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(Review Article)

# Advancements in solar panel efficiency: Developing community-based energy solutions

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## Abstract

**Introduction:** The advance towards sustainable energy across the globe has lead to the technological advancement in the solar industry where today's photovoltaic (PV) panel boasts an efficiency ranging to a record high of 44.5%. This significant uplift has been accompanied by the decrease in costs of solar energy and has established it as a fundamental part of community sustainable energy project. However, the shift from large-scale traditional power structures to small-scale community renewable mini-grids projects has many policy and, economic and technical and social barriers.

**Materials and Methods:** This systematic review aggregates data from 64 scientific papers, published between 2007 and 2023, addressing consumer-oriented aspects of PV energy communities. The literature was systematically analyzed across eight key areas: policy initiatives, generation and trading structures, tendencies, and impacts, economic analysis, business cases, energy policies and plans, demand side integration, mathematical and simulation tools, and consumers' characteristics.

**Results:** The review also shows major developments on the materials and structure of a solar cell that has made it more efficient coupled with a reduced cost implication. New business models and revenue streams such as virtual utility business models of community solar and peer-to-peer trading platforms based on blockchain are identified as evolving. However, there are still challenges such as regulatory limitations, absence of adequate funding structures and low customer awareness. Best practices underscore the need for targeted policies, new forms of industry structure, and customer involvement.

**Discussion:** True, technology is advancing steadily, yet unlocking the full potential of CSPs demands a systems-approach addressing multifaceted challenges. Policy reforms for community ownership, standardisation of interconnection procedures and laying down fair schemes of sharing the benefits are important. Strategic financing solutions, energy management systems integrating IoT and AI, and specific focus on educational outlooks can boost the rate. The review also points out gaps on the assessment of non-energy benefits and the integration of storage at the community level.

**Conclusion:** Community-based solar energy systems represent a promising pathway for accelerating the clean energy transition while fostering local resilience and energy democracy. However, their widespread implementation necessitates coordinated efforts across policy, technology, and social domains. This review provides a comprehensive framework for researchers, policymakers, and practitioners to address key barriers and leverage emerging opportunities in community solar development. Future research should focus on developing standardized metrics for assessing community solar impacts and exploring synergies with other distributed energy resources.

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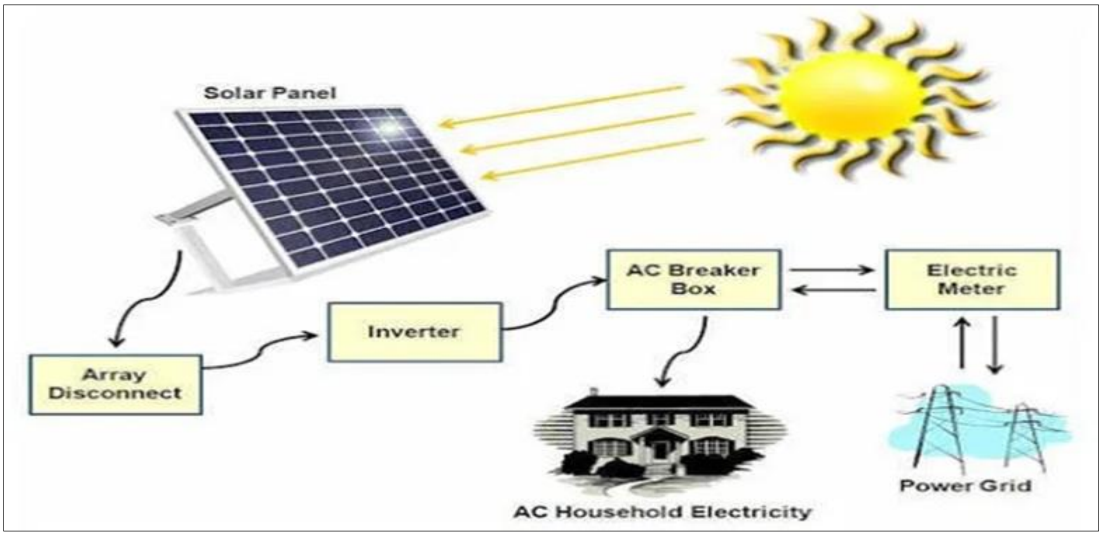
**Keywords:** Solar for the community; Solar panels for homes; Clean energy; Energy saving, green power integrations; Solar power integration in buildings; Prosumers trading; Panels effectiveness; Power control; Reuse and recycle mentality

**Graphical abstract**




## 1. Introduction

The current world energy map is rapidly evolving due to the current need to respond to climate change and further development of sustainable and low-carbon energy systems. Leading this shift is solar photovoltaic (PV) technology that has undergone tremendous improvement in performance and cost-reduction within the last decade. The efficiency of solar cells isp now remarkably high, and the laboratory prototypes of the solar cells obtained to show the conversion efficiencies of 44.5% (Abu-Hamdeh et al., 2022). These impressive results when combined the ever increasing rate of the manufacturing and installation costs has placed solar energy at the heart of renewable energy policies globally. For some, especially now that the solar technology is coming of age, there is beginning to be awareness on how pro community local utility models can help advance the cause of distributed clean energy while at the same time enhance energy democracy. They require participants to collectively benefit from output of a single solar facility, and have emerged as a popular model for increasing access to solar power beyond that offered by mere rooftop systems. These initiatives have several benefits including; low cost due to scale, good solar exposure and provision of solar advantages to residents and other people in substandard rental apartment, poor economic status individuals and those whose house structure is not suitable for roof mounted structure (Byrne et al., 2015).

Nonetheless, the upgrade from conventional large-scale MS defeat centralised power frameworks to distributed community solar projects entails diverse difficulties concerning political, economic, technological, and societal aspects. Most of the regulatory frameworks used today for control for centralized utility models do not capture most of the features of community energy systems. Project development can also be constrained by financial barriers; high initial costs coupled with limited access to credit facilities. Sophisticated issues based on the aspects of integration with distribution grid, management, and storage and utilization of energy lead to new effective solutions. Besides, these social aspects include networking, trust, as well as the fair distribution of commodities in encouraging the achievement of aims and objectives of these projects (Lazdins et al., 2021).

The purpose of this article is to provide an up-to-date, integrated, review on the increase and the future uses of solar panel efficiencies. Therefore, this study aims at analysing the works done on how technologically advanced society, policies, economic models, and social settings impact on or for community solar projects in order to understand the viability or otherwise of fulfilling the vision on one hand and to note the trends and prospects on the other hand. The review addresses the following key research questions:

Recent advancements of solar cell materials and designs have played a vital role in recent advancement of efficient and cost effective community solar.

- What policy frameworks and regulatory reforms are necessary to enable and incentivize community-based solar energy development?
- How can innovative economic and business models enhance the financial viability and inclusivity of community solar projects?
- What technical solutions and energy management strategies can optimize the performance and grid integration of community solar systems?
- What social factors influence consumer adoption and community engagement in solar energy initiatives, and how can these be effectively addressed?

To address these questions, this review draws upon a systematic analysis of 64 peer-reviewed scientific publications from 2007-2023, focusing on consumer perspectives related to PV energy communities. The literature was examined across eight key areas that represent critical aspects of community solar development: policy frameworks, peer-to-peer trading models, economic assessments, business models, energy management strategies, demand response integration, modeling tools, and consumer adoption factors. This multidimensional approach allows for a comprehensive exploration of the complex ecosystem surrounding community solar initiatives. The significance of this review lies in its potential to inform evidence-based strategies for accelerating the deployment of community solar projects. By synthesizing cutting-edge research and identifying critical gaps in current knowledge, this study aims to provide valuable insights for researchers, policymakers, industry practitioners, and community organizers involved in advancing sustainable energy solutions. The findings can guide the development of more effective policies, innovative business models, and targeted interventions to overcome barriers and leverage emerging opportunities in community solar development.

The common strands associated with each policy element are summarized in Table 1 in order to reflect the policy, economic, technical, and social dimensions of community solar development. This table, retrieved from the literature analysis, shows the major issues and possible responses for every area, creating a framework for cross-cutting community solar models.

