CHAPTER 5

BARRIERS, ENABLERS, AND BUSINESS MODELS FOR SCALING SOLAR PHOTOVOLTAIC ENERGY SYSTEMS

5.1 Introduction

The deployment of solar photovoltaic energy systems has emerged as a cornerstone in the transition towards sustainable energy solutions. Particularly in rural regions, solar PV systems hold immense promise for improving energy access, promoting socio-economic development, and reducing carbon emissions. Despite their potential, the growth and scalability of these systems face significant obstacles that need to be systematically addressed. This Chapter focuses on identifying the barriers impeding the progression of solar PV systems in rural Assam, explores enablers that can foster growth, and proposes viable business models that align with existing government initiatives to promote solar energy. The goal is to provide an in-depth understanding of the challenges while offering structured pathways to overcome them, with an emphasis on leveraging policies, financial frameworks, and community-based approaches [1, 2].

The Chapter is organized into three core segments *viz.*, barriers, enablers, and business models. The barriers are categorized into four specific dimensions, namely: technical, economic, policy, and social factors. Similarly, the enablers are analysed to illustrate the facilitating factors essential for overcoming these challenges.

Identifying the barriers and enablers influencing the expansion of solar PV systems in the study region presents significant challenges. However, the analysis draws on the findings from Chapter 3A, which examines the potential solar energy resources, including available space and insolation levels; Chapter 3B, which evaluates the decarbonization potential at a lifecycle scale; and Chapter 4, which assesses the feasibility of powering crop irrigation through solar energy. To further analyse the barriers and enablers, **Table 5.1** presents a synthesis of the available literature and provides insights into the key challenges and facilitating factors, as discussed in the subsequent sections. The business opportunities associated with solar PV systems are assessed using a standardized methodology, incorporating key parameters relevant to the study region. These aspects are discussed in detail below [3].

Table 5.1: Analysis of barriers and enablers for scaling solar PV systems

Title	Key information used for the study	References
Challenges in solar energy deployment	Deficiency in skilled workforce, intermittency in power generation, complexities in grid integration, and infrastructure inadequacies	[4]

Financing solar power projects	Elevated capital expenditure, constrained access to financing mechanisms, volatility in financial returns, and economic viability concerns	[5]
Policy framework for solar development	Fragmented regulatory policies, insufficient fiscal incentives, procedural bottlenecks, and regulatory uncertainty	[6]
Social perceptions of renewable energy	Knowledge gaps, resistance rooted in socio-cultural beliefs, perception biases, and preference for conventional energy paradigms	[7]
Technological innovations in solar PV	Breakthroughs in photovoltaic efficiency, advancements in energy storage technologies, integration with smart grid frameworks	[8]
Financial incentives for solar adoption	Strategic capital subsidies, fiscal stimulus through tax benefits, economies of scale in module production, and evolving cost dynamics	[9]
Regulatory support for solar expansion	Optimization of permitting procedures, implementation of investor-friendly tariff structures, fostering public-private partnerships	[10]
Community engagement in solar projects	Holistic public engagement strategies, participatory governance models, localized capacity development, and socio-economic inclusivity	[11]

5.2 Barriers to scaling solar PV energy systems

5.2.1 Technical barriers

Insolation and irradiance

Solar irradiance and insolation are critical factors influencing the feasibility and efficiency of solar PV systems. Irradiance refers to the instantaneous power of solar radiation received per unit area, typically measured in watts per square meter (W/m^2), while insolation denotes the cumulative solar energy received over a specific period, usually expressed in kilowatt-hours per square meter per day ($kWh/m^2/day$). In Assam, the average solar radiation is approximately 4.31 $kWh/m^2/day$, with peak values reaching up to 4.7 $kWh/m^2/day$. The state's average insolation is around 352 W/m^2, peaking at 959 W/m^2. In contrast, regions such as the Western dry and Trans-Gangetic plains, encompassing states like Rajasthan and Gujarat, receive significantly higher solar insolation. During the summer months, these areas can experience insolation levels reaching up to 7.5 $kWh/m^2/day$. Annually, these regions receive average global insolation above 5 $kWh/m^2/day$, making them more favourable for solar energy generation. This disparity in solar irradiance and insolation between Assam and the high solar potential states presents a technical barrier to scaling solar PV energy systems in Assam. The lower solar energy availability in Assam necessitates larger collection areas or more efficient technologies to achieve the same energy output as in higher insolation regions, potentially increasing the cost and complexity of solar PV projects in the state [12].

Space availability

Space availability is a critical barrier to scaling solar PV energy systems in Assam compared to high-potential states such as Rajasthan and Gujarat, which have more extensive land resources. Assam has a per capita land availability of approximately 0.22 hectares, significantly lower than Rajasthan's 0.51 hectares, limiting large-scale GMS projects. The designated area for solar deployment in Assam is around 8-10% of the total geographical area, whereas it exceeds 17% in Rajasthan. Within the 61 villages under study, space availability varies, influenced by population density and competing land uses. For GMS, land ownership poses a major challenge, as much of the available land falls under government or community ownership, necessitating clear policies for acquisition and compensation to mitigate disputes. Local governance bodies, such as Gram Panchayats and Gaon Panchayats, play a crucial role in facilitating land allocation and community participation. In RTS installations, technical challenges arise from structural limitations, shading due to trees and landscape changes, and evolving housing patterns that may not support PV installations. Traditional sloped tin roofs and small rooftop spaces further restrict RTS deployment. In the case of SWP systems, competitive land use with agriculture presents another challenge, as land allocated for SWP competes with productive farmland. The average land requirement for SWP in Assam is 0.005 hectares per kW, which could otherwise be used for high-yield crops [13].

Performance

The performance of solar PV systems in Assam is significantly affected by factors such as dust accumulation, inadequate cleaning provisions, and shading, which collectively impact the performance ratio. Dust accumulation on solar panels reduces energy output by blocking sunlight, and the lack of regular cleaning provisions exacerbates this issue, leading to long-term efficiency losses. In many rural areas, proper maintenance infrastructure and awareness regarding panel cleaning are insufficient, resulting in suboptimal performance. Furthermore, shading from trees, buildings, and landscape variations poses another major challenge, particularly in regions with dense vegetation or changing land-use patterns. These factors collectively lower the performance ratio, which measures the actual energy output compared to the theoretical potential, highlighting the need for systematic maintenance strategies, awareness programs, and the implementation of self-cleaning or automated cleaning technologies to enhance system efficiency and reliability.

PV system availability

The availability of solar PV systems in the study region is hindered by the absence of a well-established market network, which poses significant challenges to the widespread adoption and long-term sustainability of solar energy solutions. The lack of an organized supply chain results in limited access to quality components, delays in procurement, and higher costs for end-users. Furthermore, post-installation maintenance, including after-sales service, remains a critical concern due to the unavailability of service providers and the absence of structured support mechanisms. This situation is exacerbated by a shortage of skilled manpower required for system troubleshooting, periodic maintenance, and efficient operation of solar PV installations. Addressing these issues requires the development of local supply chains, capacity-building initiatives to train technicians, and the establishment of service centres to ensure prompt and reliable after-sales support, thereby enhancing the long-term viability and effectiveness of solar energy systems in the region [14].

Additionally, issues related to energy storage present a significant obstacle. Most rural households lack effective energy storage solutions due to high costs and limited technical expertise, which restricts their ability to utilize solar power effectively during non-sunlight hours. Furthermore, grid integration challenges pose problems in regions where infrastructure is underdeveloped, as the existing grid may not be robust enough to accommodate the variable energy output from distributed solar systems [15].

5.2.2 Financial and economic barriers

The financial viability of solar PV systems is significantly constrained by the substantial upfront capital investment required for installation and commissioning. This challenge is particularly acute in rural areas, where households and micro-enterprises often operate within limited financial means and lack the liquidity to make substantial initial investments in solar technology. The capital intensity of solar PV systems encompasses procurement, installation, and ancillary infrastructural costs, which collectively hinder widespread adoption. Furthermore, the limited financial literacy prevalent in rural communities, coupled with the sparse penetration of formal banking institutions, exacerbates the challenge by restricting access to concessional financing, credit instruments, and government-backed subsidy programs. Consequently, potential adopters are often unable to leverage financial incentives effectively, thereby stalling market penetration and scalability of solar PV systems [16].

A critical economic impediment is the perceived risk associated with extended payback periods, typically spanning 10-15 years. Rural consumers, often constrained by irregular income streams and competing financial priorities, exhibit a heightened aversion to long-term investments with uncertain returns. The apprehension regarding revenue stability and return on investment (ROI) diminishes confidence in adopting solar PV technologies. Additionally, the absence of robust financial risk mitigation mechanisms, such as dedicated solar insurance products, guarantees, and performance-based incentives, further deters investment. The financial sector's reluctance to provide tailored financial products, such as micro-loans with flexible repayment terms, further exacerbates the challenge, leaving end-users to bear the full brunt of investment risk [17-19].

5.2.3 Policy and regulatory barriers

The policy landscape for solar PV deployment in rural areas is supported by a range of government initiatives designed to promote adoption and enhance financial accessibility. However, the procedural intricacies associated with regulatory compliance can present challenges for rural stakeholders seeking to leverage these benefits. The multi-layered approval processes, diverse eligibility criteria, and extensive documentation requirements may pose complexities that necessitate greater awareness and facilitation mechanisms to optimize accessibility. Enhancing procedural transparency and streamlining administrative frameworks can further strengthen the implementation of these initiatives, ensuring a more inclusive approach to solar PV adoption [20, 21].

An additional challenge within the policy and regulatory framework is the lack of a clear and structured carbon financing policy in India. While carbon financing presents significant opportunities for monetizing carbon reductions through mechanisms such as carbon credits and trading schemes, the absence of well-defined guidelines, regulatory oversight, and standardization of carbon accounting methodologies creates uncertainty among investors and project developers. This ambiguity hinders the ability of solar PV project developers to fully capitalize on the potential revenue streams offered by carbon markets, thereby limiting the overall financial attractiveness of solar investments. A robust and transparent carbon financing framework, with clear guidelines on eligibility criteria, verification mechanisms, and integration with international carbon markets, is essential to unlocking additional financial incentives and enhancing project bankability [22, 23].

Additionally, policy implementation across different regions may exhibit variations due to localized administrative practices, leading to potential delays in deployment timelines. Ensuring consistency in regulatory execution and providing clear, standardized guidelines can further augment the effectiveness of existing policies and enhance stakeholder engagement. Furthermore, the dynamic nature of subsidy structures and evolving regulatory frameworks necessitates adaptive financial planning by stakeholders to align with emerging policy directions. Strengthening communication channels between policymakers and end-users can enhance clarity and enable smoother transitions in policy frameworks, fostering long-term investor confidence and accelerating market penetration [24-26].

A concerted effort towards capacity building and awareness initiatives can empower rural communities to better navigate the regulatory landscape and leverage available incentives effectively. The integration of digital platforms for application processing and real-time tracking of approvals can contribute to improving efficiency and accessibility. Additionally, fostering collaboration between government bodies, financial institutions, and local governance structures can create a more enabling environment for solar PV adoption while aligning with broader sustainable development objectives. Addressing these policy and regulatory barriers with a comprehensive and harmonized approach will be crucial for scaling up solar PV deployment and achieving national renewable energy targets [27-29].

