSS.

Such tools as neural networks are vital for CSS systems since they provide a better and more accurate prediction of CSS performance compared to using generally available solar radiation models, and they help the members of CSS systems to plan for the following days accordingly. However, many other accurate tools also need to be assessed extensively to overcome the technical uncertainties associated with CSS so that the CSS niche can be pushed upwards to the regime level.

4.1.2. Combining CSS with Other Technologies and Renewable Resources

Different studies have investigated the combination of other technologies with solar PV CSS. For instance, Canova et al. [34] compared two states for users in the same residential building: the first was when the building used only solar PV as the supply source for the electricity demand of the buildings and the second was when a heat pump (HP) was added to the solar PV system. The results demonstrated a cost saving of 26–29% when using HP and solar PV, but the saving was around 10% when using only solar PV. In another study, Di Somma et al. [32] went beyond comparing the benefits of CSS over not using CSS by developing a stochastic multi-objective optimization model that strategically optimized the performance of the various technologies available in CSS. They developed the optimization model based on energy cost and carbon emission criteria. The results showed that in terms of daily net energy cost savings and carbon emission savings, the optimized model of the studied CSS experienced 5–14% and 6–18% savings, respectively, in comparison to the non-optimized CSS. Mustafa et al. [57] also evaluated using hybrid solar PV and wind turbines in CSS by predicting the fluctuation of solar and wind energy using an ANN. To carry out energy planning under the uncertainty of a net zero energy community, Liu et al. [55] developed a simulation model based on future-oriented peer-to-peer (P2P) energy trading by 2050. They evaluated the climate change uncertainty effect by 2050 using the Markov chain Monte Carlo method and predicted the solar PV and wind turbine generation with a data-driven supervised machine learning method. The yearly solar generation and carbon emissions in the year 2050 were predicted to be 11.69% lower and 9.15% higher than the current reference year, respectively. Self-consumption and self-sufficiency in the community would go up by about 24.77% and 17.55%, respectively, by 2050. Karunathilake et al. [58] found the optimum mix of technologies for community renewable energy using a fuzzy model for a case study in Canada. The best mix consisted of grid electricity, a solar PV system, biomass, and waste-to-energy from the largest share to the smallest. To reach nearly zero energy community buildings, Suh and Kim [59] evaluated the energy performance of community buildings using energy simulation software. The results showed that integrating the solar PV system with additional solar PV modules and geothermal HP could attain the performance of nearly zero CSS.

While each technology type, such as HPs and wind turbines, can be independently considered a competitor of CSS at the niche level, combining them with PV systems in CSS can lead to the faster growth of the CSS niche so that it may move to the regime and landscape levels.

4.1.3. Integrating with Storage Systems

In combining storage systems with solar PV systems in CSS, Aranzabal et al. [60] provided an energy management strategy for a community with solar PVs and battery storage systems participating in an automatic frequency restoration reserves market to reduce each CSS member's ownership costs. Using the levelized cost of energy as an evaluation parameter, all the participants experience a reduced levelized cost of energy when applying the proposed EMS. They also reported that the most viable scenario was when only solar PV was used in CSS. Colarullo and Thakur [61] tried to use second-life electric vehicle (EV) batteries as the stationary storage system to maximize self-consumption in order to reach more sustainable CSS. They compared different scenarios with and without batteries and considered different meter services. The results revealed the payback time was generally acceptable when batteries were used. Moreover, when second-life batteries were used, the payback time with and without batteries was approximately 5 years. However, using new batteries instead increased the payback time by approximately 2 years. To show the importance of prosumer participation in the electricity market, Naware et al. [56] tried to investigate the effect of the prosumers' demand response management on battery energy storage degradation. They used an autoencoder long short-term memory neural network to predict day-ahead solar generation. The assessment of the degradation cost also showed that for the different initial states of charge of the batteries, the daily savings were between 11.18 and 18.78%, 8.88 and 16.15%, and 12.16 and 20% for summer, mild, and winter conditions, respectively, when they were compared to the response program without emergency demand. Liu et al. [62] also studied the impact of combining batteries and hydrogen vehicle storage with zero CSS. They carried out a multi-objective optimization to find the optimum size of the solar PV, wind turbines, and storage systems. The storage system integration resulted in higher self-consumption and covering of demand, improved hydrogen system efficiency, and grid interaction of the community. Syed et al. [63] reported a significant enhancement in the self-sufficiency and reliability of the grid when using solar PV systems with battery storage systems, which also helped the grid network to manage peak demands. Similar results were also obtained by Roberts et al. [64] when they added a central battery system to an embedded network. However, they concluded that using battery systems in the embedded network was not feasible without considering subsidies if they were to be viable in individual residences.