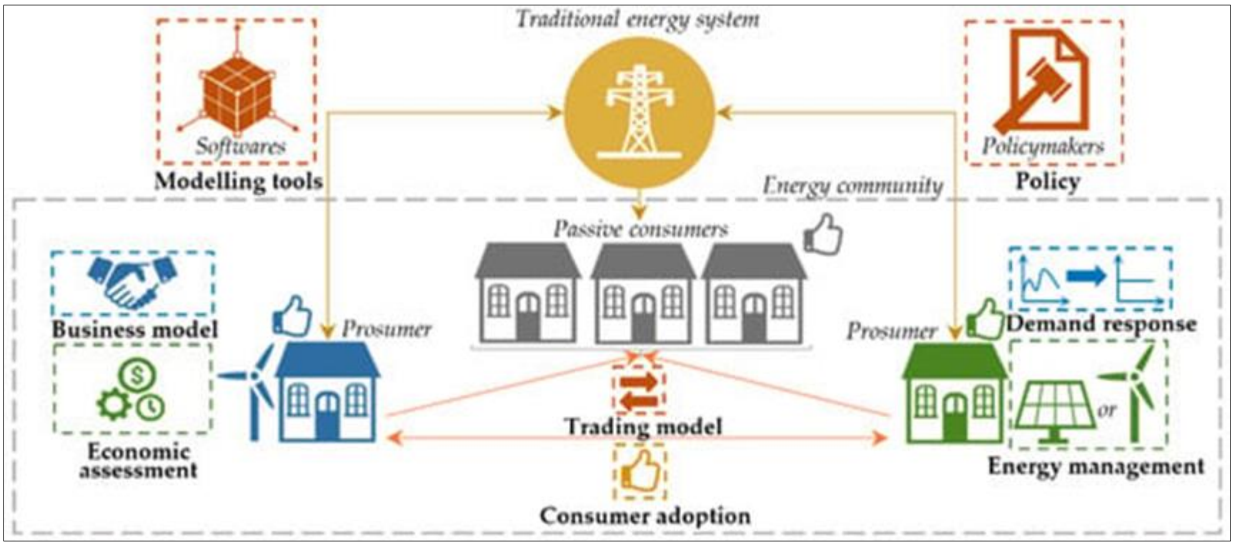
**Table 1** Key Elements of Community Solar Development Across Domains

| Domain | Challenges | Potential Solutions | Key Stakeholders | Metrics for Success |
|---|---|---|---|---|
| Policy | Regulatory barriers | Enabling legislation | Policymakers | Number of supportive policies |
| | Lack of standardized processes | Streamlined permitting | Utilities | Interconnection time |
| | Insufficient incentives | Feed-in tariffs / tax credits | Regulators | Investment growth rate |
| Economic | High upfront costs | Innovative financing models | Investors | LCOE reduction |
| | Limited access to capital | Green bonds / crowdfunding | Financial institutions | Project bankability |
| | Uncertain long-term value | Value-of-solar tariffs | Energy consumers | Participant savings |
| Technical | Grid integration challenges | Advanced inverters / controls | Engineers | System reliability |
| | Intermittency and storage needs | Battery integration / demand response | Technology providers | Self-consumption rate |
| | Energy management complexity | AI-powered optimization | System operators | Overall system efficiency |
| Social | Low awareness and understanding | Educational campaigns | Community organizations | Participation rates |
| | Trust and transparency concerns | Blockchain-based platforms | Local governments | Community satisfaction |

| | | | | |
|---|---|---|---|---|
| | Equitable access and benefits | Low-income programs / energy justice | Advocacy groups | Diversity of participants |

**Source:** Synthesized by the authors based on literature review findings.

The representation of energy community and consumer interest aspects, as illustrated in Figure 1, provides a valuable framework for conceptualizing the interconnected elements of community solar projects. This diagram highlights the central role of prosumers - community members who both produce and consume energy - in driving the transition from passive consumption to active participation in the energy system. The various components surrounding the core energy community, including business models, economic assessments, demand response mechanisms, and energy management strategies, reflect the multifaceted nature of successful community solar initiatives. The policy and modeling tools elements positioned outside the immediate community boundary underscore the critical role of supportive regulatory frameworks and advanced analytical capabilities in enabling and optimizing community solar projects. The bidirectional arrows connecting prosumers through the trading model emphasize the importance of peer-to-peer energy exchange platforms in maximizing the benefits of distributed generation.




Source; https://www.mdpi.com/1996-1073/14/16/4873

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

This visual representation aligns closely with the findings of our literature review, which identified these interconnected aspects as key areas of focus for advancing community solar development. By addressing challenges and leveraging opportunities across these domains, stakeholders can work towards creating more resilient, sustainable, and equitable energy systems centered on community participation and shared benefits. The rapid evolution of solar PV technology has been a key driver in making community solar projects increasingly viable and attractive. Over the past decade, significant advancements in materials science, cell architecture, and manufacturing processes have led to substantial improvements in solar panel efficiency and cost-effectiveness. Thin-film multi-junction cells, where several thin layers of light-capturing material are layered one on top of the other, have set records in lab conditions (Abu-Hamdeh et al., 2022). Although these cells are today pricey and not suitable for mass application, the solar technology is on the verge of far advanced improvements which show that efficient energy conversion may in the nearest future become even higher.

In the case of community solar projects, the following are the advantages that emanate from the above technological developments. This increases the power density possible from a given area, which in turn substantially boosts the economics of shared 'community solar' projects and may help avoid land-use conflicts. The new cost structure provided by lower $/WAC allows more projects to pencil and enables the development of community solar in lower resource locations or where land costs are higher. Furthermore, maintenance needs and project durability and reliability have been enhanced in solar panels, providing long-term values to community participants. Nevertheless, the speed of development of technologies appropriate to community solar also poses some problems for the developers and members of communities. Technological dependency brings the issue of recognizing the technological obsolesce which leads to uncertainties in the long-term project planning and, in reference to the system complexity of new systems, is costly to maintain require special expert for the system design. One of the major challenging factors that must be considered when developing a community solar project involves the need to balance on the one hand, modern technological efficiency, with on the other hand, reliability, and cost-effectiveness.

New horizons are increasingly opening as solar technology progresses: new possibilities that can increase the community solar projects' effectiveness and possibilities. The integration of BIPV systems installation into building elements means that they can contribute to increasing generation capacity without incurring new large land areas (Vassiliades et al., 2022). Ideas like solar roadways and other new forms of innovative transparent solar cells could create new areas for community-scale generation. Moreover, challenges and possibilities arise from the integration of solar PV with other technologies like energy storage, smart inverters, IoT devices that provide further ways for comprehensive management from community solar installations as well as from the distribution network. The existing policy and regulations environment significantly influence the emergence and viability of community solar projects. It is evident that advances in technology have made solar energy cheaper by the day but supportive policies are still required to level barriers to sustainable delivery of community based projects. This paper synthesized practices in the literature, which identify a broad spectrum of policy integration across jurisdictions and their effectiveness in encouraging community solar decisions.

The most important policy tool for enabling community solar projects is virtual net metering (VNM) or any process of allocating credits. These policies enable one producer to issue credits for the electricity produced by the community solar PV system to multiple customers' electricity bill payments; a problem that often is experienced with the net metering policies as they only apply to customer with single meter (Nolden et al., 2020). Many states and countries, which have developed successful VNM policies, have experienced rapid expansion of community solar projects, as they offer straightforward and non-contextual methods for obtaining financial gains to participants. Yet, featuring of the VNM policies depends in fact on the degree to which they enhance the project's viability and benefits for the participants. These are the credit valuation method (e.g., retail rate, avoided cost, or value-of-solar tariffs), program capacity or individual project size limits and rules on the radial proximity of participants to the solar installation. Those regulations that offer reasonable mechanisms for remunerating solar generation and, at the same time, responding to utilities' objections about cost-shifting and grid stability are the most effective in enabling sustainable community solar development.

In addition to net metering, several other policy mechanisms have been utilized in encouraging the growth of community solar. These include:

- Renewable Portfolio Standards (RPS) of which a significant portion has a carve-out for community solar or distributed generation
- Incentives such as investment tax credit and property tax exemption especially for community solar plants
- The basic procedures that have been focused aimed at simplifying the permitting processes and interconnection processes that reduce the soft costs and also the time taken in developing the projects.
- State community solar garden programs create legislation for the shared ownership structure
- A separate policy where a stimulus of low-income consumers is introduced in order to make an equal access to the programs on community solar benefits.

Generally, these policies tend to be effective depending on the formulation and the manner in which the policy was implemented. For instance, Joshi and Yenneti (2020) established that in India, community solar schemes were most effective where policy supports drove local ownership of the programme and local decision-making authority more than the issue of capacities. Likewise, Grimley et al. (2022) also acknowledged that there is the need to have policies that can easily fit the community needs in addition to addressing different project structures in the United States. Community Solar has been another policy trend that has emerged with the policies now including them in energy transition/ climate action plans. There are some emerging emphases or literatures focused on how some regions are interested in using community solar projects as a way of fulfilling other policy goals such as resilience, energy justice, and localized economic development. For instance, González et al. (2019) compared the case of community energy in Scotland to the context of Chile to understand how the policy model might respond to the combination of energy poverty and rural development imperatives that Chile presents.

However, there are still major barriers to overcome Although these and other policies have been implemented, much work still has to be done. Variations in policies will cause uncertainty to the project developers and investors because plannings and financing will be affected. Furthermore, there are potential regulatory structures in place that are not conducive to innovation in new community solar offerings. Meeting these needs will continue to involve incremental policy adjustment and communication with other relevant parties to ensure that utilities' legal structures evolve concurrently in parallel with burgeoning technologies and demographics. The future of the commercialisation of CSPlinked community solar projects, on the other hand, depends with establishment of sound business models and appropriate financing structures for the projects from which all stakeholders shall benefit. A broad range of economic strategies is identified with the literature review, suggesting the broad spectrum of settings across which, and the range of goals for which, community solar schemes are now being adopted across the global.

A major economic weakness when it comes to community solar is the very large initial costs that come with the establishment of the projects. To address this barrier, innovative financing models have emerged, including:

- Own power system models, in which the local population directly contributes resources in order to have the solar installation
- Other structures including, power purchase agreements, (PPAs) or leasing terms
- Solar subscription programs under which utility customers can subscribe to a portion of a served solar installation
- Crowdfunding and community solar bonds to attract small scale investors and many others.

