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Sustainable Solar Energy Through PV Net Metering Systems: A Roadmap for Bangladesh

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Abstract

The primary purpose of this research is to assess the current state of photovoltaic (PV) net metering (NEM) systems in Bangladesh and explore their potential to contribute to rural electrification. The methodology involves a comprehensive review of existing policies, technologies, and market trends, alongside an analysis of the barriers to widespread PV NEM adoption. The study identifies key challenges, including high upfront costs, limited financing options, technical integration issues with the grid, and socio-cultural resistance, particularly in rural areas. Despite these barriers, the findings highlight the rapid growth of solar adoption through government programs, such as Solar Home Systems (SHS) and large-scale solar projects. The research concludes that to maximize the benefits of PV NEM, policy reforms are necessary, including financial incentives, simplified approval processes, and increased public-private partnerships. The implications suggest that overcoming financial, technical, and social obstacles can unlock Bangladesh's renewable energy potential, supporting both economic development and environmental sustainability. This study is crucial for informing future policy and investment strategies in Bangladesh and similar regions with limited access to energy.

Key words: Photovoltaic, Net metering, Policy, Renewable Energy, Bangladesh

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Introduction

The global energy landscape is undergoing a significant transformation due to challenges such as fossil fuel depletion, climate change, and concerns over energy security. As energy demand increases, renewable sources, particularly solar energy, have gained prominence as sustainable alternatives to fossil fuels (Mangla, 2023). Solar energy, derived from sunlight, offers an abundant, clean, and renewable source of power, capable of addressing global energy needs without contributing to greenhouse gas emissions (Nikolaidis, 2023). Advancements in photovoltaic (PV) technology have reduced installation costs and increased efficiency, making solar energy increasingly competitive (Lazaroiu et al., 2023). Solar systems, ranging from rooftop panels to large-scale solar farms, are scalable and versatile, providing reliable energy for both urban and remote areas. Additionally, energy storage solutions, particularly lithium-ion and flow batteries, enable the effective integration of solar power into existing grids, thereby improving system stability (Deguenon et al., 2023),(Hill et al., 2012). Rooftop solar PV systems present a viable solution for improving electricity reliability and reducing costs, particularly in developing countries (Saddari et al., 2025). The global solar energy market has experienced exponential growth, driven by technological innovations, reduced costs, and supportive government policies. Countries like China and India lead the way in solar deployment, while emerging markets in the Middle East and North Africa are also heavily investing in solar energy (Mathews et al., 2014; Varadi et al., 2018). With continued advancements in technology and policy support, solar energy is poised to play a central role in the transition to a sustainable and resilient global energy future.

Due to its rapid economic growth, Bangladesh faces a significant energy crisis, particularly in rural areas where access to reliable electricity remains limited (Mollik et al., 2016). High infrastructure costs, geographical challenges, and vulnerability to natural disasters contribute to the energy gap that exists in both urban and rural Bangladesh. A promising solution lies in photovoltaic (PV) systems coupled with net metering (NEM), which requires minimal infrastructure investment and is well-suited for Bangladesh, given its high solar irradiance (Hil Baky et al.,

2017). These systems provide clean, sustainable, and affordable energy, thereby reducing reliance on fossil fuel-based, costly imported energy sources that also emit greenhouse gases. However, the high initial cost of the system is attributed to the expensive solar panels and the net-metering setup, which includes a grid-tied inverter and either one two-way meter or two one-way meters (Qamar et al., 2016; Shabbir et al., 2020). Several challenges hinder the widespread adoption of PV NEM systems in Bangladesh, despite their cost-effectiveness and sustainability as an energy source. These challenges include the high upfront capital investment and limited on-ground technical expertise. Additionally, grid interconnection requirements, which limit single-phase consumers from selling excess generation, further restrict the deployment of net-metered systems (Memon & Hussain, 2019). Delays in installation and maintenance are exacerbated by the presence of insufficiently trained technical staff (Dhankhar & Anwer, 2019). Existing gaps in Bangladesh's renewable energy policy framework hinder the growth of renewable energy (Podder et al., 2021). Existing literature highlights the challenges of integrating renewable energy into conventional grids, emphasizing the need for advanced control and monitoring systems. Internet of Things (IoT) technologies hold promise for enhancing energy management and grid stability (Pathare & Sethi, 2024). Bangladesh, where policy shifts influence solar investments, contrasts with Brazil, which has successfully implemented a sophisticated net-metering system through a regulatory framework that aligns with the energy sector's progression and optimizes investor returns. A successful model, Bangladesh, with similar socio-economic norms, can follow (Leite et al., 2024). Overcoming these barriers requires innovative financing models, capacity-building initiatives, and policies that encourage private sector involvement. Successful pilot projects, such as those initiated by the Infrastructure Development Company Limited (IDCOL), demonstrate the potential of PV NEM systems to provide reliable and cost-effective energy (Miskat et al., 2023). Scaling up these solutions requires sustained government and international support, along with regulatory and financial innovations, to address Bangladesh's ongoing energy crisis.