As the studies showed, integrating storage systems could boost the performance of CSS in many ways, i.e., increased self-consumption and decreased dependency on the grid. The last factor could make a considerable difference in the speed of transition from niche innovation to the regime level. The reason is that the regime governing the distribution system welcomes the fact that it has less need to update its distribution system to overcome the overloading problem due to solar electricity penetration. Therefore, this could result in a smooth transition for CSS from an innovation niche to the mainstream at the regime level. However, the initial investment cost may be seen as a deterrent to the adoption of storage systems in CSS.

4.1.4. Designing CSS

In terms of designing CSS, Mehta and Tiefenbeck [65] presented recommendations to CSS planners and distribution system operators based on an investigation of the impacts of three design parameters, including community size, prosumer ratio, and the production-to-demand ratio of three key performance indicators, including profitability, self-sufficiency, and grid impact. The results showed that when the prosumer ratio goes above 30% and when the ratio of production to demand is equal or double, the prosumers' profit decreases to below 25% and 50%, respectively. The self-sufficiency increases with increasing system size and the consumer ratio increases to a maximum of 37.8%. Moreover, to avoid grid upgrade, the prosumer ratio should be limited to 60–100% and 30–50% for the production-to-demand ratios of one and two, respectively. To investigate the sizing of CSS with solar PV and batteries, Cielo et al. [66] developed mixed integer linear programming to consider two key performance indicators: self-sufficiency and self-consumption. The optimum sizing showed 75% self-consumption and 60% self-sufficiency for the case study investigated. Novoa et al. [67] also developed an optimization model to find the best size and location of solar PV and battery systems in an advanced CSS, while considering the grid constraints. They showed that adding battery storage to CSS and optimizing solar PV reallocation in the community could prevent transformer overloads without upgrading the transformers. ur Rehman et al. [68] demonstrated that adding a solar PV system to CSS was reasonable when a significant number of EVs were added to the community. Koskela et al. [69] also showed the impact of using batteries and appropriate electricity pricing on increasing the optimum size of the solar PV system in CSS. Scognamiglio and Garde [70] considered the architectural and landscape options in designing solar PV systems for net zero energy communities. Shimizu et al. [71] tried to design CSS to minimize the cost and emissions. The developed method gave the community developers a vision by which to observe the impact of a combination of different consumers, a mix of various technologies, and their combination when designing the community.

As the studies demonstrated, the design of CSS could be crucial because the incorrect selection of the size and system parameters can lead to a reduction in self-consumption, self-sufficiency, and profit, which can ultimately affect the acceptability of the CSS niche.

As a result, using the right tools for the optimal and attractive design for CSS members seems highly necessary to keep the innovation niche alive.

4.1.5. Combining with Thermal Systems

In terms of integrating solar PVs into CSS thermal systems, Doroudchi et al. [72] compared the collective action of generating and storing thermal energy based on a solar PV system using an optimization model. They concluded that the ownership of shared thermal storage by houses in a neighborhood compared to having separate storage caused a reduction in energy import and export with the grid. Furthermore, the shared thermal storage payback time was less when compared to individual thermal storage. Pursiheimo and Rämä [73] suggested that combining solar PV modules, heat storage, and ground-source HPs was an efficient way to overcome the economic problems of separating CSS from the district heating network. Hachem-Vermette et al. [74] reported that a neighborhood of residential, commercial/institutional buildings could cover 70% of its energy demand if solar PV systems and solar thermal collectors were integrated with a borehole thermal energy storage system.

Domestic hot water and heating are among the inevitable needs of buildings and supplying them in CSS in a way that makes the members comfortable is vital. Therefore, many other detailed studies are needed apart from those mentioned above to evaluate the combination of thermal systems with PV systems in CSS; this is a key factor in helping the innovation niche to obtain the momentum to reach the regime level.

4.2. Economic

The two main topics discussed under the economic aspect in the past studies are the sharing of benefits between CSS members and business models. The details of each topic and how they are related to the MLP framework are provided in the following subsections.

4.2.1. Sharing Benefits between CSS Members

Regarding sharing benefits between members of a CSS, Oh [75] presented a community solar operation strategy to help CSS members minimize their electricity bills while considering the fairness constraint in the sharing of resources. The results showed that there was a tradeoff between incomes from savings in electricity bills and the need to ensure fairness. Gbadega and Sun [39] developed an optimization model to find the financial benefits for ten prosumers participating in a CSS with solar PV and battery storage systems. Those prosumers considered had participated in a centralized P2P transactive energy market. The calculation of the share due to each prosumer when selling aggregated surplus electricity to the main grid was carried out by the energy community manager, who was obliged to be fair to all the participating prosumers. The developed model provided the optimum planning, exchange, and regulation of the prosumers' domestic loads in addition to the optimum economic benefit. Moreover, Casalicchio et al. [76] developed a linear single-objective optimization model to distribute benefits fairly among CSS participants. The results revealed that a 14% increase in benefit would be observed if the demand and the installed solar PV system were the same, and the heterogeneity (i.e., a diversity of actors and energy sources that collaborate to generate, distribute, and utilize electricity) of CSS went from 0.33 (low) to 1.0 (high). They also concluded that each user had a different impact in terms of contribution; for instance, when the heterogeneity was maximum, the presence of a specific user could escalate the benefit from 10% to 97%. Applying a cooperative game theory, Fleischhacker et al. [77] allocated fair sharing of values to make a coalition between members of CSS. Norbu et al. [50] also showed that by using a redistribution model, the benefit could be fairly shared among community members even with existing storage systems. Fairness in distributing the benefits and income between CSS members could be a strong motivation for them to trust in participating in CSS. This eventually could change the socio-technical regime to accept the CSS niche as a new stream in the existing regime.