5.2.4 Social and awareness barriers

The widespread adoption of solar PV systems in rural communities is influenced by an array of socio-cultural dynamics that shape perceptions and acceptance of renewable energy technologies. Limited awareness regarding the economic, environmental, and social benefits of solar energy remains a critical barrier, often compounded by inadequate exposure to technical knowledge and practical applications. The perceived complexity of solar PV systems, coupled with the reliance on conventional energy sources, can result in hesitancy among rural populations to transition to decentralized renewable solutions. This lack of familiarity may stem from traditional energy consumption patterns, where solar technology is viewed as supplementary rather than a primary source of energy, leading to underutilization of available opportunities [30, 31].

Furthermore, deeply rooted socio-cultural beliefs and behavioural inertia contribute to scepticism regarding the reliability, efficiency, and affordability of solar PV systems. Misinformation, coupled with anecdotal experiences of system failures due to improper installation or maintenance, fosters doubts about the long-term viability of solar solutions. The absence of well-structured community engagement frameworks and participatory decision-making processes further limits the sense of ownership among potential adopters. Empowering communities through targeted awareness programs, demonstration projects, and hands-on training can play a pivotal role in dispelling misconceptions and fostering a more positive outlook toward solar energy adoption [32, 33].

Another significant challenge is the scarcity of localized technical expertise and service infrastructure, which creates concerns about post-installation support and system longevity. The limited presence of skilled technicians and service providers in rural areas exacerbates apprehensions regarding system maintenance and reliability, discouraging widespread adoption. Strengthening capacity-building initiatives through vocational training programs, establishing decentralized service hubs, and leveraging local institutions for technology dissemination can bridge the existing knowledge and service gaps, enhancing user confidence and adoption rates [34].

5.3. Enablers for scaling solar PV energy systems

5.3.1 Technological enablers

Recent advancements in PV technology have significantly enhanced the feasibility, efficiency, and reliability of solar energy systems, providing critical enablers for their widespread deployment in regions such as Assam. A key technological enabler is the development of high-efficiency PV modules, which are designed to deliver improved performance even under low irradiance and diffused sunlight conditions. This is particularly advantageous for Assam, where the variability in sunlight availability due to frequent cloud cover and high humidity levels necessitates the use of modules with superior light absorption and conversion efficiency [35]. The advent of bifacial PV modules, tandem solar cells, and advanced anti-reflective coatings has further contributed to enhanced energy yields in suboptimal weather conditions, enabling better performance under the region's climatic dynamics [36-38].

In addition to module advancements, the increasing affordability and accessibility of battery energy storage systems (BESS) have emerged as a transformative enabler for rural electrification. The continuous decline in lithium-ion battery costs, coupled with improvements in energy density and cycle life, has made energy storage a viable solution for ensuring a stable power supply, particularly during non-peak sunlight hours. These storage solutions not only provide energy reliability but also enable better load management and grid independence, addressing key challenges faced in remote rural areas with intermittent grid access [39-41]. The integration of smart inverters and advanced energy management systems equipped with real-time monitoring, fault detection, and adaptive energy distribution capabilities further optimizes system performance, enabling proactive maintenance and efficient utilization of solar resources [42].

An additional technological advantage for solar PV deployment in Assam stems from its relatively moderate temperature conditions compared to high solar potential states such as Rajasthan and Gujarat. Although these states receive higher solar irradiance and insolation levels, their elevated ambient temperatures often exceeding 45°C negatively impact PV module efficiency due to increased thermal losses and degradation rates [43, 44]. In contrast, Assam's lower average temperatures, which generally range between 20-35°C, provide a more favourable operating environment, reducing heat-induced performance losses and enhancing overall system efficiency and lifespan. This inherent climatic advantage allows PV installations in Assam to operate closer to their optimal efficiency points, potentially improving long-term energy yields and reducing degradation-related maintenance costs [45].

Furthermore, the rapid development of hybrid PV systems, integrating solar with other renewable energy sources such as biomass and hydro, presents additional opportunities for enhancing energy security in rural Assam. Hybrid systems provide complementary energy generation capabilities, ensuring a more resilient and reliable power supply, especially during seasonal variations [46, 47]. The integration of decentralized microgrids and net-metering frameworks also facilitates the adoption of distributed energy systems, empowering rural communities to become prosumers both consumers and producers of energy thereby fostering local energy independence and economic empowerment.

To fully leverage these technological advancements, there is a need for sustained investments in research and development, capacity-building initiatives, and policy-driven incentives that encourage the adoption of cutting-edge PV solutions tailored to the specific climatic and socio-economic context of Assam. Strategic collaborations between technology providers, policymakers, and local stakeholders can further accelerate the deployment of innovative solar solutions, ensuring long-term sustainability and scalability of solar PV systems in the region [48].

5.3.2 Financial enablers

The expansion of solar PV systems in rural areas is increasingly facilitated by a range of financial enablers aimed at addressing cost-related challenges and enhancing economic viability. Government-backed fiscal instruments, such as capital subsidies, interest subvention schemes, and tax incentives, have been instrumental in reducing the initial financial burden on end-users and stimulating market growth. These initiatives, coupled with concessional financing through specialized green funds and sovereign guarantees, create an enabling environment for the widespread adoption of solar energy solutions. Additionally, the role of microfinance institutions (MFIs) and cooperative banks in offering customized financial products tailored to the needs of rural consumers has significantly improved access to credit. The availability of collateral-free loans and flexible repayment structures ensures financial inclusivity, allowing economically weaker sections to benefit from solar PV installations without stringent credit requirements [49].

Innovative financing mechanisms, such as third-party ownership models, have emerged as transformative solutions to overcome the challenge of high upfront capital investments. Under solar leasing and power purchase agreements (PPAs), consumers can access solar energy without bearing the full capital cost, instead paying for the energy consumed over time. Pay-as-you-go (PAYG) financing models, leveraging mobile-based payment systems and smart metering technologies, have proven effective in rural settings by aligning payment schedules with users' cash flow cycles. Such models provide a viable pathway for achieving financial accessibility while simultaneously ensuring sustainability through performance-based payments [50, 51].

Crowdfunding and impact investments have also gained prominence as alternative funding sources, enabling communities and social enterprises to mobilize resources for decentralized solar projects. Furthermore, blended finance approaches that combine public and private sector investments are fostering risk-sharing and encouraging greater participation from financial institutions. Strengthening financial literacy and awareness programs within rural communities remains crucial to enhancing the effective utilization of these financial enablers and ensuring long-term financial sustainability of solar PV systems [52].

5.3.3 Policy and regulatory enablers

The regulatory and policy framework for solar PV deployment in rural areas is evolving to facilitate greater adoption by providing a conducive environment through well-structured interventions. Proactive policy measures have introduced financial incentives, grid interconnection facilitation, and streamlined approval processes that simplify compliance requirements and enhance market participation. Government initiatives such as PM Surya Ghar and PM-KUSUM schemes not only provide financial support but also offer technical assistance and capacity-building programs to ensure the effective implementation and long-term sustainability of solar projects. These schemes aim to promote decentralized energy generation, reduce dependency on conventional grid power, and empower rural communities with sustainable energy solutions [53, 54].

Decentralized energy policies that empower local governance institutions, such as Panchayati Raj bodies and rural cooperatives, have been instrumental in driving solar adoption by integrating renewable energy targets within local development plans. These policies encourage participatory planning approaches, ensuring community involvement and ownership, which are critical for the long-term sustainability of solar initiatives. Furthermore, capacity-building programs under government initiatives have facilitated the training of local technicians and entrepreneurs, fostering job creation and local economic development [55, 56].

A key regulatory enabler is the implementation of net metering and feed-in tariff policies, which provide financial incentives for surplus energy generation and integration with the grid.

These policies encourage prosumer participation and enable rural consumers to generate additional revenue from excess solar energy production. Regulatory support for innovative business models, such as community solar projects and microgrid frameworks, has further enhanced energy access while promoting resilience and energy security in rural areas [57-59].

Efforts to streamline subsidy disbursement processes, improve transparency in eligibility criteria, and reduce administrative bottlenecks have further bolstered the accessibility of financial incentives. The integration of digital platforms for application processing and real-time tracking has contributed to greater efficiency and accountability in policy implementation. Continued policy innovation, regulatory clarity, and adaptive governance will be crucial in scaling solar PV adoption, ensuring alignment with broader energy transition goals and sustainable development objectives [60].

5.3.4 Social and community enablers

Social and community-driven approaches play a pivotal role in the widespread adoption and long-term sustainability of solar PV systems in rural areas. Effective community engagement through participatory frameworks fosters a sense of ownership and collective responsibility, which is essential for ensuring the successful implementation and maintenance of solar installations. Involving local stakeholders in the planning and decision-making processes enhances trust, mitigates resistance to technological change, and empowers communities to actively participate in the transition to renewable energy solutions. The establishment of decentralized governance structures, such as village energy committees and cooperative societies, provides a platform for inclusive decision-making and ensures that community-specific energy needs and socio-cultural dynamics are adequately addressed [61, 62].

Capacity-building initiatives are fundamental in equipping communities with the technical and operational knowledge necessary to sustain solar PV systems over the long term. Structured training programs targeted at local technicians and community members can enhance technical competencies in system operation, troubleshooting, and routine maintenance. Awareness campaigns, knowledge-sharing workshops, and demonstration projects can further facilitate behavioural shifts by dispelling myths, increasing familiarity with solar technologies, and demonstrating tangible benefits such as energy cost savings and improved livelihoods. These initiatives not only strengthen local expertise but also create employment opportunities, contributing to socio-economic development within rural communities [63, 64].

The role of non-governmental organizations (NGOs), self-help groups (SHGs), and cooperative societies is instrumental in bridging the gap between government policies and end-user implementation. These entities serve as crucial intermediaries by providing communities with access to information, facilitating financial linkages, and offering technical support for solar PV deployment. Through advocacy and grassroots-level engagement, they can assist in streamlining subsidy applications, ensuring compliance with regulatory requirements, and providing post-installation support. Moreover, NGOs and cooperatives play a critical role in promoting gender inclusivity by empowering women to take active roles in the energy transition process, enhancing overall community resilience and fostering social equity [65, 66].

A key aspect of social enablement is the customization of solar solutions to align with local socio-economic conditions and cultural practices. Tailored deployment strategies that account for local energy consumption patterns, economic constraints, and traditional value systems can significantly improve adoption rates and acceptance. By incorporating indigenous knowledge systems and engaging traditional leadership structures, solar initiatives can gain greater traction and long-term sustainability [67].

Strengthening community engagement requires a multi-stakeholder approach involving government agencies, private sector entities, and academic institutions. Collaborative efforts that combine financial incentives, technological support, and capacity development can create an ecosystem conducive to large-scale solar PV deployment. Furthermore, leveraging digital platforms and community-driven monitoring mechanisms can enhance transparency, accountability, and efficient system utilization. A well-structured social and community engagement framework not only facilitates smooth project implementation but also reinforces the broader objectives of rural energy access, economic development, and environmental sustainability [68, 69].

5.4. Business models for scaling solar PV energy systems

The transition to renewable energy sources, particularly solar PV systems, is rapidly gaining momentum as a viable solution to meet the rising energy demand and achieve sustainability goals. Business models play a pivotal role in the successful deployment and scaling of solar PV systems by ensuring economic viability, operational efficiency, and stakeholder inclusivity. A well-structured business model not only facilitates the financial feasibility of solar installations but also addresses critical factors such as market dynamics, regulatory frameworks, and consumer engagement. In the context of rural and urban energy planning, the implementation of robust business models is crucial to overcoming financial and technical barriers, enhancing energy access, and driving socio-economic development.