The increased utilization of renewable energy (RE) resources offers significant cost savings and helps address the challenges of global

warming. The advent of RE technologies has led to the development of the smart grid, an advancement over traditional power grids. Unlike the traditional electromechanical, unidirectional grid, a smart grid is a digital, bidirectional network with distributed generators, sensors, and capabilities for self-monitoring, self-healing, remote testing, and control. Smart grids enable consumers to both consume and produce energy, benefiting economically through net-metering systems. Net-metering, as a policy incentive, supports the deployment of RE technologies for sustainable energy generation.

Despite extensive research on net metering globally, a comprehensive review of its implementation and potential in Bangladesh remains underexplored. This study seeks to address this gap by providing an in-depth analysis of the current state of net metering, the share of RE in the national grid, and the future targets for green energy adoption in Bangladesh. By evaluating these aspects, this research aims to provide policymakers, researchers, and stakeholders across Asia with valuable insights. The findings will serve as a key resource for advancing net metering initiatives and accelerating the transition to sustainable energy systems in the region.

Current Energy Scenario of Bangladesh

Renewable energy sources are sustainable and can help reduce dependence on fossil fuels, thereby mitigating their environmental impact. While Bangladesh's primary concern may not necessarily be driven to limit greenhouse gas emissions, renewable energy is crucial to limit its dependency on imported fossil fuels. The country has limited potential for hydropower and wind power, with solar and biomass being the most promising options (Hossen et al., 2017; Hussain & Park, 2021; Miskat et al., 2021; Podder et al., 2021). Figure 1 illustrates that Bangladesh's electricity generation is predominantly from natural gas, with smaller contributions from furnace oil, coal, and diesel. Imported high-value electric energy is minor. Hydro and renewable energy sources, such as solar and wind, are relatively minor components in the country's total energy mix. This heavy reliance on fossil fuels raises concerns about sustainability, supply security, and environmental impact. To address these

issues, Bangladesh must prioritize renewable energy, especially photovoltaic (PV) solar technology, which offers abundant resources, lower costs, and minimal environmental impact. A shift to PV could diversify the energy mix, reduce fuel imports, and lower carbon emissions, thus fostering a more sustainable and secure energy future.

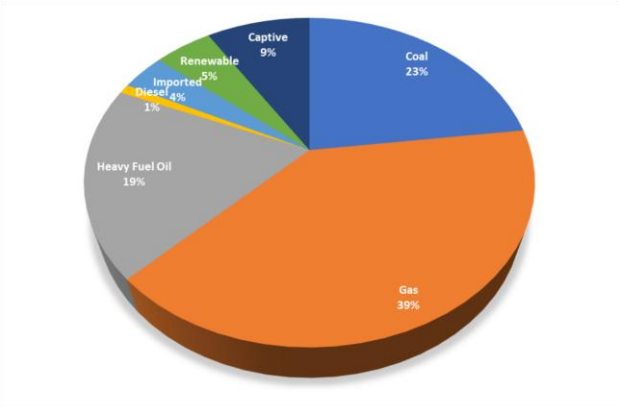

Fig.1. Breakdown of Fuel Usage for Electric Energy generation in Bangladesh, developed from source data, Sustainable and Renewable Energy Development Authority (National Database of Renewable Energy, n.d.)

Compared to other renewable sources, such as wind and hydroelectric energy, solar energy stands out. Bangladesh receives an average of 4–6.5 kWh/m² of solar radiation daily, sufficient to meet a significant portion of the country's energy needs. Solar photovoltaic (PV) systems have experienced rapid growth, with solar home systems (SHS) proving highly successful in rural areas. Currently, there are six million SHS installations with a total capacity of 263 MW. Additionally, grid-connected solar systems and solar mini-grids are expanding to provide power to remote areas (SREDA, n.d.).