Radl et al. [78] compared individual and community participation in distributed solar PV systems in eight European countries and demonstrated an improvement in electricity price mitigation when investing at a community level and in aggregating loads of individuals together. They reported that acting as a community yielded lower electricity costs compared to individual participation; however, this was not necessarily a reason to increase the distributed solar PV.

The studies so far have considered the economic viability of CSS from the viewpoints of CSS members inside the community. However, Deutsch and Berényi [79] compared the economical parameters of utility-scale solar PV systems and community-invested solar PV systems from the utility side of the meter in Hungary. The NPV value of community-based solar PV systems was compared to the traditional ones. They showed that in terms of savings even community-invested solar PV systems were sensitive to taxes and capital costs. This could be a hindering factor for the niche innovation of CSS to move forward unless taxes and incentives are adjusted in a way to encourage stakeholders to invest in CSS.

4.2.2. Business Models

In terms of business models and markets for CSS, Saif et al. [80] provided an analysis of smart buildings with fully passive to fully active consumers under the business model of smart community-based electricity markets. Five scenarios were investigated, including passive homes, homes with solar PV only, home energy management systems with solar PV and energy storage, smart community-based electricity markets with solar PV only, and smart community-based electricity markets with solar PV and energy storage only. They also considered the impact of the smart community on low-voltage distributed networks. Time-of-use (ToU) tariffs affected energy storage, home energy management systems, smart community-based electricity markets, and low-voltage distributed networks. The results demonstrated the maximum saving of 50% and 36.6% in summer and winter, respectively, when the last scenario was applied. They also showed that under the smart community-based electricity market scenario, clean energy generation was consumed 31% more in the summer, while considering that energy storage under smart community-based electricity markets deteriorated the network's stability during the winter. In another study, Roberts et al. [28] utilized an embedded network business model to distribute costs and benefits between CSS members of a 72-apartment complex, while considering various tariffs. The results showed that a specific size of PV system per building was required to produce enough savings between members.

Many studies used the P2P model to evaluate the economic features of CSS. For instance, to maximize the revenue for both prosumers and consumers of CSS through a grand coalition, Malik et al. [40] developed a cooperative game theory to evaluate the P2P interaction of participants in a local CSS in order to overcome the instability problem of P2P transactions due to the uncertainty of solar energy. Three priorities were considered, including energy demand, geographical distance, and trading price. The results revealed that the economic revenue of the participants could be maximized when the geographical distance and trading price were considered for daytime transactions and peak energy demand at night. To evaluate a virtual local energy market, Hashemipour et al. [81] developed a dynamic P2P clustering model. They also investigated the impact of adding EVs to the virtual local energy market. The results revealed that allowing P2P transactions between CSS members in the virtual local energy market decreased electricity costs and made CSS less dependent on the grid. The participation of EVs could also further enhance electricity costs and grid independence by about 60% and 30%, respectively, compared to not including them. Liu et al. [82] compared the P2P and peer-to-grid schemes and developed ToU P2P energy trading management. They concluded that the P2P scheme worked better than peer-to-grid in terms of self-consumption, self-sufficiency, and energy trading profit. Moreover, the ToU trading model improved the grid stability and reduced the penalties imposed by the grid on individuals because it prevented the import and export of electricity during on-peak and off-peak times, respectively. Moreover, as discussed previously, Gbadega and Sun [39] considered a centralized P2P transactive energy market to evaluate the fair distribution of profits between CSS members.

Henni et al. [83] developed a simulation model to investigate the influence of the shared economy approach on the different technical and economic aspects of solar-shared communities. The study demonstrated that such an approach could lead to higher economic feasibility (as well as benefits) for the participants while being able to resolve some of the technical challenges. Cielo et al. [66] also compared three different business models for renewable energy communities (RECs), including full investment by RECs themselves, full investment by outside REC developers with the sharing of some revenue with the REC, and cost and benefit-sharing between a developer and the REC. While all three models showed a positive NPV, the last model had the best economic advantages in terms of NPV.

To evaluate the grid interaction of a zero CSS during on-peak and off-peak times, Liu et al. [62] used a ToU grid penalty model. Compared to the scenario without renewable energy usage in the community, they reported significant reductions in grid penalty costs. To explore the investment strategies, the optimal planning and operation of a shared-solar community are presented in [84]. The study demonstrated approximately 30% cost and significant GHG emission reductions by such communities. To evaluate the cooperative forming of a solar PV solar and storage community by utilities and households, Liang et al. [54] developed a novel business model using the Nash bargaining solution. The results showed a win–win situation and a boost in income for each of the participants.