This section focuses on the business models for scaling two key types of solar PV systems viz., Rooftop Solar (RTS) and Ground-Mounted Solar (GMS), while considering both consumer and vendor perspectives. Solar Photovoltaic Water Pumping (SWP) systems have already been analysed in the previous Chapter 4, highlighting their specific financial and operational aspects. In the case of RTS and GMS, business models are developed to accommodate diverse stakeholders, including residential consumers, commercial entities, and institutional investors. A crucial aspect of these models is the consideration of prosumers, where consumers not only utilize solar power for their own needs but also contribute to the energy grid as generators or suppliers, thereby fostering decentralized energy production. Cost analysis is a key component, ensuring the economic feasibility and sustainability of these systems in various deployment scenarios.

Definition of business model

A business model can be defined as the conceptual framework that describes how an organization creates, delivers, and captures value within a given market or ecosystem. In the context of solar PV systems, business models encompass a structured approach to financing, ownership, revenue generation, and risk management to ensure long-term sustainability and scalability. These models incorporate elements such as capital investment structures, operational cost frameworks, stakeholder roles, and revenue streams, which collectively determine the feasibility and attractiveness of solar PV adoption. An effective business model provides a pathway for stakeholders to maximize returns, minimize risks, and contribute to the broader objectives of clean energy transition and economic development.

Table 5.2: Key parameters used for business model analysis

Parameter	Symbol	Value	References
Capital cost (per kW)	C_{cap}	-	[70]
Operation and Maintenance Cost (per year)	C_{OandM}	1%	[71]
Capacity Utilization Factor	CUF	10-20%	[72]

Project Lifetime	L	25 years	[73]
Solar Insolation (kWh/m²/year)	E_{sol}	1,564	[12]
Payback Period	PBP	Calculated	[74]
Levelized Cost of Energy	$LCOE$	Calculated	[75]
Net present value	NPV	Calculated	[74]
Discount rate	r	8%	[76]
Government Subsidy	S	As per scheme	[77, 78]
Loan Interest Rate	i	6-10%	[79]
Carbon Emission Reduction	CO_2	0.716 kg CO_2/kWh	[80]
Electricity Tariff (Grid)	₹	7.00 per kWh	[81]
Electricity Tariff (Solar)	₹	3.50 per kWh	(as per PPA)

5.4.1 Overview of RTS business model

The business model for RTS systems is developed in alignment with the prevailing government initiatives, particularly the PM Surya Ghar Scheme, which offers financial incentives and support mechanisms to accelerate adoption. The proposed business model is comprehensively analyzed from the perspectives of consumers, vendors, and prosumers to ensure a holistic understanding of the economic feasibility and scalability of RTS deployment.

To establish a structured approach, the model begins with a cost analysis, incorporating data from multiple reliable sources, including market assessments, policy benchmarks, and technical feasibility studies. This analysis provides a detailed cost breakdown across ten RTS system sizes, ranging from 1 kW to 10 kW, enabling a comparative evaluation of financial requirements at different scales of deployment. The cost framework considers capital expenditure (CAPEX), operational expenditure (OPEX), and potential financing mechanisms, offering insights into affordability and investment feasibility for end-users.

From the vendor perspective, the business model evaluates the revenue streams associated with RTS installations across varying system sizes. This assessment includes revenue generation through direct sales. Additional revenue opportunities, such as participation in government subsidy disbursements and financing arrangements, are also considered. The model further analyzes market expansion potential, customer acquisition strategies, and operational scalability to enhance vendor profitability and market penetration.

From the prosumer perspective, the model extends beyond self-consumption by incorporating opportunities for surplus energy generation and grid interaction. Key financial performance indicators such as Levelized Cost of Energy (LCOE), Net Present Value (NPV), and Payback Period (PBP) are thoroughly evaluated to determine the long-term economic viability of the RTS systems. The analysis factors in revenue potential from feed-in tariffs (FiTs), net metering policies, and energy cost savings, providing a comprehensive understanding of the financial benefits and investment recovery timelines for prosumers.

Furthermore, the proposed business model identifies critical factors influencing system performance and revenue realization, including geographical location, solar irradiance levels, and regulatory compliance requirements.

5.4.2 Business model

Cost analysis

The cost analysis for the proposed RTS business model incorporates financial details from the PM Surya Ghar: Muft Bijli Yojana, a government initiative launched in 2024 to promote residential solar adoption by offering substantial financial subsidies. This scheme aims to enhance affordability and encourage energy-efficient solutions by providing financial support to homeowners willing to transition to solar energy. Under the scheme, the central government subsidy offers ₹30,000 per kW for system sizes up to 2 kW and ₹18,000 per kW for additional capacity up to 3 kW, with a maximum limit of ₹78,000. Additionally, the state government subsidy in Assam contributes ₹15,000 per kW up to 3 kW, with a total cap of ₹45,000. For systems exceeding 3 kW, the total subsidy is capped at ₹1,23,000, ensuring financial feasibility for mid-scale installations. These subsidies significantly reduce the upfront financial burden on consumers, thereby fostering greater adoption of RTS systems while aligning with national sustainability objectives and energy transition goals.

The cost analysis is structured to provide insights from both the consumer and vendor perspectives, offering a comprehensive evaluation of financial feasibility across the solar value chain.

Consumer perspective

From the consumer standpoint, the financial analysis encompasses the total capital investment required for RTS installation, inclusive of key cost components such as solar PV modules, inverters, mounting structures, balance of system (BOS) components, transportation, and installation labour. The subsidies provided under the PM Surya Ghar scheme are deducted from the total installation cost to determine the net financial outlay for consumers. Additionally, recurring operational and maintenance (O&M) expenses, which include cleaning, periodic inspections, and component replacements, are factored into the analysis to estimate the long-term financial implications. The cost-benefit analysis accounts for energy savings derived from reduced electricity bills and potential revenue from net metering policies, providing a detailed assessment of economics, and lifetime financial savings for consumers.

Vendor perspective

From the vendor perspective, the analysis delves into the procurement and operational expenditures associated with RTS deployment. This includes costs related to sourcing PV modules, inverters, and associated BOS components from manufacturers or suppliers, transportation logistics, and workforce training for installation and maintenance services. Additionally, the business model evaluates the costs associated with marketing and customer acquisition. The analysis further explores the scalability of the business model across different system sizes, ranging from 1 kW to 10 kW, and assesses revenue generation potential across various deployment scales.

Table 5.3: Consolidated data sources for financial assessment of RTS systems in India

Cost component	Primary data sources	Period of data collection	References	Remarks
Solar PV modules cost	MNRE benchmark reports, domestic manufacturer pricing trends	2022-2024	[82, 83]	Reflects variations in domestic manufacturing, import tariffs, and policy-driven price adjustments
Inverter cost	Market analysis reports, solar EPC contractor quotations	2023-2024	[83, 84]	Based on technological advancements, efficiency

				improvements, and procurement trends
Mounting structure cost	Solar EPC contractor reports, structural engineering studies	2021-2023	[85, 86]	Evaluates design optimization and material selection for varying system sizes
Other accessories	Supply chain reports, industry research studies	2022-2024	[82, 87]	Includes critical BOS components such as wiring, connectors, and safety devices
Transportation costs	Logistics sector reports, solar deployment case studies	2022-2024	[88]	Cost considerations based on logistics, site accessibility, and distance from supply hubs
Total estimated cost	Aggregation of the above cost components	2023-2024	Derived from compiled sources	Provides a comprehensive financial estimate across different system capacities

Total system cost (C_{total}) includes PV modules, inverters, balance of system, labour, and transportation. Subsidy (S) combines contributions from central and state governments.

Net consumer cost (C_{net}) is calculated as:

$$C_{net} = C_{total} - S \tag{5.1}$$

Table 5.4: Component-wise capital expenditure analysis for RTS systems

System Size (kW)	Cost of Panels (₹)	Inverter (₹)	Mounting Structure (₹)	Other Accessories (₹)	Transportation (₹)	Total Estimated Cost (₹)
1	37,500	16,667	10,000	6,667	3,000	73,833
2	70,833	20,833	15,000	8,333	3,500	118,500
3	100,000	29,167	18,333	10,000	4,000	161,500
4	125,000	37,500	20,833	11,667	4,500	199,500
5	166,667	41,667	25,000	15,000	5,000	253,333
6	191,667	50,000	29,167	16,667	5,500	293,000
7	225,000	58,333	33,333	20,833	6,000	343,500
8	258,333	62,500	37,500	25,000	6,500	389,833
9	283,333	66,667	41,667	29,167	7,000	427,833
10	291,667	75,000	50,000	33,333	7,500	457,500

Revenue streams

Consumer perspective: Revenue generation from energy savings, government subsidies, and potential earnings from selling excess electricity back to the grid.

Vendor Perspective: Profit margins from equipment sales, installation services, and long-term maintenance contracts.

Profit margin (P_{margin}) determined by:

$$P_{margin} = Selling\ price - C_{total} \quad (5.2)$$

Monthly and annual profit:

$$P_{monthly} = P_{margin} \times Monthly\ Sales\ Target \quad (5.3)$$

$$P_{annual} = P_{monthly} \times 12 \quad (5.4)$$

Table 5.5: Financial analysis of RTS systems

System Size (kW)	Cost (₹)	Selling Price (₹)	Subsidy Received by Consumer (₹)	Final Cost to Consumer (₹)	Profit Margin (₹)
1	73,833	88,000	45,000	43,000	14,167
2	118,500	141,500	90,000	51,500	23,000
3	161,500	193,000	123,000	70,000	31,500
4	199,500	238,500	123,000	115,500	39,000
5	253,333	303,000	123,000	180,000	49,667
6	293,000	350,500	123,000	227,500	57,500
7	343,500	411,000	123,000	288,000	67,500
8	389,833	466,500	123,000	343,500	76,667
9	427,833	512,000	123,000	389,000	84,167
10	457,500	547,500	123,000	424,500	90,000

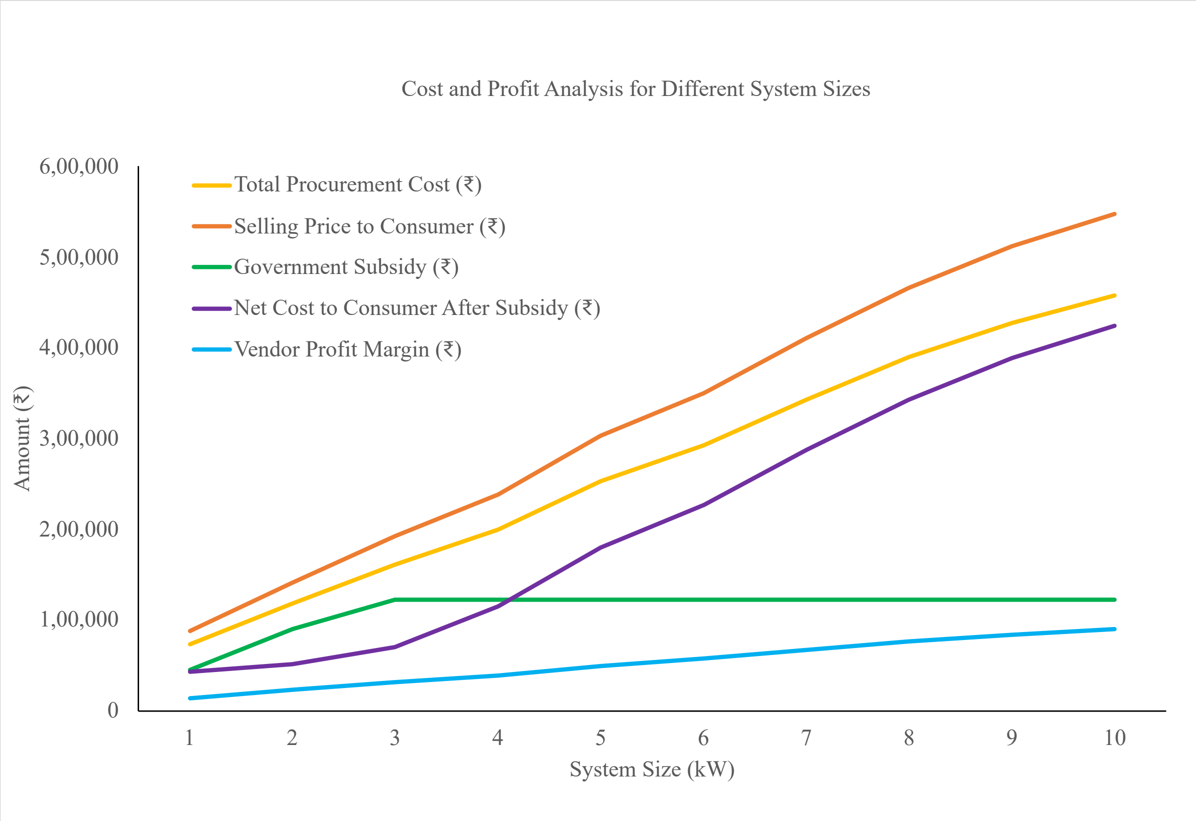

Fig 5.1: Cost-benefit analysis of RTS system for capacities ranging from (1 to 10 kW)