Bangladesh receives an average daily solar radiation of 4–6.5 kWh/m², which can potentially generate a total energy output of approximately 1018×10^{18} joules (Hil Baky et al., 2017). Figure 2 illustrates the solar irradiance levels across major cities in Bangladesh from January

to December, showing higher values from March to June due to the summer season and lower values from July to February during the monsoon and winter seasons. The western regions, particularly Rajshahi, Jessore, and Bogra, consistently experience higher irradiance levels, making these areas more suitable for solar power generation. Notably, even during the monsoon and winter months, when irradiance drops to around 4 kWh/m²/day, this level is still adequate to meet significant energy demands, demonstrating the potential of solar energy to provide a reliable and consistent power source throughout the year.

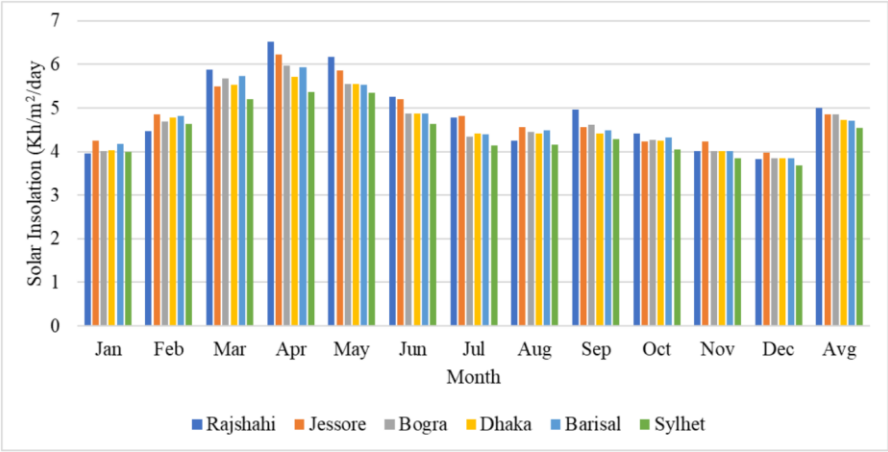

Fig. 2: Solar irradiance level in major cities of Bangladesh all year round (Islam, 2002)

PV NEM systems: Concepts, Trends, and Benefits for Rural Electrification

The net-metering system consists of components on both the customer and utility sides. On the customer side, solar panels generate DC electricity, which is converted to AC by an inverter and distributed via a service panel to household appliances. Any excess energy is sent to the grid through a bidirectional net meter, which records the difference between the power consumed and the power generated. The utility side includes a control center that receives data from the net meter for billing

and energy management, while the power grid supplies electricity when generation is insufficient. Power flows in both directions, from the customer to the grid or vice versa, and data flows from the net meter to the control center, enabling effective demand-side management. This system facilitates efficient energy consumption and generation tracking, reducing the need for expensive batteries while ensuring grid stability (Badr et al., 2022). Figure 3 illustrates the net metering system model.

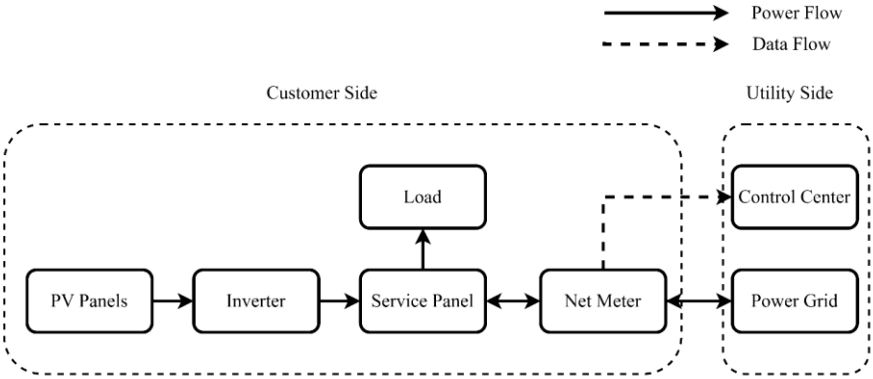

Figure 3 : The PV NEM system model (Badr et al., 2022)