Although the works so far have generally pointed to the feasibility of community-shared solar projects, Faria et al. [85] revealed that a shared-solar production business model was not feasible under Brazil's policies and legislation. However, they mentioned the feasibility of acquisition and rental business models.

Almost all the business models demonstrated the economic viability of CSS, which is a significant factor in encouraging different stakeholders to participate in CSS. These business model outputs, such as low electricity cost [80,81], reasonable NPV [83], lower on-peak penalties [62], and maximum income [40], shown in [13] as cost improvement, could turn CSS into a niche innovation that was mature enough to be pushed to the regime level.

4.3. Socio-Political

Based on the literature, in the MLP framework, the socio-political regime focuses on six subcategories, including (i) society's willingness to join CSS; (ii) behavioral responses; (iii) decision-making processes; (iv) participation in demand response programs; (vi) ownership; and (vi) cooperative behavior. Each one is explained in detail in the following subsections. Note that because the number of studies under each subcategory is limited, the MLP analysis of all the subcategories is provided in a separate subsection.

4.3.1. Society's Willingness to Join CSS

To show society's willingness to participate in CSS, Adewole et al. [38] empirically investigated using surveys the motivation factors for households to participate in P2P energy trading. The results revealed that financial benefits, reduced electricity costs, and the advantages of independence by decreasing reliance on the grid are the main inspiration for peers to get involved in P2P trading. To study the impacts of policies in introducing multi-scalar solar energy, Sareen and Nordholm [86] conducted an interview-based investigation to analyze the change from large-scale solar energy usage to small-scale usage. The results from surveying various solar energy stakeholders revealed that the large-scale introduction of solar energy had ecological advantages compared to the socio-economic benefits of small-scale solar energy roll-out. They concluded that to encourage people to be involved in solar energy promotion to approach sustainability the policies must form joined-up environmental and socio-economic pillars of different scales of solar energy usage. To evaluate the decisions of community members in adopting rooftop solar PV in a city district, Schiera et al. [37] used agent-based modeling to consider the social patterns, member interactions, and geographical location of buildings. The results revealed that, based on supportive policies, an 80% increase in installing rooftop solar PV in community-shared spaces was observable when changing the paradigm from solar PV ownership by individual houses to that of CSS PV systems.

4.3.2. Behavioral Responses

To consider the behavioral responses of CSS members, studies such as those carried out by Hodencq et al. [33] developed a method to evaluate the optimal sizing of CSS with regard to the behavioral responses to and ecological impacts of self-sufficient CSS. This new method showed that GHG emissions were minimal for optimally sized solar PVs and battery systems with different self-sufficiency rates for different countries. Todeschi et al. [30] investigated the urban planning impact on the self-consumption and self-sufficiency of concentrated homes at a city level using the particle swarm optimization model. The result emphasized that the building shapes were a basic parameter for improving self-sufficiency and self-consumption. They also showed the viability of establishing CSS if their self-sufficiency was at an acceptable level. The other important factor considered was the roofs of buildings when designing their 3D dimensions. Lovati et al. [87] also showed that prosumers in CSS could have diverse self-sufficiency, ranging from 15% to 30%. This is because prosumers have different capabilities, such as different social and cultural differences and energy demands when exploiting solar energy in the absence of demand response management and different behavioral patterns.

4.3.3. Decision-Making Processes

Several studies focused on decision-making processes and network perspectives. By using a participatory modeling approach, Pacheco et al. [88] empirically explored the decision-making processes within shared-solar communities. Along with the availability of different technologies, the study illustrated the necessity of including the communities' perspectives and the involvement of a broad range of actors (e.g., local authorities and industrial companies) to establish a shared-solar community. Karunathilake et al. [58] developed a system dynamic model to evaluate different renewable energy establishment plans and considered the technical, economic, environmental, and social aspects. Their model provides developers with the ability to view the impacts of their current decisions on the success of the community in the future and to handle the risks and challenges reasonably.

4.3.4. Participation in Demand Response Programs

To encourage prosumers to participate in demand response programs and load curtailment, Naware et al. [56] conducted a study based on seven different incentive scenarios with different features of the prosumers' load profiles. A 20 ₵/kWh incentive was found to motivate prosumers to participate in emergency demand response management. To obtain the best method of demand curtailment, Knirsch et al. [89] developed a "trust-less" decentralized approach that allowed all community members to suggest optimum solutions instead of using a single party. With the proposed approach, all the members agreed on one solution to manage shiftable loads.