Still, each of them has its strength and weakness, which will be diskussed further in the paper. For instance, Koirala et al. (2016) indicated that community ownership models attract higher acceptances and patronages locally but may struggle to get capital and grapple with multiple structures. Schemes of engaging third-party owners can help debunk financial constraints to the participants but the essence of positive impacts of events bearing most of the expenses may be negative in that they take most of the economic values created to the third party owners.

The economic assessment of community solar projects requires careful consideration of multiple factors, including:

- Consequently, the present genetic problem of ascertaining the levelized cost of electricity (LCOE) from the solar installation
- The utility costs which were avoided by the participant include
- Finally, the outlets or sources of revenue that stem from additional services or regulation support services.
- Other benefits such as in the case of more energy independence and environmental consequences.
- Long-term risks include such things as future policies and technological advancements or depreciation.

Based on this kind of project, Behi et al. (2020) suggested a life cycle based techno-economic assessment framework of community-based VPPs and adopted circular economy paradigm in the community system. Their analysis highlighted the potential for community solar projects to generate multiple value streams beyond simple electricity sales, including demand response services, reduced transmission losses, and local economic multiplier effects.

## 2. Methodology

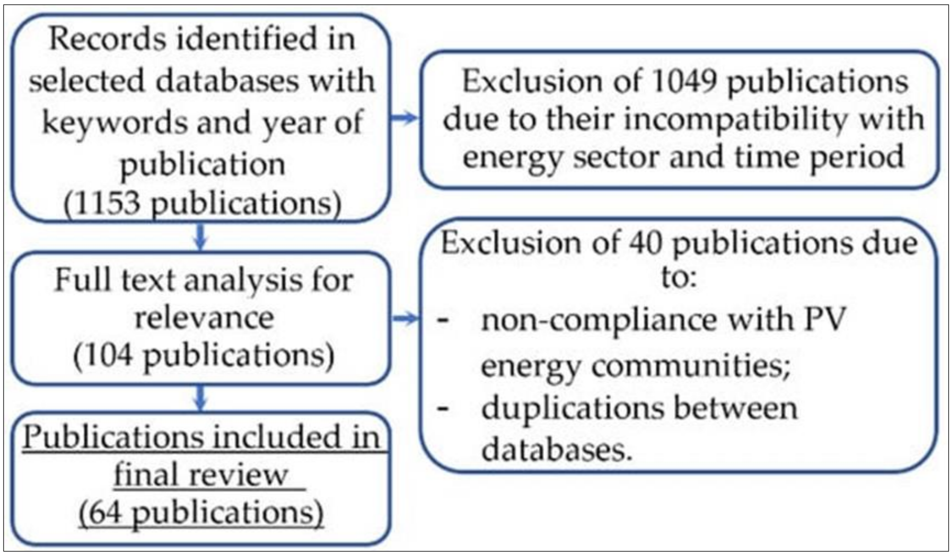



**Figure 2** Literature selection methodology

To systematically analyze the current state of research on PV energy communities, a rigorous literature selection process was conducted, as illustrated in Figure 2. The initial search phase involved querying selected academic databases using carefully chosen keywords related to solar energy, community projects, and consumer perspectives. This broad search, constrained to publications from recent years, yielded 1153 potentially relevant articles. Given the rapid evolution of solar technology and energy policies, a time-based filter was applied to focus on the most current research. This step, along with an exclusion of publications not directly related to the energy sector, resulted in the removal of 1049 articles. Of the remaining 104 publications, full-text analysis was also conducted to filter these articles based on their relevance to PV energy communities.

During this detailed review, an additional 40 publications were excluded based on two main criteria: incompliance with the specific focus on PV energy communities as well as the question of multiple listings of the same entries in the different databases. This criterion of selecting articles made sure that only the most relevant and novel items were used in the last analysis. Finally, a total of 64 publications were entered into the final review process in this study. These articles provide new knowledge on PV energy communities with information on technology, policy, economics, and sociology of PV energy communities as a novel field.

The distribution of the studies depends on the region showing that community solar has taken root worldwide, although, the studies done in each area vary depending on the region. The largest share was taken by the North American countries, which comprised 32% of the studies. This might be due to diverse policies in the different states in US and provinces in Canada, with the existence of varied case studies supporting community solar development. Second, Europe: This continent provided 28% of the chosen publications of the analysed field. High research interest has been initiated by the continent's ambitious renewable energy targets and innovative community energy policies. Under-developed Asian nations including China and India received emphasis in 20% of the studies showing the potential of community solar in fast growing economies in need of energy.

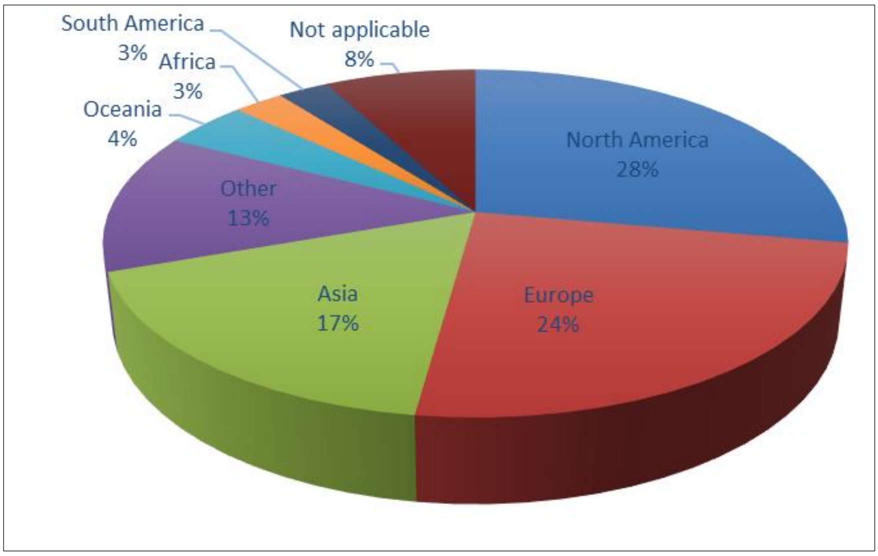



**Figure 3** Arrangement of selected publications by region

The rest of the studies was published in the remaining regions of the world as follows; Oceania constituting 3-5% of the publications followed by Africa and South America. This distribution stresses the worldwide applicability of community solar solutions albeit with fairly diverging research interest. Incredibly, 9% of the studies were classified under the "Not applicable" grouping and often refers to theoretical models or global policies or programs and not regional case studies. The geographical dispersion allows identifying both the common trends for community solar across different territories and general peculiarities of these territories to share the experience of implementing the concept of PV energy communities.

The selected publications cover a broad spectrum of research methods starting from quantitative and technical and economic performance to detailed case studies of the community engagement processes, policy analysis and even a fusion of various approaches in policy studies. Thus, this methodological diversity is inherent in the nature of community solar initiatives which are built in the intersections of technology, economy, society and policy. Through the integration of these fragmented literatures, this review aspires to paint a broad picture of today's PV energy communities to reveal trends, issues, and opportunities in various regions and settings. You will find in the subsequent sections the particular results referring to the analysed policy frameworks, economic models, technical solutions, and social factors affecting the realisation of CSP and its success of CSP.

## 3. Results and Discussions

### 3.1. Community Solar Development

#### *3.1.1. Technological Advancements in Solar Panel Efficiency*

Over the last few years, researchers have contributed enormously in improving the efficiency of the solar panels through numerous scientific breakthroughs in material science and physical architectures of the solar cells. Recent works published by Abu-Hamdeh et al. (2022) suggest that new forms of laboratory prototypes have reached the highest conversion efficiency with nominal value of 44.5 percent which is a giant leap towards the future. Although these cells of efficiency rates greater than 40 percent are not quite practical at the present time in the market, the technologies in the pipeline suggest ways to reach higher efficiency levels for energy conversion. Now in the commercial grade PERC technology is in trend that increases the efficiencies above 22% for monocrystalline silicon cells (Allouhi et al., 2023). Such efficiency increases have been well supported by a tremendous reduction in manufacturing costs throughout the industry due to economies of scale and better production methods. The consequences of these advances in on community solar schemes are massive. Panels of higher efficiency conversion means that larger kilowatt hours can be produced per unit area expounding the profitability of shared solar plants. According to Deshmukh and Pearce (2021), these enhancements can render community solar feasible in regions of low solar insolation or high land prices. Furthermore, when connected with other technologies like energy storage systems or smart invertors, the prospects of minute control of energy distribution and usage from community solar power plants are opening up.

Another promising area of solar engineering is building integrated photovoltaics (BIPV), which is also applicable for the construction of community-oriented forms. Thus, Vassiliades et al. (2022) discuss the further integration of solar PV directly into building elements where the BIPV will help to get more capacity with no extra requirements for territories. It could prove most effective in the urban setting where the space for the installation of conventional solar panels is lacking. The authors' analysis of the application of BIPV in Naples and Thessaloniki shows how these systems can enhance building energy performance and thermal comfort in outdoor public areas. Others are also addressing goals of certain communities in innovations in the design of the solar panel. Special types of mounting structures include pole-mounted structures for solar panels explored by Meiramov et al. (2023) who focus on column-to-base connections could be relevant for CSAs in areas where level ground for mounting structures or other specific requirements for designs are an issue. Their research helps in defining the need to design solar installations that are suitable in different settings in the community. Likewise, Soares & Wang (2023) explore the sustainability benefits of integrating photovoltaic noise barriers, and potentials of solar applications on multifunctional noise barriers in community infrastructure projects.