Globally, PV mini-grids are gaining traction, particularly in regions like Africa, the Middle East, and South Asia, as nations shift toward greener energy solutions in response to climate change and the decline of fossil fuel dependence (Varadi et al., 2018; Asif et al., 2024). In Europe, countries like Germany are adopting PV technology as part of their broader transition away from fossil fuels (Von Appen et al., 2013). In developing countries, PV mini-grids are increasingly used to expand energy access in areas where affordable grid power is scarce. For instance, in Sub-Saharan Africa, countries such as Kenya heavily rely on PV mini-grids to address limited grid coverage resulting from underdevelopment and challenging terrain (Micangeli et al., 2017). India leads South Asia in adopting grid-tied PV mini-grid technology, benefiting from a stronger grid infrastructure (Gulia & Garg, 2021). In Southeast Asia, nations like Indonesia, Malaysia, and Myanmar use PV mini-grids to improve

electrification in remote islands and challenging terrains (Anang et al., 2021; Hyun et al., 2021; Putranto et al., 2022). Despite the growth of rooftop PV systems in Indonesia, high investment costs and low electricity prices hinder their economic viability. Financial incentives and improved NEM schemes could enhance their adoption (Pramadya & Kim, 2024). Meanwhile, countries in the Middle East and North Africa, such as Morocco and Egypt, are actively adopting this technology. In Western nations, including Germany, the United Kingdom, the United States, and Canada, both single-phase and three-phase grid-tied PV mini-grids are utilized, supported by well-developed grids that facilitate the efficient integration of solar power. These systems help reduce overall energy costs, encourage public participation in energy generation, and contribute to the global shift toward sustainable energy solutions.

The bar chart in Fig. 4 illustrates the significant growth in the number of countries adopting net metering between 2004 and 2023. Initially, adoption was slow, with only a few countries implementing the system by 2004, followed by gradual growth until 2012. From 2013 onwards, there was a marked acceleration in adoption, indicating a broader global shift towards renewable energy solutions and the increasing integration of net metering systems. The period from 2021 to 2023 saw an exponential rise, with nearly 92 countries adopting the practice, reflecting a global emphasis on sustainability and the transition to renewable energy. This trend highlights the growing recognition of net metering as a vital component in reducing carbon emissions and empowering consumers to contribute to energy production (Rehman et al., 2020).

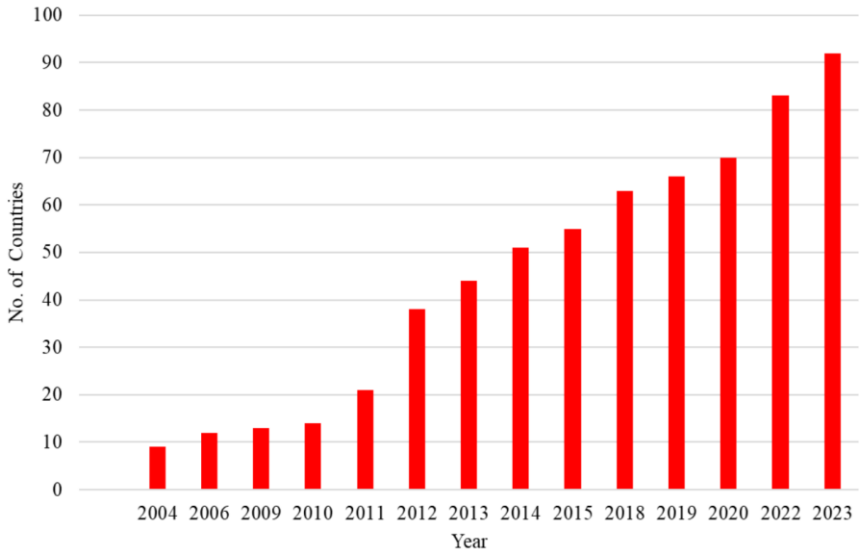

Figure 4: Graphical view of the number of countries adopting the net metering system through 2004-23 (*REN21, 2024*)

PV NEM systems in Bangladesh: Current Status and Challenges

Bangladesh has made significant strides in solar energy adoption, particularly through the introduction of the Net Metering Policy in 2018, which has been a major driver for rooftop solar installations. This policy allows residential and commercial users to sell excess electricity back to the grid, incentivizing the adoption of solar power systems. The data in Table 1 on rooftop solar installations in Bangladesh reveals distinct patterns across different power organizations. BREB leads with the highest installed capacity of 68.71 MWp, despite having fewer installations, indicating a focus on larger systems in rural areas. In contrast, organizations like DESCO and DPDC, which serve the urban Dhaka area, have more installations but smaller capacities, likely due to limited rooftop space in densely populated urban settings. This highlights the challenge of expanding rooftop solar in urban areas, where space is more constrained compared to rural areas, where larger systems can be deployed more easily.