4.3.5. Ownership

To evaluate the ownership concept, Pacheco et al. [88] showed that infrastructure ownership (e.g., solar PV and microgrid) could potentially impact the establishment of energy communities such as CSS positively. Klein et al. [90] also compared three approaches, including leasing to own, buying panels with a developer, and "true ownership", by conducting a cost-benefit analysis and considering three stakeholders (developer, host, and subscriber). They suggested the lease-to-own scheme, which eventually could lead to ownership, as the best option in terms of net present value for all three stakeholders. Lovati et al. [87] compared three ownership structures in a local energy community using agent-based modeling. They explained different structures based on the direct participation of households in investment, operation, maintenance, and revenues or ownership by a single third-party provider and showed how various selling prices could make different ownership models work.

4.3.6. Cooperative Behaviors

Considering the cooperative behaviors of different participants in a CSS, Ferster et al. [91] constructed a community solar "catalyst" to trigger the cooperative efforts between different stakeholders to encourage the establishment of CSS. The results revealed a 53% increment in the adoption of CSS with the application of an experimental catalyst. In the experiment, various stakeholders got involved in activities resulting in cooperative behavior. In [92], the authors also used a noncooperative game analysis to consider the consumers' preferences in order to match the prosumers' electricity production attributes and, at the same time, to make sure that privacy was preserved. The observations from the case study showed that flexibility in a CSS could make more income for prosumers than consumers, while both types of participants could considerably reduce their demand. Importantly, they showed that the main driver for prosumers to be part of a CSS is an economic parameter; however, consumers participate in a CSS due to the green nature of the electricity supply. To evaluate the consumers' response to different renewable energy options, Mittal et al. [36] developed agent-based modeling to evaluate consumers' adoption of buying and loaning rooftop solar PV, utility green pricing, and community solar. The results showed that introducing the community concept to the members gave them greater encouragement to participate in the community compared to before the introduction. They also emphasized the importance of social interactions between community participants in establishing a successful zero-energy community. By using cooperative game theory in an equilibrium model, Abada et al. [93] explored the grid tariffs and behavior of distribution system operators on the formation of energy communities with a game theory framework. The results showed that including the case studies of joint investment in solar PV and battery solutions could lead to higher financial benefits and positive environmental impact in a long term. Mishra [94] considered the social, economic, and technological aspects of developing energy cooperatives through field observations. The results showed that the CSS concept has social acceptance; however, from the financial and technical viewpoints, there could be a challenge related to adopting energy cooperatives due to the replacement of battery banks and the corresponding maintenance costs.

4.3.7. MLP Analysis of Socio-Political Parameters

The socio-political aspect is among those aspects that, if practiced well and adopted by the majority of society, could make an innovation niche emerge and could enable it to reach the landscape level. Those factors mentioned in the above subsections, such as social willingness, ownership, and cooperative behaviors, if they get more attention from society members, force the institutions and governors to pay more attention to CSS systems and to establish firm legal frameworks for the extensive adoption of CSS.

4.4. Regulatory and Institutional

Finally, the main focus of the literature on the regulatory and institutional aspects is on the legal framework, including the various tariffs and incentives explicated in the following paragraph.

Legal frameworks, considering different tariffs and incentives, are explored extensively in the literature. For instance, Canova et al. [34] evaluated the Italian collective self-consumption regulation and concluded that the profitability of solar PV or PV and HP CSS in Italy was because of those available incentives which recovered a large portion of the initial installation cost of solar PV systems and HP as a tax deduction. Pacheco et al. [88] showed that available funding and adaptation of urban administrative processes were crucial for establishing solar-shared communities. Different tariff structures were explored in [28], demonstrating that peak demand charges in particular were more influential in establishing solar-shared communities. Cielo et al. [66] and Garavaso et al. [84] also mentioned the importance and role of policies, incentives, and legal frameworks for solar-shared communities. Ascione et al. [46] explored the environmental and economic impact of solar-shared communities, considering various Italian legislation and regulatory frameworks and demonstrating the flaws in Italian public policy (e.g., available public grants). To explore the investment strategies, the optimal planning and operation of CSS are presented in [84]. The study demonstrated approximately 30% cost and significant GHG emission reductions by such communities. Gallego-Castillo et al. [29] used the self-consumption indicator to explore the influence of the Spanish legal framework on solar-shared community establishment. A techno-economical optimization was performed, delineating self-consumption's cost-effectiveness while showing that certain technologies, such as batteries, still require considerable cost reduction. An optimization model and its application for two countries (i.e., Austria and Australia) are presented by Fina et al. [95], who consider different factors, including legal frameworks, that could influence the deployment of CSS. The study demonstrated that investment costs, lower solar exposures, and administrative hurdles constrained the deployment of CSS in Austria, an example of a European country. In contrast, the main barriers in the Australian context were lower electricity tariffs and regulatory barriers. By collecting empirical data through interviews, Michaud [96] showed the advantages, barriers, and potentials of CSS in the United States. The study gave particular attention to the different policies and showed that state-level policies needed to be improved and to be more inclusive for CSS.