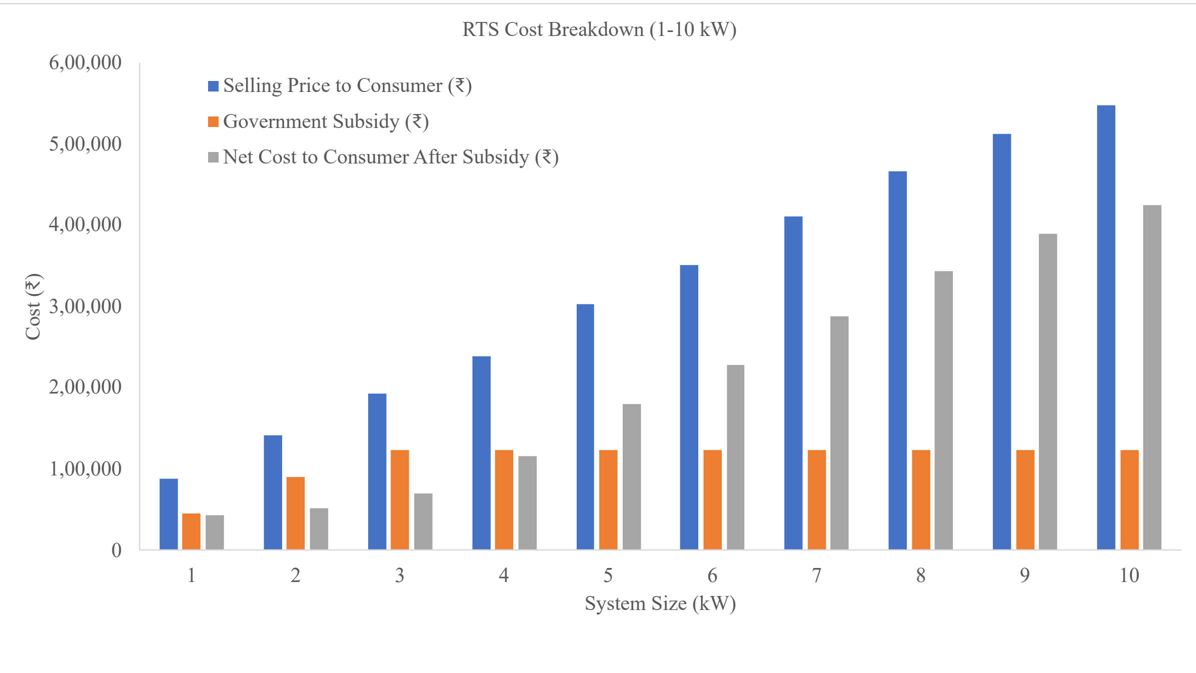

Fig 5.2: Cost breakdown of RTS systems (1 to 10 kW)

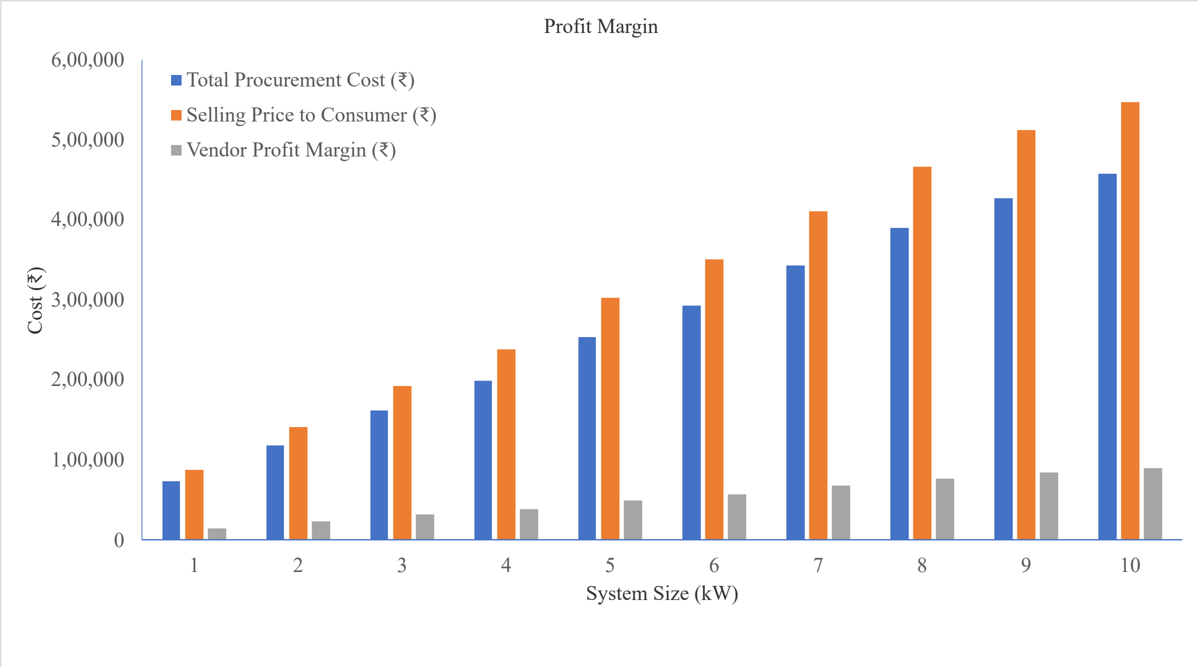

Fig 5.3: Profit margin analysis of RTS systems for capacities ranging from 1 to 10 kW

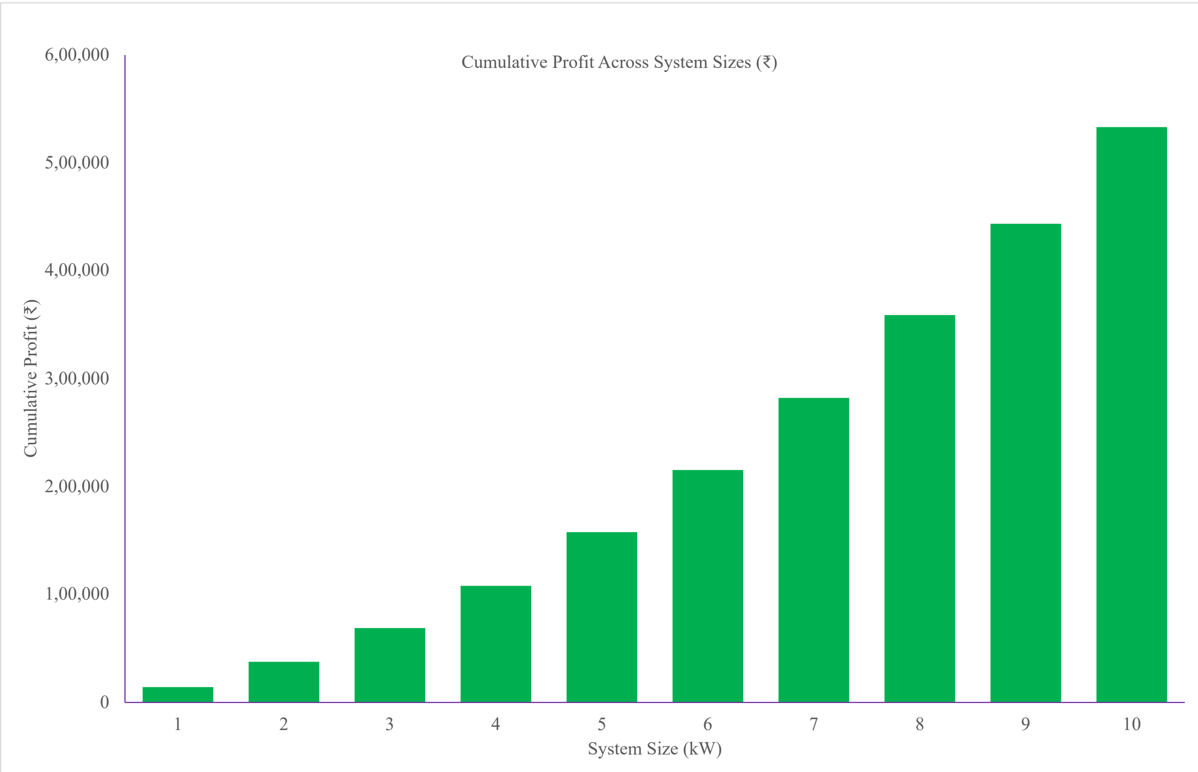

Fig 5.4: Cumulative profit analysis across RTS systems ranging from 1 to 10 kW

The market for rooftop solar (RTS) systems is anticipated to be predominantly driven by 1 kW, 2 kW, and 3 kW capacities, primarily due to the structured subsidy framework under the PM

Surya Ghar Scheme, which offers financial incentives up to a cumulative capacity of 3 kW. With the subsidy cap set at ₹1,23,000, these system sizes present the most financially attractive options for residential consumers, ensuring affordability and quicker payback periods. As a result, the adoption of these systems is expected to gain significant traction in the market, particularly among middle-income and rural households seeking to offset their electricity expenses and achieve energy independence. In order to comprehensively assess the financial feasibility and revenue generation potential for vendors, a 10-year revenue analysis has been conducted, focusing exclusively on these three system sizes. The analysis assumes an annual sales target of 48 units per system capacity, enabling an in-depth understanding of revenue streams, operational scalability, and market penetration potential over the analysis period. This revenue assessment incorporates dynamic variables such as evolving market demand, cost reduction trends due to economies of scale, and the potential impact of policy interventions, offering valuable insights for stakeholders, policymakers, and investors aiming to scale RTS adoption under the existing subsidy regime.