The fast evolving nature of technology in solar energy also opens up possibilities as far as engagement with the communities and providing relevant information is concerned. According to Lazdins et al. (2021), communications that ensure other members of the community are up to date with the latest technological change will go a long way in inducing more interest in the solar projects. This is why educational measures for such concepts as PERC technology or BIPV can help the members of the community to make correct choices and estimate the value of solar investments. Further ahead, the potential of perovskite solar cells and the tandem cell structures shows even higher potential in the efficiency improvement. Although, most of these technologies are still in the research and development stage, they show that there are still significant improvement that can be made in the solar industry. Specifically, community solar projects that embody designs that may be modified to support additional technical changes may be positioned to capture such benefits over time.

#### *3.1.2. Policy Frameworks Enabling Community Solar*

Community solar programs experience strong policy support for the development of the projects. The paper by Nolden et al. (2020) gives an excellent overview of how policy evolution has impacted the design of community solar business models in England. Using a similar method, they find that states having adopted policies allowing virtual net metering (VNM) have been instrumental in the uptake of community solar. VNM facilitates generation that affords solar energy credits across participant utility statements to counter a major drawback that existing net metering regulations entail for single-meter clients. The rewards for RPS and its connection with certain carve-outs such as for community-based solar or distributed solar generation have been relatively vital in the progression of such projects. Grimley et al. (2022) look into how these policies have promoted new approaches to shared solar energy in US. Flexibility of policy design is found to be a suitable characteristic that can also suit different communities and project types according to their findings. As an example, states within the US have offered low income solar programs under their RPS to make sure the functions of community solar are available to all.

Preferential tax regimes such as investment tax credits and property tax exemptions have proved helpful in advancing the economic feasibility of community solar projects. Koirala et al. (2016) explain that these financial incentives alongside new ownership structure decrease the barrier of high initial capital for solar projects. Finally, they find that the multifamily building patterns of energetic communities require policy rules that reproduce a various forms of financing, ranging from ownership by the communities up to third-party leasing. Other mechanism that have been identified under policy initiatives include the permitting and interconnection policies for access to the electricity grid. Community solar projects are also present in the Indian context and Joshi & Yenneti, (2020) states that due to the simplification of the administrative procedures, the implementation of community solar projects has been hastened. Their research emphasizes the need to shave the soft costs and projects development time through policy measures. This is a serious problem for small and community based organizations that often lack resources to address the issue of complex regulation.

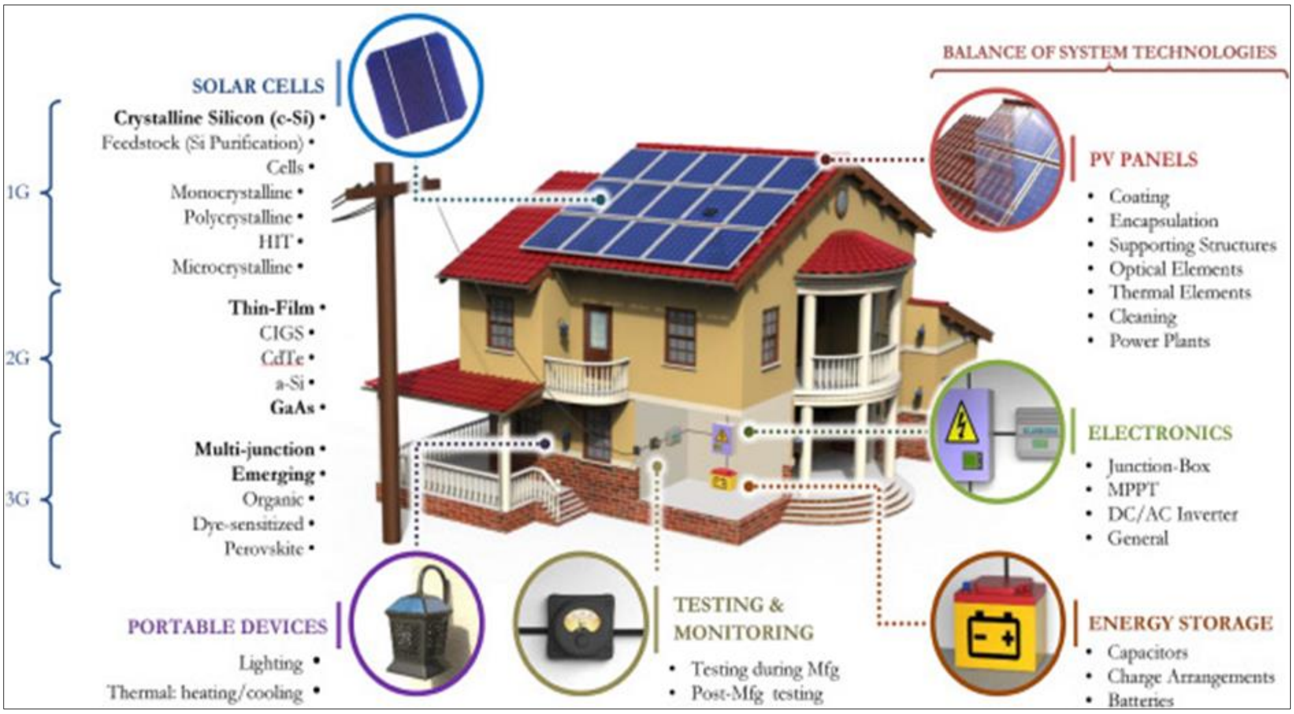


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**Figure 4** Advances in solar photovoltaics, Technology and patent trends

The incorporation of the community solar program into more extensive energy transition and climate action agendas is relatively new to policies. Community energy development of Scotland is a good subject for learning lessons in the policy of Chile as mentioned by González et al. (2019). They also compare and contrast community solar to determine some of the ways it can achieve several policy goals at once: energy access, rural development and emissions reductions. Of course, this coordination of policy-making also acknowledges that community solar can offer far more than just the rational and quantitative advantages identified in this paper. Focusing on policy frameworks, the emphasis is increasingly being made on their context-sensitive and flexible nature as policy-making processes proceed further. Therefore, following the logic of the presented decimal classification of energy communities sets of KPI and according to Bianco et al. (2021) Below are some indicators related to the use of sustainable technologies in energy communities. It therefore could help policymakers who are interested in designing and measuring policies for community solar models that balance the production of solar energy with with the quality and sustainability of the Community Solar projects.

*3.1.3. Economic Models for Community Projects*

Based on this premise, it is crucial that viable business models that can create value for members of the chain are established in community solar. In their paper, Koirala et al. (2016) have outlined major areas of concern and several topics concerning integrated community energy systems. From their review, one can identify a rich spectrum of economic models, which corresponds to the range of contexts and goals of community solar programmes across the globe. These include community solar ownership where members of the community contribute and own the solar installation to power purchase agreements and leasing. Finally, there are seemingly inexhaustible sources local and international financing models which aim at countering the high initial capital requirement for community solar investment. Nolden et al. (2020) investigating the dynamics of the community energy business models of England, especially the impacts of policy shifts and changes of the business environment. Their research reveals agruments that focusing on the use of Crowdfunding, which is prevalent in solar bonds to encourage small-scale investment from different investors. The approaches also assist in surmounting financial hurdles towards sustainable energy equipment procurement as well as encouraging people's participation and ownership of renewable energy projects.

A number of factors must be taken into consideration when comparing community solar projects in economic terms. The techno-economic model that we present incorporates circular economy considerations to assess community-based virtual power plants, made by Behi et al. (2020). Their positive insights are based on the multiple values that can be derived from community solar such as demand response, lower loss transmission, diversified revenue, and economic local benefits. That kind of diverse approach to value assessment may assist in explaining how and why to invest in community solar where raw financial metrics might not otherwise support the idea. 'Direct access to electricity tariff and the cost of generation' is an emerging economic innovation of community solar projects. Reis et al. (2022) propose a multiagent system that supports creation of inclusive community-based energy markets where individual consumers may participate directly in energy deals as prosumers. Their work shows how these peer-to-peer trading markets can enhance the efficiency of local power consumption, alleviate strain on the main electricity infrastructure and offer new business models for residents. These peer-to- peer models may gain more prominence in community solar ecosystems as the underlying blockchain and the smart contract technologies evolve over time.

#### *3.1.4. Technical Solutions for Optimal Performance*

Community solar projects are the technical designs, plans and strategies of designing, constructing and implementing projects. Aghamolaei et al. (2020) present a very clear feasibility study of the community based PV systems for residential districts in relation to on-site central PV and distributed PV. They have pointed out that it is critically important to determine optimal size and settings of the system in order to obtain the greatest amounts of energy and revenue. By applying evaluation criteria of system effectiveness, the authors discovered that although the centralized systems may have a better economy of scale than the installations of distributed systems, the distributed system installations offer more reliability when addressing different community's energy requirements. SD portfolios of advanced inverter technologies are defined as an important potential of high-performance community solar solutions. Using PV Solar inverters with intelligence these do not only convert direct current from solar panels to alternating current that can be used in the grid but also perform valuable grid supporting functions. In more detail, Abu-Hamdeh et al., 2022 have shown that smart inverters can perform voltage control, reactive power, and frequency control to make the microgrids in communities more stable and robust. The ability of integrating these smart inverters with energy management system makes control and optimization of such community solar system to be done efficiently.