This aspect is the most vital one among the others since it could completely stop the growth and emergence of the CSS innovation niche or pave the road for the pervasive use of an innovation niche. As mentioned in [13], support from powerful actors could increase internal momentum and allow the niche to diffuse into and adjust the existing socio-technical regime. Subsequently, the new system of the regime, including CSS, could affect the landscape. It is also worth mentioning that in some regions, such as Italy [34], because of the established legal frameworks, there is a great opportunity for CSS to join the socio-technical regime stream. However, the absence of a legal form of CSS even in developed countries (e.g., many parts of the US) [96] is delaying the emergence of CSS. Therefore, it is crucial to investigate why the laws do not exist or are not allowed to be developed in different countries.

5. Discussion

5.1. Reflection on the Existing Body of Literature

Based on the analysis, a clear observation was made that the technical and economic aspects of CSS have received considerably more attention than the socio-political, regulatory, and institutional aspects. Table A1, in Appendix B, provides a comprehensive overview of which studies fall under which aspect and subcategory. It is important to note that certain studies may fall under multiple aspects.

While analyzing the technical aspect, the focus was on examining the performance of CSS, the combination of solar PVs with other technologies, such as wind turbines, heat pumps, and biomass systems, the impacts of adding storage systems to CSS, designing CSS, and the integration with thermal systems. As also discussed in [48,51], participating in CSS rather than individually owning solar PV results in higher self-consumption, self-sufficiency, income, and lower GHG emissions. Moreover, as mentioned in [56,63], improvements in self-consumption and reduced dependency on the grid are observed when CSS is integrated with storage systems. However, it is important to note that these additional features require more investment from participants [64]. Generally, from a technical point of view, the performance improvement and advantages of CSS have a strong positive impact on moving the CSS niche dynamics towards higher levels, namely the regime and landscape levels.

The technical aspects discussed in this current study connect to previous reviews for single rooftop solar PV (excluding the collective action and sharing concept). For instance, ref. [11] discussed the fact that the technical challenges related to rooftop solar PV are mainly related to grid constraints, such as electricity demand and supply mismatch, lack of visibility and controllability of the generation in small-scale PV systems, the vulnerability of the grid frequency, grid voltage instability, or ramp rate requirements. Generally, this study showed that the improved self-sufficiency of CSS, reported by many studies such as [49,65], could help to mitigate the above-listed challenges mentioned in [11]. In this line, studies such as ref. [4] showed the influence of collective action on the social and technical aspects of energy communities. The current work also added more details to the technical part of CSS, in comparison to [11], by evaluating the viability of adding other technologies and renewable resources and the impacts of integrating with thermal and storage systems.

Regarding the economic aspect, the main focus of the reviewed literature was on sharing benefits between CSS participants and evaluating different business models and markets. The results revealed an increase in benefits for all prosumers and consumers when participating in CSS. Moreover, the viability of the fair distribution of benefits and values is reported in many studies using different models and approaches. Furthermore, different business models resulted in better NPV, reduced electricity costs, reliance on the grid, reduction in GHG emissions, and enhanced demand coverage. However, a few studies warned that taxes and capital costs could affect CSS development. All of those enhancements in economic parameters, such as more income, higher NPV, and reduction in electricity cost, as emphasized in [12], could lead the CSS niche to break through into the regime level.

Ref. [14] provided categories for the economic aspect of the MLP framework to analyze energy communities; some were similar to those found in this study. Those categories included the improvement of local income, as reported by many studies, such as [40,76]; market conditions, as reported by studies such as [40,80]; the viability of cooperative business models, as reported by [40,54]; and financing, as presented in studies such as [28,80]. However, compared to [14], some areas have been missed in the literature on CSS, such as the openness of the energy market, local economic crises, and local job creation; these areas need more attention in future studies.

In the socio-political aspect, the willingness to participate in CSS, behavioral responses, decision-making processes, participation in demand response programs, ownership, and cooperative behaviors were studied in the literature. The reduction in electricity costs, autarky from the grid, infrastructure ownership, and supportive policies were the main drivers for prosumers to participate in CSS. Furthermore, supportive incentives and allowing CSS participants to suggest their opinions on managing shiftable loads are helpful in load response programs. Considering the cooperative behaviors and social interactions of prosumers and consumers is important to address their different objectives and to encourage participation in CSS. Those social parameters could be the main drivers for the CSS niche diffusion into the regime and landscape levels because no matter how advanced the technologies used in CSS are, CSS will eventually fail if it is not used and accepted by society. Different studies, such as [4,14], showed the importance of the social aspects related to the development of energy communities.

In a review study [43], which investigated the challenges that integrated community energy systems face, the paradigm changes throughout community involvement, the willingness to pay for local energy production, energy independence and security of supply, and energy poverty were mentioned as issues. Similarly, in the current study, a few studies have investigated the first three issues, such as [38,56], but further studies are also needed to clarify how CSS could overcome those issues. Moreover, the last challenge, energy poverty, has not been touched on vividly in the CSS literature.