Table 5.6: Costing and sales analysis of (1-3 kW) RTS systems with targeted sales 48 units

System Rating (kW)	System Costing (₹)	Sale Price (₹)	Profit per Unit (₹)	Targeted Per Year Sale (Units)
1	73,833	88,000	14,167	48
2	118,500	141,500	23,000	48
3	161,500	193,000	31,500	48

Table 5.7: 10-Year revenue projections

Year	1 kW Cumulative Revenue (₹)	2 kW Cumulative Revenue (₹)	3 kW Cumulative Revenue (₹)
1	6,80,016	11,04,000	15,12,000
2	13,60,032	22,08,000	30,24,000
3	20,40,048	33,12,000	45,36,000
4	27,20,064	44,16,000	60,48,000
5	34,00,080	55,20,000	75,60,000
6	40,80,096	66,24,000	90,72,000
7	47,60,112	77,28,000	1,05,84,000
8	54,40,128	88,32,000	1,20,96,000
9	61,20,144	99,36,000	1,36,08,000
10	68,00,160	1,10,40,000	1,51,20,000

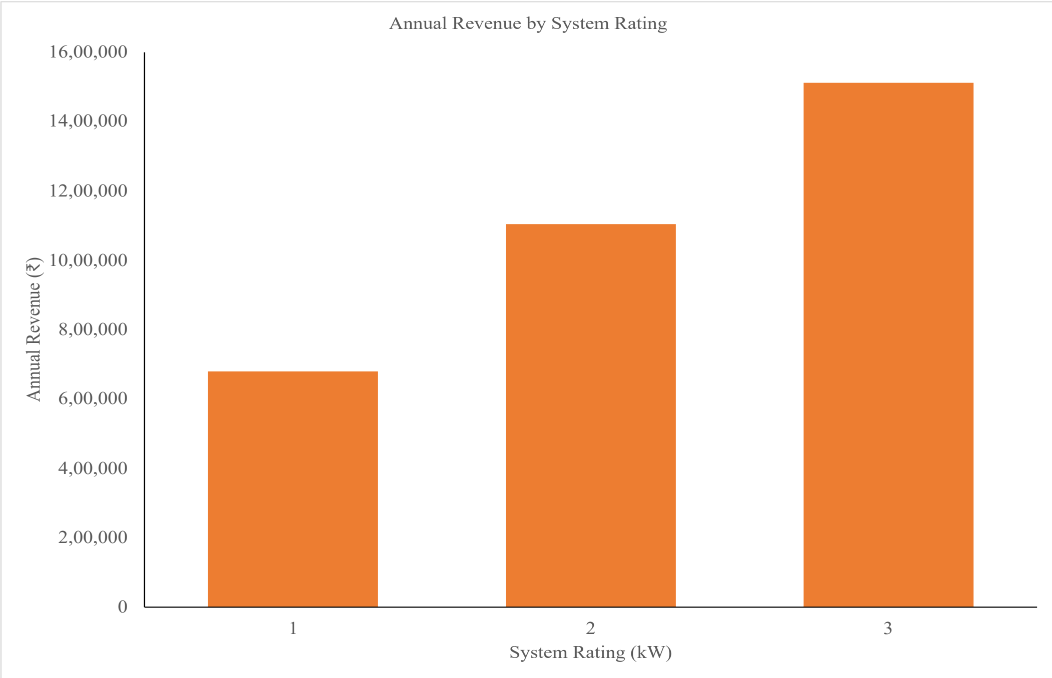

Fig 5.5: Annual revenue analysis for 1-3 kW RTS systems with a targeted sales volume of 48 units per year

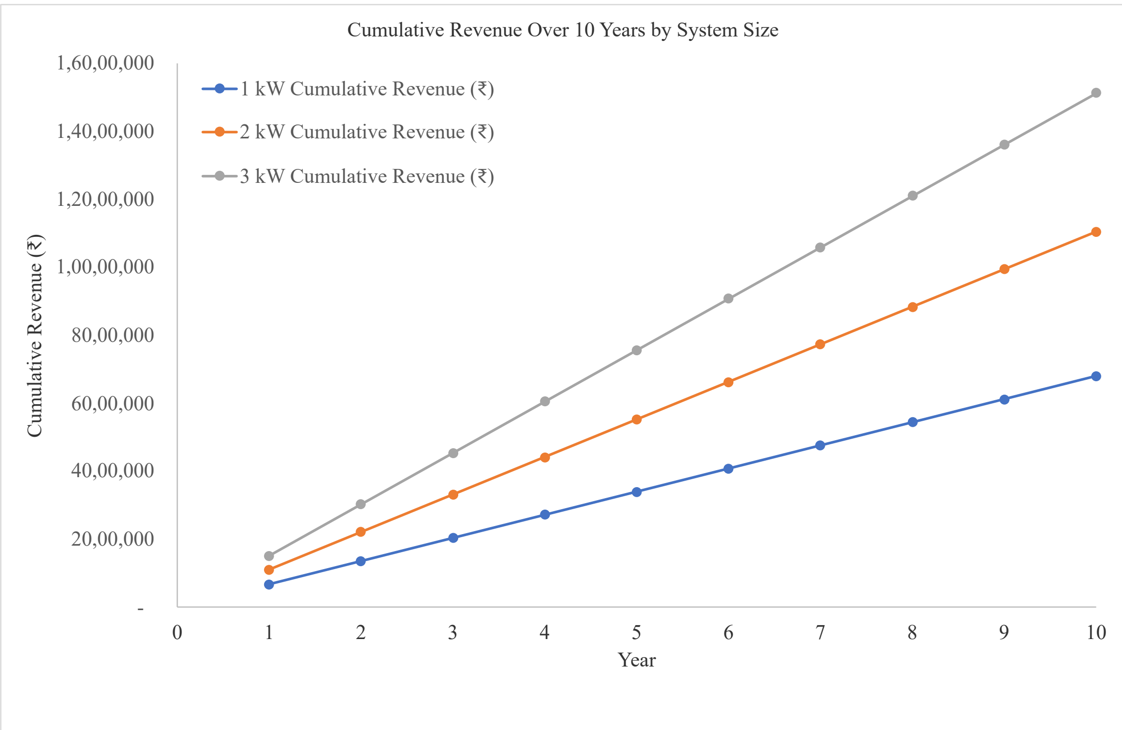

Fig 5.6: Cumulative revenue analysis over 10 years for 1-3 kW RTS systems with a targeted sales volume of 48 units per year

5.4.3 Case study analysis for RTS consumer

Residential household installing a 3 kW RTS system under the PM Surya Ghar scheme.

Table 5.8: Case study - analysis for 3 kW RTS system

Parameter	Value	Remarks
System Size	3 kW	Residential Household
Installation Cost	₹1,61,500	Benchmark Cost
Subsidy Received	₹1,23,000	PM Surya Ghar
Net Cost	₹38,500	Post-Subsidy
Annual Solar Insolation	1,564 kWh/m²/year	For the location (Assam, India)
Performance Ratio	0.75	Accounts for system losses and environmental factors
Annual Energy Generated	3519 kWh/year	3×1564×0.75
Electricity Tariff	7 ₹/kWh	Average residential electricity rate
Energy Savings	₹24,633/year	Annual Energy Generated×Tariff
Payback Period	1.56 Years	Net Cost÷Annual Energy Savings
Lifetime Savings	₹6,15,825	Energy Savings×25 years
Total Energy Generated	87,975 kWh	Annual Energy Generated×25 years
Annual Emission Reduction	2,519 kg CO_2/year	Annual Energy Generated×0.716 kg CO_2/kWh
Lifetime Emission Reduction	62,975 kg CO_2	Annual Emission Reduction×25 years

The analysis of a 3 kW RTS system installed under the PM Surya Ghar scheme for a residential household in Assam highlights the financial and environmental benefits of adopting solar energy. The total installation cost of the system is ₹1,61,500, which is significantly offset by a subsidy of ₹1,23,000 provided under the scheme, reducing the net cost to the consumer to ₹38,500. With an annual solar insolation of 1,564 kWh/m²/year in Assam, the system is expected to generate approximately 3,519 kWh of energy annually, accounting for a performance ratio of 0.75 to consider system losses and environmental factors. At an average residential electricity tariff of ₹7 per kWh, the annual energy savings amount to ₹24,633, leading to a payback period of just 1.56 years, making the investment highly attractive for homeowners. Over its estimated 25-year lifespan, the system is projected to generate a total of 87,975 kWh, resulting in cumulative savings of ₹6,15,825. In addition to financial benefits, the environmental impact is substantial, with an estimated annual CO_2 emissions reduction of

2,519 kg, leading to a lifetime reduction of 62,975 kg CO_2, thereby contributing to climate change mitigation efforts. The case study demonstrates how government incentives, favourable climatic conditions, and financial viability converge to make rooftop solar an economically and environmentally sustainable solution for residential energy needs.

5.4.4 Economic analysis of RTS systems

Levelized Cost of Energy (LCOE)

The Levelized Cost of Electricity (LCOE) is a comprehensive economic metric that quantifies the average cost per unit of electricity generated over the operational lifetime of a solar photovoltaic (PV) system. It provides a holistic assessment by incorporating all relevant cost components, including initial capital expenditures, ongoing operation and maintenance (OandM) costs, and the time value of money through appropriate discounting. LCOE serves as a critical decision-making tool for policymakers, investors, and energy planners to evaluate the cost-effectiveness and competitiveness of solar PV technologies compared to conventional energy sources.

The methodological framework for calculating LCOE is mathematically represented in Eq. 5.5, which integrates both capital and operational expenditures while distributing them across the total energy output over the system's lifetime. This approach enables a standardized comparison of energy generation technologies, facilitating informed decision-making regarding investment feasibility and long-term financial sustainability. Moreover, the LCOE analysis aids in identifying the financial viability of solar PV systems under different economic and technical scenarios, including variations in system size, capacity utilization factor (CUF), and financial incentive structures.

$$LCOE = \frac{\sum_{t=0}^{n}(C_t + O_t + M_t)}{\sum_{t=0}^{n}(E_t)} \tag{5.5}$$

where, C_t is Capital cost at time t; O_t is Operating cost at time t; M_t is Maintenance cost at time t; E_t is Energy generated at time t; n is System lifetime.

Table 5.9: Calculated levelized cost of electricity for 1–10 kW RTS systems

System size (kW)	Capital Cost (₹)	Net present cost (₹)	Present Value of Total Energy (₹)	LCOE (₹/kWh)
1	43,000	47,600.40	12,542.32	3.80
2	51,500	57,000.20	25,084.64	2.27
3	70,000	77,476.00	37,626.96	2.06
4	1,15,500	1,27,834.40	50,169.28	2.55
5	1,80,000	1,99,224.00	62,711.60	3.18
6	2,27,500	2,51,770.00	75,253.92	3.34
7	2,88,000	3,18,758.40	87,796.24	3.63
8	3,43,500	3,80,193.80	1,00,338.56	3.79
9	3,89,000	4,30,553.20	1,12,880.88	3.81
10	4,24,500	4,69,866.60	1,25,423.20	3.75

The LCOE analysis reveals that mid-sized solar PV systems (ranging from 2 kW to 4 kW) offer the most cost-effective electricity generation, with LCOE values ranging from approximately 2.06 ₹/kWh to 2.55 ₹/kWh. Smaller systems like the 1 kW system have a higher LCOE of around 3.80 ₹/kWh, due to the relatively higher capital cost per unit of installed capacity. Conversely, larger systems (5 kW to 10 kW) exhibit higher LCOE values, ranging from 3.18 ₹/kWh to 3.81 ₹/kWh, attributable to their significant capital cost increases without a substantial proportional increase in energy production. These trends underscore the critical role of system size in optimizing the financial feasibility of solar PV installations, as well as the influence of capital cost scaling and performance ratio on the levelized cost of generating electricity. The findings suggest that careful consideration of system size is essential to achieving optimal cost efficiency, with mid-sized systems appearing to offer the best economic advantages in this particular scenario.