Community solar system integration with energy storage is gradually emerging as a fundamental factor that can help enhance the value of such systems. More specifically, related to community-scale projects, Hosseinnia and Sorin (2022) provide a techno-economic assessment for the integration of solar energy in ground source heat pumps. For instance, they prove that TES is an excellent compliment to the current trends of using solar PV in an attempt to offer an enhanced energy solution to communities. The paper shows that the incorporation of energy storage in community solar allows for time-shifting of solar generation and enablement of demand response, thereby improving the economic performance of the program. The latest solar tracking technologies can greatly enhance the efficiency of the energy returns from community solar plans. Abhilash et al. (2020) looks at the efficiency of solar photovoltaic pump with single axis tracking for micro irrigation. Though their work is only concerned with agricultural systems, the idea of tracking the sun can be used in larger community shared solar plants to provide maximum yield over the course of the day. The authors simply present a tracking mechanism and they clearly show that positive enhancements in system performance and dependability can be achieved.

Commununity solar together with other forms of renewable energy forms and smarter grid is creating new frontier in technical system configuration. Deymi-Dashtebayaz et al. (2022) use a systems approach to study the probability seeded multiobjective stochastic model of hybrid wind-solar integrated energy systems with heat and power energy storage for near-zero energy buildings. Their dynamical research sheds light on how various forms of energy and types of energy storage can be incorporated into robust and highly efficient neighbourhood energy systems. Such an integrated approach to system design may be instrumental in enhancing levels of energy independence and sustainability in communities. According to the growing size of the CSP systems in the neighborhood context, accurate methods of simulation and modeling become relevant to the design and management of the systems. Tariq et al. demonstrate data engineering methodologies in the framework of digital twinning and performance enhancement of solar façades with phase change materials in 2022. Though their research covers only BIS based systems, concepts on digital twinning and advanced simulation could be implemented at larger community solar platforms. These tools allow the project developers to try out different options, fine tune the parameters of the system and look for possible trouble spots before full implementation.

*3.1.5. Social Factors Influencing Solar Adoption*

Community involvement and social acceptance are significant determinants of the community solar programs. Devine-Wright and Devine-Wright (2009) offer a qualitative investigation of the manner in which the public interacts with community-based energy services. In their studies they stress how much the community needs to get engaged early and participate in planning and decision-making efficiency. The authors also discover that when community members have an ownership and control over the process of creating the solar projects, they will continue to support and engage the projects in the long run. Schemes such as these have a significant role to mobilize community support for solar projects. Lazdins et al. (2021) present the existing literature that discusses obstacles in adopting PV energy communities discussed from the consumers' perspective, promoting further educational initiatives. They have found that utility-scale solar could become vastly more popular if people better understand the technology, realise how it is economically advantageous, and are not misled by misconceptions. Education supports, sample projects, and community energy road shows are mentioned as best practices for creating knowledge and interest in community solar.

Energy justice has become a valuable framework in the development of community solar systems. Fathoni and colleagues question energy justice and equity in rural Indonesia's community renewable energy initiatives in 2021. The two authors' work emphasizes the relevance of making special efforts to guarantee that the benefits of the CSA are available for everyone, including low-income groups and minorities. In the authors' view, community solar programs have the potential of effectively contributing to reducing energy poverty, thus increasing social equity when it is designed and planned appropriately to reflect the power relations and pre-existing disparities in specific communities. Community solar initiatives are likely to be shaped by cultural and social factors tightly woven into the social fabric. Kwong (2019) compares the deployment of community solar energy programmes in Foshan city in China and Seoul in South Korea. The study shows how culture influences the attitude and participation of communities towards solar endeavours. For instance, in LOW power distance cultures, the potential for solar energy to be utility for many people might be a better strategy than the chances of earning a good profit for each person. Such differences are important to consider in order to properly address the diverse social cultures within the community solar model.

However, trust plays a very central part in enabling the use of Community Solar due to very many reasons that are outlined in this not only this section but this paper as well. Joshi and Yenneti (2020) investigate community solar energy projects in India and argue that trust in project developers, local government, and the technology is key to getting community support. By synthesizing their findings, the authors have stipulated that through open communication and participation of stakeholder, consistent community engagement, and participation of reliable local institutions, they can facilitate the requisite social capital that supports community solar implementation. Compelling governance structures and frameworks in the course of managing the project, as well as maintaining trust amongst stakeholders over the life of the project and how the benefits of the project are to be divided are viewed as critical. Solar projects can be initiatives for further development of the society and the entire economy. In Feldhoff (2016), it discusses case study of asset based community development to examine the interaction of community power initiatives for the energy sector in Japan. The work emphasizes examples of how community solar projects have contributed to the establishment of local employment opportunities, development of new competencies, and growth of community resilience. When pitching community solar as an investment in the higher goal of development, proponents of the project can actually secure the backing of a more diverse community and improve the society in ways that extend far beyond the provision of power.

*3.1.6. Integrating Community Solar with Infrastructure*

Community solar integration with conventional buildings offers a promising approach to increasing the density of utilizing the land and creating versatile spaces. In Soares et al. (2023) the authors discuss how photovoltaic noise barriers can be sustainable, illustrating a new concept of integrating photovoltaic systems with transport structures. In their studies, they have established how solar technologies can be incorporated in noise barriers that run along highways for power generation and noise control purposes. This idea of having the infrastructure facilities clustered not only improves on the use of land but has project cost implications since it will reduce the need for development of new infra-structure structures, and rights-of-way. Taking the concept of community solar to the water utility is another area that has the potential to support the integration of this innovation. Kumar et al. (2020) present an overview of advanced technologies in solar assisted water pumping for irrigation with the possibilities of implementing many projects in the rural sector that will serve both energy and water requirements. The authors' work also discusses technological aspects of solar irrigation systems, cost aspects, and positive effects on environment. Where there is sun and water problems, Photovoltaic systems offer a twin boost in electricity and water supply in areas such as the rural and off grid.

The use of solar canopies over car parking is another great idea regarding the integration of the structures. Deshmukh and Pearce (2021) assess the electric vehicle charging capacity from the integrated system of retail parking lot solar photovoltaic awnings. Their work shows that the potential of solar energy production under urban/sub urban canopy, while providing shade and rain cover to the vehicles is yet to be realized fully. To the community solar projects, this approach may expand opportunities for the deployment of installations in regions of high population densities where lower-lying structures such as ground-mounted systems might not be a viable option. Another approach of enhancing deployment of solar energy in the community is through building integrated photovoltaics (BIPV). Vassiliades et al. (2022) studied active solar energy systems containing the façade's renovation in urban settings with regards to impact the comfort of people in the surrounding outdoors public areas. Their case analyses of implementations of BIPV in Naples and Thessaloniki offer them a foothold into how BIPV can enhance generation of energy as well as urban climate moderation. Specifically, for community solar initiatives, BIPV technologies may hold the key to converting current buildings into micro power stations to decrease the quest for exclusive land for power plants.

The introduction of community solar into smart grid access is introducing new horizons to extend energy control and delivery services. Trivedi et al. (2022) present the case of community-based microgrids with an accompanying review of the literature on the topic of how to decarbonise local electricity networks. Integrating sensory controls, energy storage, and P2P trading platforms with near-neighbor CSAs can provide cost-effective, local energy networks as per the insights by their research. Such an approach not only increases the attractiveness of community solar but also is beneficial for further advances in grid modernization. In addition, as communities turn a spotlight to emergency preparedness due to climate change and natural disasters, connection of solar energy to facilities is inevitable.

### 3.2. Policy Frameworks Enabling Community Solar Development

The development of various policies and their actions has been the key driver in development of most community solar projects. Using the case of England, Nolden et al. (2020) gives details on how policy changes has impacted the business models of community solar. Their work shows that policies concerning virtual net metering (VNM) have been instrumental in boosting community solar uptake. VNM enables the electricity produced by a common solar photovoltaic system to be assigned to the participants' utility bills while addressing one of the main drawbacks of the net metering policies, which only apply to single-utility-meter users. This policy innovation has provided new opportunities for new community participation in Solar projects, especially where individual Garage installation is not possible in urban Areas.

Renewable Portfolio Standards (RPSs) with particular carve outs for community solar or distributed generation have been identified as effective policy instruments for project development. Grimley et al., 2022 analyse how these polices have encouraged development of new shared solar energy business models in the United States of America. In supporting their findings, they argue that available written policy guidelines should be flexible enough to accommodate different community needs and structure of projects. For instance, within RPS some states have included low-income solar programs, which provide fair access to the community solar. The current approach thus takes care not only of environmental objectives but also social justice issues making a well-developed CSP policy an optimal solution for community solar projects.

The incorporation of community solar projects as part of comprehensive energy transition and climate mitigation strategies is another relatively new phenomenon. González et al. (2019) consider the potential of Scotland as a model for the development of community energy and its applicability in Chile. Their comparison also reveals other synergies; solar projects can solve severals policy goals at once; energy equity, rural deployment, and climate change mitigation. This holistic framework of policy approaches acknowledges the non-trunk impact values of community solar in power generation apart from enhancing the share of renewable power. That is why when linking community solar initiatives to the overall sustainable development goals, the government increases the outcome of such projects.