Table 1: Statistics of Net Metered Rooftop Solar(Statistics of Net Metered Rooftop Solar, n.d.)

Organization	Quantity	Installed Capacity
BREB	438	68.71 MWp
BPDB	531	17.81 MWp
WZPDCL	468	13.45 MWp
DESCO	996	12.08 MWp
NESCO	119	5.63 MWp
DPDC	356	3.73 MWp
Total	2908	121.4 MWp

While Bangladesh has made notable progress in the renewable sector, there are still barriers to the widespread adoption of PV NEM systems. These include the lack of political will, inadequate policy support, and complex approval processes, which hinder the expansion of photovoltaic systems (The Daily Star, 2024). Nevertheless, with the continued support of the government, private companies, and NGOs, along with the growing popularity of the Net Metering Policy, there is significant potential for further growth in both urban and rural regions. As demand for renewable energy increases, PV NEM adoption is expected to play a key role in meeting the country's energy needs, supporting environmental sustainability, and promoting energy security.

The widespread adoption of PV NEM in Bangladesh also faces significant financial and technical challenges. Financially, the high upfront costs of PV systems, including expenses for solar panels, inverters, and installation, are exacerbated by import duties, taxes, and regulatory compliance, making them more expensive than conventional grid electricity. This financial burden is particularly heavy in rural areas, where affordability is low and access to affordable financing is limited. Traditional financial institutions are reluctant to fund PV projects due to perceived risks, such as long payback periods and low returns. Additionally, the lack of collateral among rural entrepreneurs, high interest rates, and short-term loan structures further limit financing opportunities. Technically, issues related to grid integration and stability persist, as the

weak national grid infrastructure is unable to support significant renewable energy (RE) integration, particularly with the restriction that only three-phase power can be supplied, leaving many single-phase customers unable to participate in net metering. The lack of single-phase bidirectional meters and ambiguous regulatory guidelines also hinders the system's potential. Moreover, the requirement that renewable energy generation must be less than 70% of the sanctioned load, combined with the cap on system size (10 MW), restricts users' ability to become full producers of energy (The Daily Star, 2024). These challenges are further compounded by concerns over monopolization by organizations connected with the Infrastructure Development Company Limited (IDCOL), creating additional barriers to the widespread implementation of PV net metering.

Social-economic perceptions also serve as a barrier to the adoption of PV NEM in rural Bangladesh despite its potential advantages. A primary barrier is the perception of high costs, as rural populations often view PV systems as an expensive luxury due to the substantial initial investment required for solar panels, inverters, and associated infrastructure. This perception is further compounded by the requirement for upfront payments and a lack of awareness regarding financing options such as subsidies and microfinance. Additionally, limited financial literacy in rural areas contributes to an underappreciation of the long-term savings PV net metering can offer compared to traditional energy sources like kerosene. Loan-run marginal cost pricing in solar PV projects is further hindered by these high initial capital costs, financial institution biases, and a lack of access to suitable financing mechanisms, all of which exacerbate price distortion and limit the widespread adoption of solar technologies (Rahman, 2012).

Cultural resistance also plays a critical role, as many rural communities maintain strong traditions around conventional energy sources and may perceive PV technology as foreign or incompatible with their way of life. There is often fear that adopting such technology could disrupt social structures or necessitate the acquisition of new skills. Furthermore, a general lack of awareness regarding the economic, environmental, and social benefits of PV net metering fuels skepticism.

This challenge is exacerbated by insufficient access to information and the absence of practical demonstrations of its advantages.