Net Present Value (NPV)

The Net Present Value (NPV) is a key financial metric used to evaluate the economic feasibility of solar PV systems by assessing the present value of projected cash flows over the system's lifetime. NPV accounts for the time value of money by discounting future revenues and costs to present terms, providing a measure of investment profitability. The calculation of NPV follows the standard formulation presented in Eq. 4.8 in Chapter 4, incorporating capital costs, operational expenses, and discount rates to determine the financial viability of the proposed solar PV systems.

Table 5.10: NPV analysis for 1–10 kW RTS systems

System size (kW)	Capital cost (₹)	Annual revenue (₹)	Annual OandM (₹)	NPV (₹)
1	43,000	4,109	430	–3,708
2	51,500	8,218	515	30,768
3	70,000	12,327	700	54,186
4	1,15,500	16,436	1,155	47,701
5	1,80,000	20,545	1,800	20,197
6	2,27,500	24,654	2,275	11,508
7	2,88,000	28,763	2,880	–11,570
8	3,43,500	32,872	3,435	–29,113
9	3,89,000	36,981	3,890	–35,588
10	4,24,500	41,090	4,245	–30,995

Under the specified assumptions, the NPV analysis reveals that only the 2 kW through 6 kW systems yield positive NPVs, whereas 1 kW, 7 kW, 8 kW, 9 kW, and 10 kW exhibit negative NPVs. A positive NPV indicates that the present value of future net cash flows (i.e., electricity savings/revenues minus ongoing costs) exceeds the initial capital investment at the chosen discount rate, signifying economic viability. Conversely, the negative NPVs signify that discounted cash flows fall short of recouping the upfront expenditure. These findings highlight the interplay of system size, capital costs, and annual energy yield in determining the financial feasibility of solar PV installations and underscore the importance of accurately estimating both technical parameters (e.g., performance ratio) and financial criteria (e.g., discount rate) when assessing long-term project profitability.

In those scenarios where NPV becomes negative, the discounted value of future net cash flows (i.e., annual electricity revenues minus O&M costs) does not sufficiently exceed the initial capital outlay. Several factors collectively contribute to this outcome. First, the capital cost for certain system sizes escalates more rapidly than the corresponding increase in electricity generation, thus diminishing the net benefit each year. Second, the chosen discount rate (8%) reduces the present value of future income streams, so the annual savings from solar electricity especially if constrained by a moderate performance ratio may fail to offset the upfront expenditure once discounted over 25 years. Third, ongoing O&M costs, even at only 1% of capital cost, still erode the annual profit margin. Taken together, these elements underscore that system size, cost structure, performance levels, and discount rate must be carefully aligned to ensure the present value of anticipated benefits is sufficient to yield a positive NPV.

Payback Period (PBP)

The Payback Period (PBP) is a widely used financial metric that determines the time required to recover the initial investment in a solar photovoltaic (PV) system through accumulated cash inflows generated by energy production. It provides a straightforward measure of investment risk by indicating how quickly the capital expenditure can be recouped under prevailing economic conditions. A shorter payback period signifies a more attractive investment, while a longer payback period may imply higher financial risk and lower investment appeal.

The calculation of PBP is based on the standard formulation outlined in Eq. 4.8 in Chapter 4, which accounts for the initial capital cost and the expected annual revenue generated by the system. This approach allows for a systematic assessment of the financial viability of solar PV installations, offering valuable insights for investors and policymakers in evaluating the attractiveness of solar energy projects in comparison to alternative investment opportunities.

Table 5.11: Simple payback period for 1–10 kW RTS systems

System size (kW)	Capital cost (₹)	Net Benefit (₹)	Simple Payback (years)
1	43,000	3,679	11.69
2	51,500	7,703	6.69
3	70,000	11,627	6.02
4	1,15,500	15,281	7.57
5	1,80,000	18,745	9.6
6	2,27,500	22,379	10.17
7	2,88,000	25,883	11.14
8	3,43,500	29,437	11.67
9	3,89,000	33,091	11.76
10	4,24,500	36,845	11.53

Under the given assumptions and a constant annual energy yield, the shortest simple payback period (approximately 6 years) occurs for the 3 kW system, while the 2 kW and 4 kW systems also recover their costs in a relatively favourable 6.7–7.6 years. In contrast, both the smaller 1 kW system and larger installations above 5 kW exhibit longer payback times, stretching to over 9 or even 11 years. These outcomes underscore how economies of scale, capital-cost jumps at certain capacities, and the absolute annual net benefits (revenues minus O&M) influence the time required to recoup the initial investment. It is worth noting that these calculations do not incorporate discounting; consequently, a discounted payback period, which accounts for the time value of money, would be longer than the simple payback periods reported here.

5.4.5 Overview of GMS business model

The Ground-Mounted Solar Systems (GMS) business model is strategically developed to deploy large-scale solar installations on barren or underutilized land, offering a sustainable solution to scale up solar power generation capacity. This approach aligns with the objectives of the PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) Scheme Component A, which provides a structured framework to facilitate decentralized, grid-connected renewable energy power plants. Under this scheme, farmers can leverage their uncultivable land for solar power plants with capacities ranging from 500 kW to 2 MW, generating consistent income through power purchase agreements (PPAs) with Distribution Companies (DISCOMs). The scheme offers significant financial incentives, including capital subsidies, concessional loans, and tax benefits, which significantly reduce the initial financial burden associated with GMS installations. Implementation is carried out through partnerships between farmers and project developers, where developers provide technical and financial expertise, while farmers contribute land resources. The revenue model revolves around PPAs with pre-determined tariff rates, ensuring predictable cash flows and financial viability for all stakeholders. Furthermore, these solar installations contribute to environmental sustainability by replacing fossil-fuel-based power generation, reducing greenhouse gas emissions, and enhancing rural energy security through decentralized energy production.

A significant extension of the GMS business model is the integration of agrivoltaics, which enables the simultaneous use of land for both solar energy generation and agricultural activities. This model provides a dual benefit by allowing farmers to maintain crop cultivation under solar panels while generating additional income from solar power. Agrivoltaic systems enhance land-use efficiency, as solar panels provide partial shading that can reduce water evaporation and improve microclimatic conditions, potentially enhancing crop yields. The agrivoltaic approach offers a sustainable and economically viable model by optimizing land productivity without compromising agricultural output. Additionally, it contributes to rural economic resilience and supports sustainable agricultural practices, making it an attractive proposition for policymakers and stakeholders aiming to maximize land utilization while ensuring energy security.

The financial and technical assessment of the GMS business model considers four different plant capacities (i) 500 kW, (ii) 1000 kW, (iii) 1500 kW, and (iv) 2000 kW to evaluate the scalability and economic feasibility of such installations. The analysis focuses on key financial performance indicators such as revenue generation, payback period, and land-use efficiency. Revenue analysis examines the income streams derived from power sales under PPA agreements, taking into account variations in plant capacity and tariff structures. The payback period is assessed by factoring in subsidies, operational costs, and revenue inflows to determine the duration required to recover the initial investment. Land-use efficiency is analyzed to assess the optimal utilization of available land across different capacity scenarios, particularly in the context of agrivoltaics applications.

A comprehensive sensitivity analysis is also conducted to evaluate the impact of key parameters on the financial performance of GMS projects. This includes assessing the effect of fluctuations in the capacity utilization factor (CUF), which influences the overall energy output and project viability. The interest rate is analysed to understand its impact on financing costs and profitability, while variations in tariff rates are examined to determine revenue fluctuations under different policy frameworks. These analytical considerations provide a robust evaluation of the GMS business model, ensuring a comprehensive understanding of the risks and opportunities associated with large-scale solar deployment.

The proposed GMS business model, when integrated with the PM-KUSUM scheme and agrivoltaic solutions, presents a transformative opportunity to enhance India's solar capacity while providing socio-economic upliftment to rural communities. Through strategic financial planning, technical optimization, and effective policy implementation, this model can unlock substantial value in terms of energy security, environmental sustainability, and economic resilience. The results of the financial and sensitivity analysis will provide actionable insights for policymakers, investors, and stakeholders to make informed decisions regarding large-scale solar deployment, thereby contributing to India’s broader renewable energy and rural development objectives.

5.4.5.1 Financial feasibility and implementation strategy

Small Solar or Renewable Energy-based Power Plants (REPP) with capacities up to 2 MW can be established by farmers, cooperatives, panchayats, or Farmer Producer Organizations (FPOs) on barren, fallow, marshy, pasture, or cultivable lands. These plants can either be installed by the landowner or leased to a developer, with farmers earning ₹25,000 per acre annually from leasing or up to ₹65,000 per acre annually by self-installation through bank loans under priority sector lending at competitive rates. The central government supports the initiative by providing DISCOMs with an incentive of ₹0.40/kWh or ₹6.6 lakh/MW/year (whichever is lower) for the first five years, ensuring financial viability. To minimize transmission costs, REPPs are recommended to be installed within a 5 km radius of notified substations. Additionally, State Implementation Agencies (SIAs) will receive ₹0.25 lakh/MW post-commissioning as a service charge, further incentivizing implementation. This framework ensures sustainable energy production, promotes farmer income, and supports the renewable energy transition through strategic financial planning and government incentives.

5.4.5.2 Business model for GMS

Cost analysis

The cost analysis of Ground-Mounted Solar (GMS) systems encompasses a detailed evaluation of capital and operational expenditures to determine the financial feasibility and long-term sustainability of such projects.

Table 5.12: Cost breakdown of GMS systems across different capacities

System Capacity (kW)	O&M Cost (₹/year)	Total Cost (₹)
500	3,00,000	2,53,00,000
1000	6,00,000	4,85,00,000
1500	9,00,000	7,20,00,000
2000	12,00,000	9,55,00,000

Revenue streams

The revenue generation potential of Ground-Mounted Solar (GMS) systems is primarily influenced by the system capacity, energy generation efficiency, prevailing tariff rates, and government incentives. The total revenue is derived from the sale of electricity to Distribution Companies (DISCOMs) through long-term Power Purchase Agreements (PPAs), supplemented by financial incentives provided under schemes such as PM-KUSUM Component A, which offers additional monetary support to project developers. The revenue model incorporates the annual energy generation based on the system's capacity and Capacity Utilization Factor (CUF), ensuring that financial returns are aligned with real-world operational conditions. As system capacity increases, both energy output and revenue generation scale proportionally, with higher capacities benefiting from economies of scale and improved financial performance. The inclusion of government incentives further enhances the project's bankability by reducing financial risks and improving overall project viability. The following table provides a detailed breakdown of annual revenue streams for different system capacities, offering valuable insights for stakeholders evaluating the economic feasibility of GMS projects.

Table 5.13: Revenue streams analysis for GMS systems across various capacities

System Capacity (kW)	Energy Generated (kWh/year)	Annual Revenue (₹)	Gov. Incentive (₹)	Total Revenue (₹)
500	7,88,400	27,59,400	3,30,000	30,89,400
1000	15,76,800	55,18,800	6,60,000	61,78,800
1500	23,65,200	82,78,200	9,90,000	92,68,200
2000	31,53,600	1,10,37,600	13,20,000	1,23,57,600

Payback period (PBP)

The payback period is a crucial financial metric that determines the time required to recover the initial investment in Ground-Mounted Solar (GMS) systems through revenue generation. This analysis evaluates the relationship between installation costs and total revenue across varying system capacities, providing insights into the financial viability and return on investment (ROI) of such projects. The installation costs encompass expenditures related to procurement, installation, and commissioning of solar PV systems, while total revenue includes earnings from energy sales and government incentives under the PM-KUSUM Component A scheme. The results indicate that despite the variation in system sizes, the payback period remains consistent at approximately 7.28 years, demonstrating the scalability of the financial model across different capacities. This uniformity in the payback period highlights the economic feasibility of larger installations, which benefit from higher absolute revenue while maintaining similar investment recovery timelines. The following table presents a detailed overview of installation costs, total revenue, and the corresponding payback periods for different system capacities, serving as a valuable reference for investors and policymakers aiming to optimize solar deployment strategies.