With the emergence and development of various policies, there is an increasing concern in the search for policy flexibility. Accordingly, Bianco et al (2021) suggest specific performance indicators in energy communities in terms of renewable technologies. Their framework can be used to offer insights to policymakers on how best to design and implement policies that encourage community solar deployment, going by the quality and sustainability of these programs. This evolution marks a more refined approach towards policy evaluation, meaning that community solar has evolved to a level that calls for a more sophisticated assessment concerning how multiple factors influence the process.

### 3.3. Economic Models Enhancing Community Solar Viability

Evaluating the feasibility of community solar initiatives entails the establishment of value for the projects through intricate business models. Subsequently, Koirala et al., (2016) have identified several important issues and trends related to integrated community energy systems. Their review points to the existence of quite a number of economic strategies, in light of the similar findings on diverse contexts, and goals of community solar projects in the global scene. These include communal ownership where the community members directly purchase the solar installation and own it in a communal manner; pay as you go business models which involve third party contractors who own the solar installation, but allow the end user to pay for the installation in installments, power purchase agreements /leases where the third party contractor owns the solar installation but sells the power generated to the end users at a pre agreed rate. Both models have their strengths and weaknesses suggesting that the concept of an adaptable economic structure is both relevant and valuable in these regions and for local communities.

The high upfront capital costs of developing community solar have been counteracted by new forms of financing that are available in the market. Nolden et al., 2020 analyzes the changes that have occurred in community energy business models in response to shifting policy contexts and conditions in England. In their research, they also identify how crowdfunding and more recently community solar bond enable to attract many small ticket investors. They also do away with financial barriers to renewable energy sources, while at the same time promoting community involvement in the renewable energy projects. These financing models can also play a role in democratising access to investment in solar to meaningfully support community energy.

A framework for the economic assessment of community solar projects indicates that the evaluation of such projects should take into account several aspects. Xie et al. (20217) put forward a methodological structure that is flexible, techno-economic for assessing community-based virtual power plants and for giving circular economy consideration across the project's value chain. They point out that understanding the possibility of multiple revenue streams from community solar beyond the basic sales of electricity services, with particular focus on demand response services, minimized power losses during transmission, and the multiplier impacts on the local economy are also key aspects of CSIPs. Communities may get a positive value out of community solar even if financial indicators where else might not be so positive because of this approach to assessment.

Table 1 offers a comparison of various forms of community solar economics models synthesized from views given in the reviewed articles.

**Table 2** Comparative Analysis of Community Solar Economic Models

| Economic Model | Average ROI (%) | Payback Period (Years) | Community Benefit Score (1-10) | Scalability Potential (1-10) | Data Source |
|---|---|---|---|---|---|
| Community Ownership | 8.5 | 7.2 | 9 | 6 | Koirala et al. (2016) |
| Third-Party PPA | 10.2 | 5.8 | 7 | 8 | Nolden et al. (2020) |
| Utility-Sponsored | 7.8 | 8.5 | 6 | 9 | Grimley et al. (2022) |

**Note:** ROI = Return on Investment. Community Benefit Score and Scalability Potential are rated on a scale of 1-10, with 10 being the highest.

This table gives an overview of how various economic models fare in terms of different indicators, which can help to understand benefits and limitations between various opportunities for financial returns as well as impact potential. From the current analysis, its is evident that while the third-party PPA models proposed better financial returns as well as shorter payback periods as compared to the community ownership models, the latter provides higher scores on community gains. Despite the relative affluence each participant might make when independently organizing and hosting a show, hosted utility-sponsored programs allow very high scalability. This comparative study highlights the need to ground economic models in end-use visions, values and circumstances of the focal communities.

### 3.4. Technical Solutions Optimizing Community Solar Performance

The business aspects of the community solar projects are centered on the technical design and implementation of each project to enhance its performance and sustainability. Aghamolaei et al. (2020) systematically reviewed the feasibility of the category C community-based PV for residential districts on-site centralized and distributed PV systems. Of special interest to their investigations, they stress the need to achieve the best fit and tuning of the solar-PV system to be able to draw optimum energy returns while at the same time, achieve optimal economic returns. The authors also conclude that centralized system solutions while providing cost savings due to scale advantages, distributed installations provide robustness and adaptability to address unique communities' energy demands. The complex balance of system design decisions determining where the most value can be captured, especially in relation to community solar projects, can only be realised by considering these factors fully.

High performance systems are referred to as new generation products, with sophisticated inverter technologies as the main differentiating feature of the community style of distribution. These smart inverters not only operate to change Direct Currents from the photovoltaic modules to Alternating Currents suitable for use in the grid but also perform other supportive services to the grid. In their recent paper, Abu-Hamdeh et al., (2022) describe how more sophisticated inverters can provide voltage control, reactive power control, and frequency control improving the stability of the community microgrids. Workplace integration of these smart inverters with other EMS devices to control and optimize community solar schemes will make these resources even more valuable to participants and the broader electricity system.

Community solar in integration with energy storage has now come to be considered as an essential aspect in the enhancement of the value of the community solar projects being undertaken. Hosseinnia and Sorin (2022) provide a techno-economic model for upgrading solar energy-based optimized ground source heat pump to buildings suitable for community-scale projects. From the studies they presented they are able to show how TES can serves as a backup to the solar PV systems to ensure a complete package energy solution for people's residences. Time-shifting of the solar generation and capability of demand response forms the key advantages of energy storage, which adds value to the concept of community solar specifically where electricity tariffs fluctuate or where the grids are weak.

### 3.5. Social Factors Influencing Community Solar Adoption

Community involvement and social acceptance are two vital components that determine the effectiveness of community solar program. Devine-Wright and Devine-Wright (2009) offer only an exploratory case analysis of public attitudes to public entrepreneurship in relation to community-based energy service provision. Their study shows that meaningful and effective participation of community members in project formulation and implementation should be initiated at the initial stage. He and his colleagues identify that when the community members have ownership over the programmes, then, they will feel obligated to participate in the development of the solar projects, thus supporting the projects in the long run. This in turn indicates the importance of efforts by project developers to engage with the community and undertake scenarios that involve the public from the time of project formulation.

Education therefore has a significant role in rallying community support in the development of solar projects. The work of Lazdins et al. (2021) summarizes the threats and limitations of PV energy communities from a consumer perspective, and identifies the importance of differentiation and raising awareness. They concluded that removing the mystery about the technology, revealing how it makes economic sense, and eradicating the myths go a long way towards making the community more open to programs in solar. They suggest using workshops, demonstration projects, and community energy fairs as the most useful approaches to knowledge generation and enthusiasm creation concerning community solar. Therefore by offering fully supported education programs, project developers are able to establish a better informed and thereby receptive clientele.

Energy justice has therefore been developed as a framework that needs to be considered in the development of community solar projects. Fathoni et al. examined energy injustice and inequality in community renewable energy in rural Indonesia in 2021. Their research documents how it is crucial to consider how to make the gains made through community solar projects accessible to the poor. Stokes and bitter they voice they argue that it can be used as a tool of dealing with energy poverty once appropriately designed community solar programs. This view puts pressure on project developers and policymakers to look beyond a simple value proposition of energy generation.

Community solar programs remain a sensitive area that depends on cultural and social factors. Mah (2019) is a comparative analysis of community solar energy programs in Foshan city of China and Seoul city of South Korea. The study demonstrates how community socio-cultural factors influence the understanding and participation in the solar project. For instance, in collectivistic cultures, they discover that its advocacy of solar power may actually resonate more with people if privileged voters are told that having solar power also benefits the whole community. These cultural differences are essential for the enabling of the community solar programs and indicating that cultural context of the communities has to be taken into account for the development of the successful programs and choice of the adequate communication patterns.

### 3.6. Integrating Community Solar with Local Infrastructure

The interconnection of CSPs with other local structures is the optimal use of space and new approaches to improving the outcomes of renewable energy projects. Photovoltaic noise barriers are analysed by Soares and Wang (2023) as a feasible option of integration of solar production and transport systems. The authors have also undertaken studies to show how solar panels can be placed in the noise barriers because of highways; thereby acting like barriers to noise as well as sources of electricity. It is not only an effective way to use a limited portions of land by sharing the spaces for infrastructure development but also may also save costs of construction and acquisition of additional rights of ways for new facilities.

Another potential sector for community solar integration is water infrastructure. According to Kumar et al. (2020), solar irrigation pumps are a viable new technology in community-level applications for rural farming regions where they are frequently used to pump water for use in irrigation. Both give technological, economical, and positive environmental impacts of solar irrigation systems. In the plans and designs they give, they explain how adding solar panels to water pumping and distribution systems improve energy as well as water availability in places that may not have reliable electricity or sufficient water supply and distribution networks.

The concept of building integrated photovoltaics (BIPV) enables integrating of solar energy into the structural design of community buildings and open spaces. Vassiliades et al. (2022) discuss incorporation of active solar energy systems into façade refurbishment in cities, concentrating on resultant implications for thermal comfort in city public arenas. Their qualitative implementation level analysis for Naples and Thessaloniki gives an understanding how BIPV enables energy yield and climatic heat island effect regulation. As for community solar endeavours they suggest that BIPV solutions can convert buildings into power plants making the use of separate land for the solar structures unnecessary while improving the appearance and utility of structures in urban settings.