Finally, regarding the regulatory and institutional aspects, the only focus was on the legal frameworks considering the tariffs and incentives. The results showed the significance of the regulatory and legal frameworks in establishing CSS. Recovering part of the initial investment, existing incentives, and investment strategies encouraged prosumers and consumers to participate in CSS. However, several other parameters were mentioned in [43] as possible institutional and regulation issues for integrated community energy systems, such as energy democracy, locality, support schemes and targets, governance, regulations, and institutional design. The same issues need to be comprehensively investigated in CSS to help governors and policymakers to establish a robust legal framework for CSS.

5.2. Limitations

Although the study constructively brought new insights to light with regard to CSS, it has several limitations that are important to consider for further research. First, the current study was founded on the MLP framework to evaluate CSS from the four different aspects mentioned above; however, if these aspects are to be individually investigated in more detail, other frameworks would be better options. For instance, the techno-economic perspective (TEP) [8] could be useful for detailed economic and technical analysis. The institutional analysis and development (IAD) framework [9] could also be useful if the focus was on exploring the collective action and the actors' interactions within CSS. It should also be noted that the selection of keywords plays an important role in the investigated literature. For instance, if the scope is to be extended beyond solar PV CSS, the keywords "solar thermal" and "solar collector" could potentially help with including literature on CSS with regard to both supplying electricity and heat demand. However, as explained in Sections 1 and 2, these aspects are outside the scope of this research. Lastly, the knowledge body used in this study included only peer-reviewed articles; however, there could be possibly valuable materials in conference papers, graduate theses, and reports/white papers published by academic and non-academic organizations. For further research, we recommend including such gray literature as it could further develop the current work.

6. Conclusions

Owing to its widespread availability, solar energy is widely utilized around the world, particularly through solar PV technology. The inability of some houses to directly adopt solar PV due to the structural and textural characteristics of cities and urban areas, along with the interest of homeowners in utilizing solar PV-generated electricity without owning the panels themselves, has caused the emergence of the concept of CSS. This study aimed to investigate some of the main factors that prevent solar PV CSS from becoming one of the leading energy systems and the potential solutions to make it the dominant energy system. To achieve these research objectives, the multi-level perspective (MLP) framework was applied to the existing literature to investigate CSS energy systems from different socio-technical aspects, including the technical, economic, socio-political, and regulatory and institutional.

After analyzing the existing literature, the three main questions posed in the introduction regarding CSS dominating energy systems could be answered as follows:

- Why should solar PV CSS be the leading energy system?

The immense technical tools and economic benefits of CSS, such as improved self-consumption, self-sufficiency, and income over the individual adoption of solar PV, as discussed in [40,49], for example, in addition to the compatibility with the examples of different business models provided in [81,82] and the other technologies presented by studies such as [32,34], provide the leverage for CSS to take a more dominant role in energy systems.

- Why is solar PV CSS not the leading energy system?

The lack of investigations carried out in the socio-political area on various topics, such as ownership (e.g., [87]) and the willingness to join CSS (e.g., [38]), as well as the factors that have not been taken into account, such as social acceptance, cultural factors, trust, energy justice, changing social positions, psychological factors [14], and other related issues, make stakeholders reluctant to participate in CSS. However. most importantly, the lack of strong and specific legislative frameworks in many regions of the world and the lack of specific network planning to handle solar PV penetration by institutions and governments [11] are the main factors hindering the progress of CSS.

- What can be done to make solar PV CSS a leading energy system?

By evaluating different technical and economic aspects, it seems that CSS has reached a good level of maturity in the niche, although there is still room for improvement. However, the most important area that needs to be established or reformed for CSS to become dominant in energy systems is the change in the ruling regime, in both the socio-political and the regulatory and institutional fields, to provide space for the expansion of CSS and to help it to reach the landscape level.

In conclusion, the study showed the advantages, challenges, and possible future of CSS, as a collective and distributed energy community based on solar energy. Each studied category (i.e., technical, economic, socio-political, and regulatory and institutional) and their influence on CSS's current and future positions in the energy transition are discussed in detail. The socio-political and regulatory and institutional aspects are influential dimensions for the further developments of CSS.

Knowledge Gaps and Recommendations

The following topics are recommended for future studies to help the further development of CSS:

- Topics needing further attention:

The current study reveals the knowledge gap, especially in the socio-political, regulatory, and institutional aspects. Previous reviews of single rooftop solar PV installations (excluding collective action and sharing concepts) [11] and energy communities [14] have considered several factors relevant to these categories; these are currently missing in the CSS literature. For instance, social acceptance [97], cultural factors [98], and energy justice [99] are the areas that need more attention under the socio-political aspect to help CSS move forward from the niche level to the upper levels. The other main gap involves the establishment of a legal framework [100], which could create considerable momentum in CSS development.

The other gap is related to the technical aspect, which is moving from CSS to smart CSS and is causing the emergence of the use of AI techniques in the management of CSS. Although some machine learning methods have already been developed for estimating solar PV generation (e.g., [55,56]), further investigation is needed to advance into smart CSS. As a result, academic researchers could consider working on developing more accurate solar PV electricity forecasting tools and developing blockchain-based methods or similar methods as potential topics for investigation.