Table 5.14: Payback period analysis for GMS systems across different capacities

System Capacity (kW)	Installation Cost (₹ crore)	Total Revenue (₹)	Payback Period (Years)
500	2,25,00,000	30,89,400	7.28
1000	4,50,00,000	61,78,800	7.28
1500	6,75,00,000	92,68,200	7.28
2000	9,00,00,000	1,23,57,600	7.28

Land use efficiency

Land use efficiency is a critical factor in the planning and deployment of GMS systems, particularly in regions where land availability is a constraint. Efficient utilization of land resources ensures that the financial viability of solar projects is optimized while minimizing the ecological footprint. This analysis evaluates the relationship between system capacity, land requirements, and revenue generation, providing a metric of revenue per acre to assess the effectiveness of land utilization. The results indicate a consistent revenue per acre of ₹3,08,940, regardless of the system size, demonstrating that scaling up the installation capacity proportionally increases energy output and financial returns without compromising land efficiency. This consistency highlights the potential for strategic scaling of GMS projects to achieve higher overall financial gains while maintaining sustainable land-use practices. The following table presents a detailed overview of land requirements, total revenue, and revenue per acre across different system capacities, offering insights for stakeholders and policymakers focused on optimizing land allocation for large-scale solar energy deployment.

Table 5.15: Land use efficiency analysis for GMS systems across different capacities

System Capacity (kW)	Land Required (Acres)	Total Revenue (₹)	Revenue Per Acre (₹)

500	10	30,89,400	3,08,940
1000	20	61,78,800	3,08,940
1500	30	92,68,200	3,08,940
2000	40	1,23,57,600	3,08,940

5.4.5.3 Sensitivity analysis

The table below presents a comprehensive sensitivity analysis of the Ground-Mounted Solar (GMS) business model, evaluating the total revenue and payback period across different combinations of interest rates, tariff rates, and capacity utilization factors (CUF). The analysis aims to provide insights into the financial viability of GMS installations under varying economic and technical conditions, offering valuable guidance for investors, policymakers, and project developers.

Table 5.16: Sensitivity analysis of GMS revenue and payback period under varying financial and operational parameters

Interest Rate (%)	Tariff Rate (₹/kWh)	CUF (%)	Total Revenue (₹)	Payback Period (Years)
6	3	16	48,64,800	9.25
6	3	18	53,90,400	8.35
6	3	20	59,16,000	7.61
6	3.5	16	55,65,600	8.08
6	3.5	18	61,78,800	7.28
6	3.5	20	67,92,000	6.63
6	4	16	62,66,400	7.19
6	4	18	69,67,200	6.46
6	4	20	76,68,000	5.87
8	3	16	48,64,800	9.25
8	3	18	53,90,400	8.35
8	3	20	59,16,000	7.61
8	3.5	16	55,65,600	8.08
8	3.5	18	61,78,800	7.28
8	3.5	20	67,92,000	6.63
8	4	16	62,66,400	7.19

8	4	18	69,67,200	6.46
8	4	20	76,68,000	5.87
10	3	16	48,64,800	9.25
10	3	18	53,90,400	8.35
10	3	20	59,16,000	7.61
10	3.5	16	55,65,600	8.08
10	3.5	18	61,78,800	7.28
10	3.5	20	67,92,000	6.63
10	4	16	62,66,400	7.19
10	4	18	69,67,200	6.46
10	4	20	76,68,000	5.87

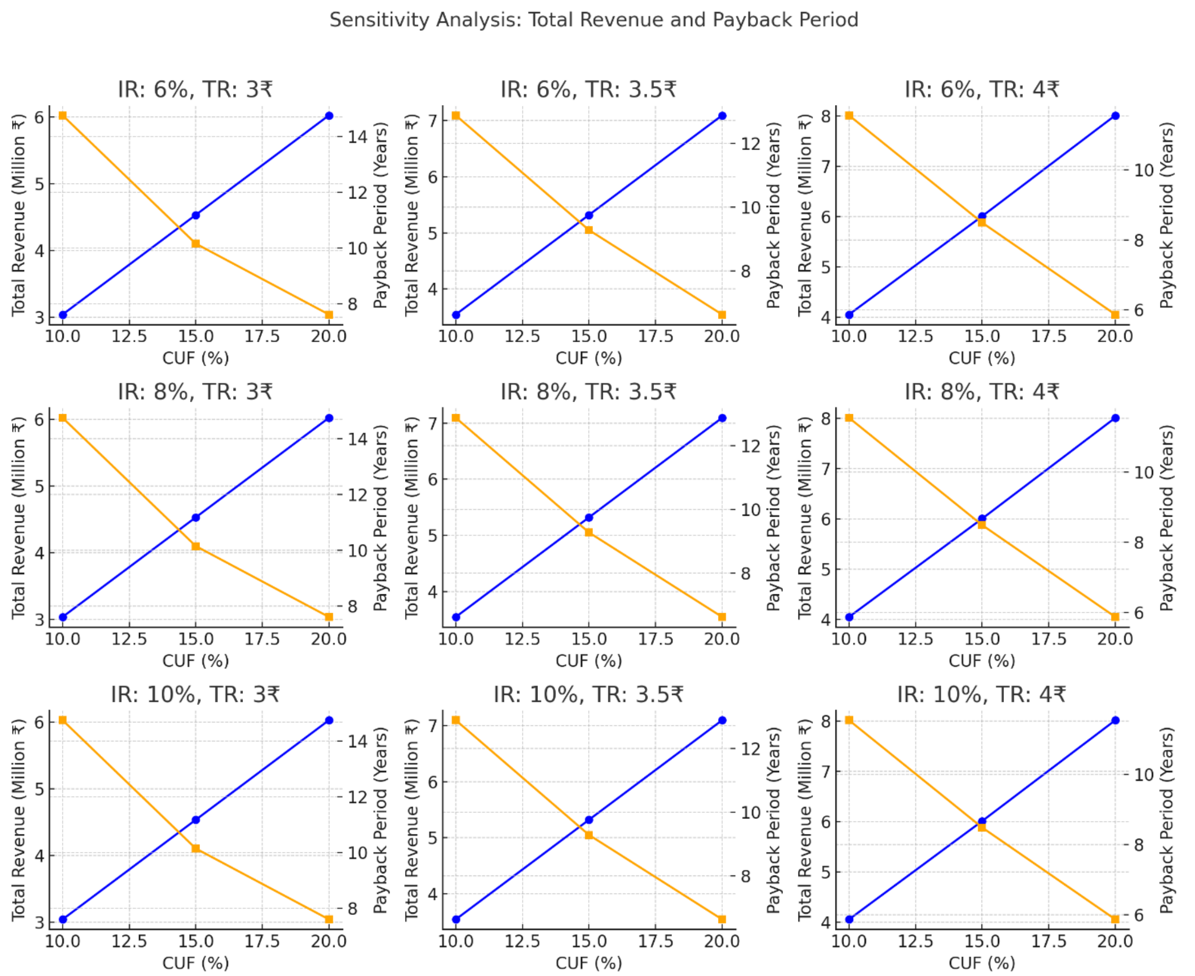

Fig 5.7: Sensitivity analysis of total revenue (Million ₹) and payback period (Years) for GMS systems at varying CUF, interest rates, and tariff rates

The sensitivity analysis evaluates the financial implications of varying key parameters, including interest rates, tariff rates, and capacity utilization factors (CUF), on the economic performance of a 1000 kW Ground-Mounted Solar (GMS) power plant. The analysis incorporates a comprehensive assessment of multiple scenarios, considering interest rates of 6%, 8%, and 10%, tariff rates ranging from ₹3.0 to ₹4.0 per kWh, and CUF values within the range of 10% to 20%. The results reveal substantial variations in total revenue and payback periods across different parameter combinations, underscoring the sensitivity of project financial viability to operational and economic factors.

An increase in the CUF from 10% to 20% leads to a significant reduction in the payback period, decreasing from approximately 14.75 years to 5.87 years, reflecting the direct impact of improved operational efficiency on investment recovery timelines. Additionally, higher tariff rates, such as an increment from ₹3.0 to ₹4.0 per kWh, result in a proportional rise in total revenue, enhancing the economic attractiveness of the project and ensuring greater financial returns over its lifecycle. Conversely, an increase in the interest rate from 6% to 10% extends the payback period, indicating the influence of financing costs on long-term profitability. These findings highlight the critical role of securing concessional financing and optimizing energy generation efficiency to improve project bankability.

The analysis further demonstrates that under favourable tariff structures and optimized CUF values, the revenue generation potential increases substantially, reinforcing the importance of policy interventions that support higher tariff realization and capacity utilization. The results provide valuable insights into the strategic planning of GMS projects, offering a roadmap for stakeholders to align project financing with operational performance targets.

These insights are visually represented through scenario-specific graphical representations, effectively capturing the interplay between interest rates, tariff rates, and CUF. The visualizations illustrate the trade-offs involved in financial planning and provide stakeholders with a data-driven approach to decision-making in the deployment of GMS systems under the PM-KUSUM scheme and similar renewable energy initiatives.

5.5 Summary

This chapter provided a comprehensive analysis of the barriers, enablers, and business models for the large-scale deployment of solar PV systems, with a specific focus on Rooftop Solar

(RTS) and Ground-Mounted Solar (GMS) systems in rural Assam. The study underscored the multi-faceted challenges impeding solar energy adoption, including technical, financial, regulatory, and social barriers, while identifying key enabling factors and proposing innovative business models that align with prevailing government schemes such as PM Surya Ghar and PM-KUSUM Component A. A structured approach was undertaken to evaluate the economic viability, feasibility, and scalability of solar PV systems through rigorous cost-benefit analysis, revenue estimation, and payback period assessments.

The findings revealed that technical barriers, such as spatial constraints, irradiance variability, and structural integrity issues for RTS, as well as land acquisition challenges for GMS, pose significant hurdles to solar PV deployment. From a financial perspective, high initial capital costs, limited access to affordable financing, and uncertainties in return on investment remain major deterrents to widespread adoption. The policy and regulatory landscape, while supportive, presents challenges related to complex subsidy disbursement processes, inconsistent implementation across regions, and the absence of a clear framework for carbon financing mechanisms. Social and cultural factors, including a lack of awareness, resistance to technology adoption, and the absence of local technical expertise, further exacerbate the adoption gap.

Despite these barriers, the study identified several critical enablers that could accelerate solar PV adoption. Government subsidies and incentives, such as capital subsidies and tax benefits under existing schemes, play a pivotal role in reducing the financial burden on end-users and improving affordability. Additionally, advancements in PV technology, including higher efficiency modules, improved storage solutions, and the integration of smart energy management systems, present opportunities to enhance system performance and reliability. The role of financial enablers, such as concessional loans, pay-as-you-go models, and community-based financing initiatives, has been emphasized as essential in bridging the affordability gap and fostering greater participation among rural consumers.