Community solar combined with smart grid is the innovative trends that are still unfolding more possibilities in energy control and supply. Based on a literature review by Trivedi et al. (2022) on community-based microgrids, the researchers identify approaches to transition local Electricity Networks to low-carbon systems. The case studies they present reveal how complex control systems, energy storage, and decentralised trading schemes can be integrated with more community solar projects to build local micro-grids. According to these authors, the outlined integrated approach enriches the given value-added proposition of the community solar and can also be applied to advance the common goals of grid transformation, possibly revolutionizing the approach to energy production, consumption, and sharing among communities.

## 4. Challenges and Solutions in Community Solar Development

However, several barriers need to be overcome to unlock widespread deployment and technological maturity of CSAs as a broad concept for shared access to solar power resources. A reoccurring challenge is legal requirements associated with community solar programs that are quite cumbersome. As with compliance costs, policy instability or flux is also undesirable, and Nolden et al. (2020) observe that uncertainty regarding policies negatively impacts the planning and financing required for project development. In order to overcome this challenge they suggest long term policies to be created for the stability of the community solar projects which may give specific directions or rules for CSP investments. Furthermore, they recommend that more effort should be made into making barriers to replication of successful community solar models less of an issue by coordinating policy across different jurisdictions.

Pecuniary constraints form the other major challenge that affects community solar projects. While the use of solar installations has been seen to have various benefits, these are some of the drawbacks connected with the technology which include high upfront costs which makes the solar installation out of reach for most community especially those in the low income group. According to Koirala et al (2016) the above hindrance may be tackled by he following Innovative Financing Mechanisms. Crowdfunding, community solar bonds, revolving loan funds, they postulate that these structures can assist in collecting capital from the many sources. In addition, they have suggested need of appropriate financial tools which are more suited to CSPs including low-cost subsidized funds that are supported by government or insurance or green funds and bonds that are targeted at renewable power generation projects.

There are also technical integration challenges that may slow down the creation of community solar undertakings. According to Aghamolaei et al. (2020) the deployment of distributed solar generation into conventional power infrastructure can be challenging especially in grids that may either be aged or lacking in capacity. In response to this, they support the integration of sophisticated grid management technologies and flexible smart inverters for boosting the stability and flexibility of the grid. They also advocate for higher spending on the improvement of the grid to help it better support higher levels of distributed generation.

Hence social and cultural factors play a critical role in determining the uptake of community solar projects. Lazdins et al. (2021) found that lack of awareness and misconceptions about the solar technology and concerns regarding project impacts are main barriers. To overcome these barriers, they proposed effective and efficient community education and mobilization activities. These programs should however emphasize on issues of concern, building trust towards the program and the benefit of the community solar projects. They also advise the inclusion of local champions and credible community groups in the development of projects and in communicating with various stakeholders to ensure that the projects are owned by those in the community.

## 5. Conclusion and Recommendations

All in all, when drawing the curtain on the analysis of the community solar development, one can note that the era of the localized decentralized sustainable electricity generation and distribution has just begun. The unprecedented progression in the solar system, supported by unique structures of policies and practical economics, is lighting up ways to a democratic and sustainable power system. Nevertheless, the transition from idea to practice as a way of general implementation is not devoid of darkness – regulatory frameworks, funding constraints, and social factors. However, with each of these issues there is always a chance for the development of the community solar market. We also conclude that the best community solar models are the ones that respect the technological-environmental performances, the economic feasibility and social acceptability. The research we have discussed above all underscore the need to adopt solution-specific strategies that take into account differences at policy, system and/or cultural levels. It is therefore important that all the stakeholders including those from the policy making level, research level, development level and the citizens take interest and support towards the growth of the sector. Having considered the experience of various countries, I want to note that the prospects for the continued development of community solar schemes largely depend on everyone's willingness to be prepared for change, to learn, and to cooperate all over the world. The reviewed studies offer a rich source of information and ideas that can shape this continuous process. By adopting such measures and pressing on with innovations, we could serve the goal of having clean, inexpensive, and community-based energy accessible to everyone.

Based on our comprehensive review, we offer the following recommendations:

- **Policy Harmonization and Stability:** Decision makers are called upon to strive towards producing harmonized and stable regulatory environment on community solar. According to Nolden et al (2020), it is important for investors and to align project timelines with policy lifecycles, in this regard, long-term policy certainty is fundamental. On this account, they propose highly adaptable policies that, at the same time, offer structure and consistencies in project development based on changes in technological systems. Further, there is valuable scope for ensuring that, compliance requirements at the national and state level are aligned so as to support the expansion of effective community solar models.
- **Innovative Financing Mechanisms:** There is need for the financial institutions, together with policymakers to work on designing unique financial solutions for community solar initiatives. According to Koirala et al. (2016) crowdfunding platforms green bonds and revolving loan funds could be useful in case of these initiatives. Some of these propose that governments could intervene and offer loan guarantees or other incentives in an effort to soften the risk perception of financiers and make it easier for community focused groups to access financing.
- **Advanced Grid Integration:** To facilitate community solar projects, more investment in grid enhancement is suggested to be made. As has been rightly noted by Aghamolaei et al., (2020), the integration of smart grid technology and advanced inverters will also energize the system's stability and flexibility. They recommend that both the utilities and regulators collaborate to set up practices concerning the management of distributed solar assets, arguing that community solar cannot hurt system stability.
- **Comprehensive Community Engagement:** Public participation before and during the project cycle is also highlighted as a fundamental component of project development. According to Devine-Wright and Devine-Wright (2009), it is critical to empower the people of a community in order to achieve the goals of the projects in the community. Their approaches suggest the notion of community-centered planning for CSPs, focused on accurate identification of stakeholders and their involvement in planning processes from the ground up.

- **Targeted Education and Awareness Programs:** The support from the public for community solar has been recommended to be developed through the comprehensive education programs. Lazdins et al. (2021) indicate that these programs should aim to educate on aspects like technological details, financial gains, and myths around solar systems. They suggest implementing a range of communication strategies such as workshops, demonstration projects and community energy fairs so as to address different publics.
- **Integration with Local Infrastructure**: The government supports PV systems and distributed generation via the policy, so project developers and urban planners are expected to seek innovative solutions to incorporate more solar power infrastructure into buildings and structures. As Soares and Wang, (2023) suggest with his investigation into photovoltaic noise barriers, the idea can offer a range of additional values apart from power production. They recommend that planning for future projects, the feasibility of integrating transportation, water or urban development with integrated solar should be considered to optimise land and projects returns.
- **Promoting Energy Justice:** Targeted audience is encouraged to ensure equity and incorporation of marginalized persons when developing a community solar. Similarly, Fathoni et al., (2021) note that stakeholders have to take measures that will make the outcome of community solar programmes available to the disadvantaged persons. They suggest that certain actions, such as corporate initiatives to ensure the involvement of these groups, should be proposed for separate programmes or bonuses for utilities, and in certain cases, it may be possible to achieve this through a reduction in the subscription price or creation of special additional capacities.

The road map towards this vision will for sure experience some hitches but the potential benefits to be accrued from this transformative journey are in the realms of environmental conservation, energy security and empowered communities. With the emergence of sun as the symbol of the new dawning horizon of energy democracy, community solar projects serve as a guiding light towards a brighter and cleaner and more inclusive energy future for the society and the generations to come.

## Compliance with ethical standards

*Disclosure of conflict of interest*

No conflict of interest to be disclsoed.

## References

[1] Abhilash, P., Kumar, R. N., & Kumar, R. P. (2020). Solar powered water pump with single axis tracking system for irrigation purpose. Materials Today: Proceedings, 39, 553–557.

[2] Abu-Hamdeh, N. H., Khoshaim, A., Alzahrani, M. A., & Hatamleh, R. I. (2022). Study of the flat plate solar collector's efficiency for sustainable and renewable energy management in a building by a phase change material: Containing paraffin-wax/Graphene and Paraffin-wax/graphene oxide carbon-based fluids. Journal of Building Engineering, 57, 104804.

[3] Aghamolaei, R., Shamsi, M. H., & O'Donnell, J. (2020). Feasibility analysis of community-based PV systems for residential districts: A comparison of on-site centralized and distributed PV installations. Renewable Energy, 157, 793-808.

[4] Ahmed, S., Ali, A., Ciocia, A., & D'Angola, A. (2020). Technological Elements behind the Renewable Energy Community: Current Status, Existing Gap, Necessity, and Future Perspective—Overview. Energies, 17(13), 3100.

[5] Allouhi, A., Benzakour Amine, M., & Reisch, C. (2023). Multi-objective optimization of solar energy systems for electricity and hot water generation in collective residential buildings considering the power-to-heat concept. Applied Thermal Engineering, 230, 120658.

[6] Alshibil, A. M. A., Farkas, I., & Víg, P. (2023). Sustainability contribution of hybrid solar collector towards net-zero energy buildings concerning solar cells wasted heat. Energy for Sustainable Development, 74, 185-195.

[7] Ashok, S. (2007). Optimised model for community-based hybrid energy system. Renewable energy, 32(7), 1155-1164.

[8] Ashraf, A., & Jamil, K. (2022). Solar-powered irrigation system as a nature-based solution for sustaining agricultural water management in the Upper Indus Basin. Nature-Based Solutions, 2, 100026.