To overcome these barriers, a comprehensive approach is necessary, including targeted educational campaigns that emphasize the long-term cost savings, environmental benefits, and economic opportunities associated with PV net metering. Expanding financial support mechanisms and raising awareness about available financing options will also be crucial. Involving local leaders and community organizations in the design and implementation of PV projects can foster a sense of ownership and enhance acceptance. Showcasing successful pilot projects and demonstrating tangible benefits, alongside providing training programs for local technicians to ensure system maintenance, can further promote adoption. By addressing these socioeconomic and acceptance challenges, PV net metering can emerge as a viable and sustainable energy solution for rural Bangladesh.

Policy Recommendations and Future Roadmap

Enhancing government policies and incentives for photovoltaic (PV) net metering in Bangladesh is crucial for accelerating the adoption of renewable energy and addressing challenges related to electrification. To overcome barriers such as high upfront costs, limited coverage, and bureaucratic delays, the government should expand eligibility criteria, simplify approval processes, and introduce performance-based incentives. Additionally, revising the tariff structure to offer higher feed-in tariffs (FiTs), long-term agreements, and a stable pricing mechanism would encourage investment in PV systems. Allowing excess energy to be sold back to the national grid would further incentivize the adoption of renewable energy sources. Expanding financing options through low-interest loans, public-private partnerships, and guarantee funds would improve access to PV systems, especially for rural communities. Moreover, raising awareness among younger generations through seminars and media campaigns in universities would foster broader adoption. These measures would not only reduce financial barriers but also attract private investment, ensuring a more sustainable energy future for Bangladesh.

Public-private partnerships (PPPs) and strategic investment strategies are essential for advancing the sustainability and scalability of photovoltaic (PV) net metering systems, particularly in countries like Bangladesh, where energy access remains a significant challenge. The government can play a pivotal role by providing regulatory support, subsidies, and infrastructure that facilitate the integration of PV systems into the grid, enabling net metering as a viable solution for energy distribution. Social businesses can also contribute by offering decentralized energy solutions, innovative financing models, and community engagement to promote widespread adoption of sustainable practices. International investment is critical, with entities such as the Green Climate Fund (GCF), the World Bank's Sustainable Energy for All (SEforALL) initiative, and development banks offering financial support to scale up PV net metering programs. Key investment strategies, including green bonds, blended finance, and foreign direct investment (FDI), can be leveraged to facilitate renewable energy projects. Additionally, crowdfunding platforms such as TrillionFund and Abundance offer alternative financing models for community-driven solar energy solutions (Lu et al., 2018).

Corporate social responsibility (CSR) initiatives can further drive the expansion of PV NEM, as multinational corporations and energy-intensive industries integrate renewable energy into their sustainability commitments. CSR strategies include direct investments in renewable energy infrastructure, partnerships with local communities, and funding for local solar entrepreneurs. Notable examples, such as Schneider Electric's BipBop program, highlight the role of CSR in promoting solar energy adoption (Desroches & André, 2012). To strengthen PPPs and CSR-driven investments, governments should introduce tax incentives, mandate CSR contributions to renewable energy, and develop a national framework to support PV net metering. In addition, strengthening regulatory frameworks, streamlining approval processes, and ensuring transparency in project implementation will be vital in attracting both private and international investment, fostering a sustainable and inclusive energy transition.

Conclusion

In conclusion, photovoltaic (PV) net metering systems offer a promising and transformative solution to the energy access challenges faced by rural communities in Bangladesh. The country has made notable strides in adopting solar energy, as demonstrated by programs such as the Solar Home Systems (SHS) initiative and large-scale solar installations, which have significantly expanded energy access in off-grid areas. However, the widespread deployment of PV net metering systems encounters several obstacles, including high initial costs, limited access to affordable financing options, and technical challenges related to grid integration and energy storage. Additionally, cultural resistance and a lack of public awareness in rural regions further hinder the acceptance and adoption of these systems.

To overcome these challenges, it is essential to implement comprehensive policy frameworks that include enhanced government incentives, increased financial support, and the promotion of public-private partnerships. Innovations in key areas, such as smart grid technologies and training programs for local technicians, are also critical for ensuring the long-term viability and operational efficiency of PV net metering systems. By addressing these barriers strategically, Bangladesh can unlock its renewable energy potential, facilitating a transition to a more sustainable and equitable energy future. Resolving the financial, technical, and social challenges will be central to ensuring broad and affordable access to reliable solar power for rural populations, contributing to both socio-economic development and environmental sustainability.

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