- Research approaches:

The two main dominating research approaches in CSS literature were optimization and input/output models. However, other approaches, such as agent-based models (e.g., [101,102]) and empirical models based on surveys and interviews (e.g., [103]), need to be evaluated as well.

- Physical conditions:

Based on the existing literature on CSS, most of the research has been carried out in Europe. Therefore, there is a geographical gap in investigating CSS. For instance, the viability of CSS could be evaluated in African, Asian, and American regions. Moreover, the technical configuration of CSS could be considered as having great potential to help CSS perform better. Mainly, the CSS literature has focused on integrating solar PV with heat pumps and storage systems. Other combinations with technologies such as geothermal or bio-energy systems, as mentioned in [4], could be assessed for CSS development.

- System boundaries:

Although previous studies have primarily focused on CSS implementation in residential buildings, future research can explore the involvement of industries in CSS [104]. Furthermore, the combined participation of both the residential and industrial sectors in CSS can also be studied.

- Socio-technical and landscape design levels:

According to the CSS literature, the concept has gained momentum at the niche level, and with emerging regulations in different regions, it has the potential to become mainstream in the socio-technical regime. However, it is important to investigate the implications of this transition from niche to socio-technical and landscape levels, particularly for the existing energy systems. If CSS were to be introduced as a new regime or landscape, it could have significant impacts on the socio-technical and energy systems. A similar study has been carried out in [105] to show how renewable energy communities change energy systems. Therefore, further research is needed to understand the potential outcomes of such a transition.

Using the MLP framework, this study's goal was to explore the advantages, challenges, and strategies that could help CSS to become a dominant player in energy systems. While the study provides valuable insights, some limitations could be addressed to yield even more meaningful and comprehensive results.

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

Appendix A

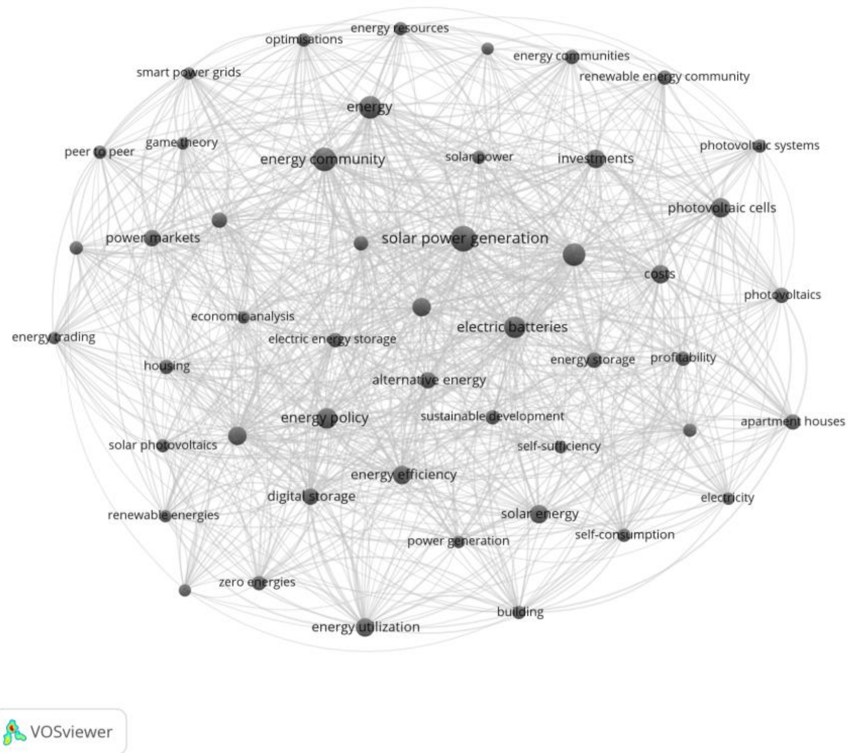

Figure A1. Keywords from the VOSviewer.

Appendix B

Table A1. Classifying papers according to their respective aspects and subcategories.

Aspect	Subcategory	References
Technical	CSS performance analysis	[27,31,44–56]
	Combining CSS with other technologies and renewable resources	[32,34,55,57–59]
	Integrating with storage systems	[56,60–64]
	Designing CSS	[65–71]
	Combining with thermal systems	[72–74]
Economic	Sharing benefits between CSS members	[39,50,75–79]
	Business models	[28,39,40,54,62,66,80–85]
Socio-Political	Society's willingness to join CSS	[37,38,86]
	Behavioral responses	[30,33,87]
	Decision-making processes	[58,88]
	Participation in demand response programs	[56,89]
	Ownership	[87,88,90]
	Cooperative behavior	[36,91–94]
Regulatory and Institutional	Legal framework	[28,29,34,46,66,84,88,95,96]

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