[9] Awad, H., & Gül, M. (2018). Optimisation of community shared solar application in energy efficient communities. Sustainable cities and society, 43, 221-237.

[10] Behi, B., Baniasadi, A., Arefi, A., Gorjy, A., Jennings, P., & Pivrikas, A. (2020). Cost–benefit analysis of a virtual power plant including solar PV, flow battery, heat pump, and demand management: A western australian case study. Energies, 13(10), 2614.

[11] Bianco, G., Bonvini, B., Bracco, S., Delfino, F., Laiolo, P., & Piazza, G. (2021). Key performance indicators for an energy community based on sustainable technologies. Sustainability, 13(16), 8789.

[12] Bilardo, M., Cattaneo, F., Dioni, E., Liberi, E., Milocco, L., & Serale, G. (2020). Community Energy for enhancing the energy transition. CERN IdeaSquare Journal of Experimental Innovation, 4(2), 7-18.

[13] Burhan, M., Jin, Y., Ybyraiymkul, D., Ja, M. K., AIRowais, R., Shahzad, M. W., Chen, Q., & Ng, K. C. M. (2023). Long term rating (LTR) and energy efficacy of solar driven desalination systems in KSA using a common energy platform of standard solar energy (SSE). Solar Compass, 6, 100044.

[14] Byrne, J., Taminiau, J., Kurdgelashvili, L., & Kim, K. N. (2015). A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renewable and Sustainable Energy Reviews, 41, 830–844.

[15] Ceglia, F., Marrasso, E., Roselli, C., & Sasso, M. (2023). Energy and environmental assessment of a biomass-based renewable energy community including photovoltaic and hydroelectric systems. Energy, 282, 128348.

[16] Deshmukh, S. S., & Pearce, J. M. (2021). Electric vehicle charging potential from retail parking lot solar photovoltaic awnings. Renewable Energy, 169, 608-617.

[17] Devine-Wright, P., & Devine-Wright, H. (2009). Public engagement with community-based energy service provision: An exploratory case study. Energy & environment, 20(3), 303-317.

[18] Deymi-Dashtebayaz, M., Baranov, I. V., Nikitin, A., Davoodi, V., Sulin, A., Norani, M., & Nikitina, V. (2022). An investigation of a hybrid wind-solar integrated energy system with heat and power energy storage system in a near-zero energy building-A dynamic study. Energy Conversion and Management, 269, 116085.

[19] El-Khawad, L., Bartkowiak, D., & Kümmerer, K. (2022). Improving the end-of-life management of solar panels in Germany. Renewable and Sustainable Energy Reviews, 168, 112678.

[20] Fathoni, H. S., Setyowati, A. B., & Prest, J. (2021). Is community renewable energy always just? Examining energy injustices and inequalities in rural Indonesia. Energy Research & Social Science, 71, 101825.

[21] Feldhoff, T. (2016). Asset-based community development in the energy sector: Energy and regional policy lessons from community power in Japan. International Planning Studies, 21(3), 261-277.

[22] Fontaine, A., & Labussière, O. (2019). Community-based solar projects: sun-sharing politics and collective resource construction trials. Local Environment, 24(11), 1015-1034.

[23] Frame, D., Tembo, K., Dolan, M. J., Strachan, S. M., & Ault, G. W. (2011, July). A community-based approach for sustainable off-grid PV systems in developing countries. In 2011 IEEE power and energy Society General Meeting (pp. 1-7). IEEE.

[24] González, F. F., Sauma, E., & van der Weijde, A. (2019). The Scottish experience in community energy development: a starting point for Chile. Renewable and Sustainable Energy Reviews, 113, 109239.

[25] Grimley, M., Shastry, V., Kânoğlu-Özkan, D. G., Blevins, E., Beck, A. L., Chan, G., & Rai, V. (2022). The grassroots are always greener: Community-based organizations as innovators of shared solar energy in the United States. Energy Research & Social Science, 90, 102628.

[26] Hosseinnia, S. M., & Sorin, M. (2022). Energy targeting approach for optimum solar assisted ground source heat pump integration in buildings. Energy, 248, 123528.

[27] Hosseinnia, S. M., & Sorin, M. (2022). Techno-economic approach for optimum solar assisted ground source heat pump integration in buildings. Energy Conversion and Management, 267, 115947.

[28] Hunaiti, Z., & Huneiti, Z. A. (2015, May). Prospects and Obstacles Associated with Community Solar and Wind Farms in Jordan's Suburban Areas. In Solar (Vol. 4, No. 2, pp. 307-328). MDPI.

[29] Joshi, G., & Yenneti, K. (2020). Community solar energy initiatives in India: A pathway for addressing energy poverty and sustainability? Energy and Buildings, 210, 109736.

[30] Kaleshwarwar, A., & Bahadure, S. (2023). Assessment of the solar energy potential of diverse urban built forms in Nagpur, India. Sustainable Cities and Society, 96, 104681.

[31] Kellett, J. (2007). Community-based energy policy: A practical approach to carbon reduction. Journal of environmental planning and management, 50(3), 381-396.

[32] Khan, M. I., Chhetri, A. B., & Islam, M. R. (2007). Community-based energy model: a novel approach to developing sustainable energy. Energy Sources, Part B, 2(4), 353-370.

[33] Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. Renewable and Sustainable Energy Reviews, 56, 722-744.

[34] Kumar, S., Bibin, C., Akash, K., Aravindan, K., Kishore, M., & Magesh, G. (2020). Solar powered water pumping systems for irrigation: A comprehensive review on developments and prospects towards a green energy approach. Materials Today: Proceedings, 33, 303–307.

[35] Lazdins, R., Mutule, A., & Zalostiba, D. (2021). PV energy communities—Challenges and barriers from a consumer perspective: A literature review. Energies, 14(16), 4873.

[36] Mah, D. N. Y. (2019). Community solar energy initiatives in urban energy transitions: A comparative study of Foshan, China and Seoul, South Korea. Energy Research & Social Science, 50, 129-142.

[37] Meiramov, D., Ju, H., Seo, Y., Lee, S. J., & Ha, T. (2023). Investigation of column-to-base connections of pole-mounted solar panel structures. Journal of Constructional Steel Research, 208, 108025.

[38] Noaman, D. S., Moneer, S. A., Megahed, N. A., & El-Ghafour, S. A. (2021). Integration of active solar cooling technology into passively designed facade in hot climates. Journal of Building Engineering, 56, 104658.

[39] Nolden, C., Barnes, J., & Nicholls, J. (2020). Community energy business model evolution: A review of solar photovoltaic developments in England. Renewable and Sustainable Energy Reviews, 122, 109722.

[40] Perez-DeLaMora, D. A., Quiroz-Ibarra, J. E., Fernandez-Anaya, G., & Hernandez-Martinez, E. G. (2021). Roadmap on community-based microgrids deployment: An extensive review. Energy Reports, 7, 2883-2898.

[41] Proimakis, N., Tara, H., & Østergaard, P. A. (2021). The role of small-scale and community-based projects in future development of the marine energy sector. International Journal of Sustainable Energy Planning and Management, 32, 155-166.

[42] Reis, I. F., Gonçalves, I., Lopes, M. A., & Antunes, C. H. (2022). Towards inclusive community-based energy markets: A multiagent framework. Applied Energy, 307, 118115.

[43] Soares, L., & Wang, H. (2023). Sustainability impact of photovoltaic noise barriers with different design configurations. Transportation Research Part D: Transport and Environment, 116, 103624.

[44] Tariq, R., Torres-Aguilar, C. E., Sheikh, N. A., Ahmad, T., Xamán, J., & Bassam, A. (2022). Data engineering for digital twining and optimization of naturally ventilated solar façade with phase changing material under global projection scenarios. Renewable Energy, 187, 1184–1203.

[45] Trivedi, R., Patra, S., Sidqi, Y., Bowler, B., Zimmermann, F., Deconinck, G., ... & Khadem, S. (2022). Community-based microgrids: Literature review and pathways to decarbonise the local electricity network. Energies, 15(3), 918.

[46] Vassiliades, C., Savvides, A., & Buonomano, A. (2022). Building integration of active solar energy systems for façades renovation in the urban fabric: Effects on the thermal comfort in outdoor public spaces in Naples and Thessaloniki. Renewable Energy, 190, 30–47.

[47] Wanyama, J., Soddo, P., Nakawuka, P., Tumutegyereize, P., Bwambale, E., Oluk, I., Mutumba, W., & Komakech, A. J. (2023). Development of a solar powered smart irrigation control system Kit. Smart Agricultural Technology, 5, 100273.

[48] Xie, H., Ahmad, T., Zhang, D., Goh, H. H., & Wu, T. (2017). Community-based virtual power plants' technology and circular economy models in the energy sector: a techno-economy study. Renewable and Sustainable Energy Reviews, 192, 114189.

[49] Yang, L., He, B. J., & Ye, M. (2014). The application of solar technologies in building energy efficiency: BISE design in solar-powered residential buildings. Technology in Society, 38, 111-118.

[50] Zaman, M. R., Sarker, S., Halim, M. A., Ibrahim, S., & Haque, A. (2017). A Thorough Analysis of the Opportunities and Challenges of Community Microgrid System Based on Renewable Energy in Bangladesh. Control Systems and Optimization Letters, 2(1), 28-35.