The business models developed in this study considered the perspectives of consumers, vendors, and prosumers, incorporating both financial and operational aspects. For RTS, the analysis focused on cost reduction strategies, revenue generation potential through net metering policies, and financial planning through tariff-based savings. The GMS business model, analyzed under the PM-KUSUM Component A framework, emphasized revenue streams through Power Purchase Agreements (PPAs), government incentives, and potential carbon credit monetization. A detailed financial analysis was conducted for varying system capacities, with sensitivity assessments on key parameters such as tariff rates, interest rates, and Capacity Utilization Factors (CUF). The results demonstrated that optimizing CUF and tariff structures significantly improves the financial feasibility of projects, while competitive financing terms further reduce payback periods and enhance return on investment.

A key takeaway from the analysis is the importance of stakeholder collaboration and capacity-building initiatives to ensure the long-term sustainability of solar PV projects. Engaging local communities through participatory approaches, strengthening institutional support through skill development programs, and leveraging digital platforms for efficient subsidy management are identified as crucial strategies for enhancing adoption rates. The study also emphasized the significance of land-use efficiency, particularly for GMS, where agrivoltaics can provide a dual-use approach that maximizes agricultural productivity while generating clean energy.

To facilitate the scaling of RTS and GMS systems, the study recommends a holistic approach that integrates policy interventions, financial innovations, and technical advancements. Policy frameworks should prioritize simplified approval processes, dynamic tariff structures, and long-term power purchase agreements to de-risk investments and encourage greater participation from private stakeholders. Financial innovations such as green bonds, public-private partnerships (PPPs), and concessional financing, coupled with community-driven business models, can further enhance market penetration. Additionally, advancements in energy storage technologies and grid infrastructure modernization should be pursued to improve grid reliability and facilitate seamless integration of distributed solar energy generation.

In conclusion, the chapter provides actionable insights into the challenges and opportunities for scaling solar PV systems in rural Assam. The proposed business models, financial strategies, and policy recommendations aim to create a conducive ecosystem for achieving national renewable energy targets and fostering economic development in underserved regions. Future research should focus on developing localized deployment strategies, exploring the role of emerging technologies such as blockchain and artificial intelligence (AI) in energy management, and addressing evolving challenges associated with climate variability and energy demand patterns.

References

[1] Yadav, P., Davies, P. J., and Khan, S. Breaking into the photovoltaic energy transition for rural and remote communities: challenging the impact of awareness norms and subsidy schemes. *Clean Technologies and Environmental Policy*, 22:817-834, 2020. DOI: https://doi.org/10.1007/s10098-020-01823-0

[2] Marques Lameirinhas, R. A., Torres, J. P. N., and de Melo Cunha, J. P. A photovoltaic technology review: History, fundamentals and applications. *Energies*, 15(5):1823, 2022. DOI: https://doi.org/10.3390/en15051823

[3] Salim, H. K., Stewart, R. A., Sahin, O., and Dudley, M. Drivers, barriers and enablers to end-of-life management of solar photovoltaic and battery energy storage systems: A systematic literature review. *Journal of cleaner production*, 211:537-554, 2019. DOI: https://doi.org/10.1016/j.jclepro.2018.11.229

[4] Khalid, M. Smart grids and renewable energy systems: Perspectives and grid integration challenges. *Energy Strategy Reviews*, 51:101299, 2024. DOI: https://doi.org/10.1016/j.esr.2024.101299

[5] Umamaheswaran, S., and Rajiv, S. Financing large scale wind and solar projects—A review of emerging experiences in the Indian context. *Renewable and Sustainable Energy Reviews*, 48:166-177, 2015.

[6] Manju, S., and Sagar, N. Progressing towards the development of sustainable energy: A critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India. *Renewable and Sustainable Energy Reviews*, 70:298-313, 2017.

[7] West, J., Bailey, I., and Winter, M. Renewable energy policy and public perceptions of renewable energy: A cultural theory approach. *Energy policy*, 38(10):5739-5748, 2010.

[8] Lamnatou, C., Chemisana, D., and Cristofari, C. Smart grids and smart technologies in relation to photovoltaics, storage systems, buildings and the environment. *Renewable Energy*, 185:1376-1391, 2022. DOI: https://doi.org/10.1016/j.renene.2021.11.019

[9] Matisoff, D. C., and Johnson, E. P. The comparative effectiveness of residential solar incentives. *Energy Policy*, 108:44-54, 2017. DOI: https://doi.org/10.1016/j.enpol.2017.05.032

[10] da Silva, P. P., Dantas, G., Pereira, G. I., Câmara, L., and De Castro, N. J. Photovoltaic distributed generation–An international review on diffusion, support policies, and

electricity sector regulatory adaptation. *Renewable and sustainable energy reviews*, 103, 30-39, 2019. DOI: https://doi.org/10.1016/j.rser.2018.12.028

[11] Prehoda, E., Winkler, R., and Schelly, C. Putting research to action: Integrating collaborative governance and community-engaged research for community solar. *Social Sciences*, 8(1), 11, 2019. DOI: https://doi.org/10.3390/socsci8010011

[12] NASA Prediction of Worldwide Energy Resources (2023). Solar and weather data resources. Retrieved on 25 February, 2024, from https://power.larc.nasa.gov.

[13] International Forum for Environment, Sustainability and Technology (iFOREST). *Assam renewable energy potential re-assessment: Focus on solar, wind, and biomass,* 2024. Saur Energy. https://img.saurenergy.com/2024/03/assam-re-potential-assessment.pdf.

[14] Ibegbulam, M. C., Adeyemi, O. O., and Fogbonjaiye, O. C. Adoption of Solar PV in developing countries: challenges and opportunity. *International Journal of Physical Sciences Research*, *7*(1):36-57, 2023. DOI: https://doi.org/10.37745/10.37745/ijpsr.17/vol6n1114

[15] Shafiullah, M., Ahmed, S. D., and Al-Sulaiman, F. A. Grid integration challenges and solution strategies for solar PV systems: a review. *IEEE Access*, 10:52233-52257, 2022. DOI: https://doi.org/10.1109/ACCESS.2022.3174555

[16] Baurzhan, S., and Jenkins, G. P. Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?. *Renewable and Sustainable Energy Reviews*, 60:1405-1418, 2016. DOI: https://doi.org/10.1016/j.rser.2016.03.016

[17] Gürtürk, M. Economic feasibility of solar power plants based on PV module with levelized cost analysis. *Energy*, 171:866-878, 2019. DOI: https://doi.org/10.1016/j.energy.2019.01.090

[18] Khan, T., Rahman, S. M., and Hasan, M. M. Barriers to growth of renewable energy technology in Bangladesh: case of solar home system in rural regions. In *Proceedings of the International Conference on Computing Advancements*, pages 1-6, Bangladesh 2020.

[19] Kayser, D. Solar photovoltaic projects in China: High investment risks and the need for institutional response. *Applied Energy*, 174:144-152, 2016. DOI: https://doi.org/10.1016/j.apenergy.2016.04.089

[20] Feron, S. Sustainability of off-grid photovoltaic systems for rural electrification in developing countries: A review. *Sustainability*, 8(12):1326, 2016. DOI: https://doi.org/10.3390/su8121326

[21] Tarai, R. K., and Kale, P. Solar PV policy framework of Indian States: Overview, pitfalls, challenges, and improvements. *Renewable Energy Focus*, 26:46-57, 2018. DOI: https://doi.org/10.1016/j.ref.2018.07.001

[22] Lambe, F., Jürisoo, M., Lee, C., and Johnson, O. Can carbon finance transform household energy markets? A review of cookstove projects and programs in Kenya. *Energy Research and Social Science*, 5:55-66, 2015. DOI: https://doi.org/10.1016/j.erss.2014.12.012

[23] Yadav, P., Davies, P. J., and Abdullah, S. Reforming capital subsidy scheme to finance energy transition for the below poverty line communities in rural India. Energy for Sustainable Development, 45:11-27, 2018. DOI: https://doi.org/10.1016/j.esd.2018.04.001

[24] Agupugo, C. P., Ajayi, A. O., Nwanevu, C., and Oladipo, S. S. Policy and regulatory framework supporting renewable energy microgrids and energy storage systems. *Eng. Sci. Technol. J*, 5:2589-2615, 2022. DOI: https://doi.org/10.51594/estj.v5i8.1460

[25] Hafeznia, H., Aslani, A., Anwar, S., and Yousefjamali, M. Analysis of the effectiveness of national renewable energy policies: A case of photovoltaic policies. *Renewable and Sustainable Energy Reviews*, 79:669-680, 2017. DOI: https://doi.org/10.1016/j.rser.2017.05.033

[26] Shukla, A. K., Sudhakar, K., Baredar, P., and Mamat, R. Solar PV and BIPV system: Barrier, challenges and policy recommendation in India. *Renewable and Sustainable Energy Reviews*, 82:3314-3322, 2018. DOI: https://doi.org/10.1016/j.rser.2017.10.013

[27] Joshi, L., Choudhary, D., Kumar, P., Venkateswaran, J., and Solanki, C. S. Does involvement of local community ensure sustained energy access? A critical review of a solar PV technology intervention in rural India. *World Development*, 122:272-281, 2019. DOI: https://doi.org/10.1016/j.worlddev.2019.05.028

[28] Oduro, P., Uzougbo, N. S., and Ugwu, M. C. Renewable energy expansion: Legal strategies for overcoming regulatory barriers and promoting innovation. *International Journal of Applied Research in Social Sciences*, 6(5):927-944, 2024. DOI: https://doi.org/10.30574/wjaets.2024.12.1.0208

[29] Norouzi, F., Hoppe, T., Elizondo, L. R., and Bauer, P. A review of socio-technical barriers to Smart Microgrid development. *Renewable and Sustainable Energy Reviews*, 167:112674, 2022. DOI: https://doi.org/10.1016/j.rser.2022.112674

[30] Lin, B., and Kaewkhunok, S. The role of socio-Culture in the solar power adoption: the inability to reach government policies of marginalized groups. *Renewable and Sustainable Energy Reviews*, 144:111035, 2021. DOI: http://dx.doi.org/10.1016/j.rser.2021.111035

[31] Streimikiene, D., Baležentis, T., Volkov, A., Morkūnas, M., Žičkienė, A., and Streimikis, J. Barriers and drivers of renewable energy penetration in rural areas. *Energies*, 14(20):6452, 2021. DOI: https://doi.org/10.3390/en14206452

[32] Mathew, T. C., and Nagaraja Pandian, S. Unveiling the shadows: a qualitative exploration of barriers to rooftop solar photovoltaic adoption in residential sectors. *Clean Energy*, 8(5):218-228, 2024. DOI: https://doi.org/10.1093/ce/zkae065

[33] Ansari, M. F., Kharb, R. K., Luthra, S., Shimmi, S. L., and Chatterji, S. Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique. *Renewable and sustainable energy reviews*, 27:163-174, 2013. DOI: https://doi.org/10.1016/j.rser.2013.07.002

[34] Ibegbulam, M. C., Adeyemi, O. O., and Fogbonjaiye, O. C. Adoption of Solar PV in developing countries: challenges and opportunity. *International Journal of Physical Sciences Research*, 7(1):36-57, 2023. DOI: http://dx.doi.org/10.37745/10.37745/ijpsr.17/vol7n13657

[35] Das, D., Saikia, S., Saharia, S. J., and Mahapatra, S. Performance analysis of MW-scale grid connected rooftop and ground-mounted solar power plants installed in Assam, India. *Energy for Sustainable Development*, 76:101309, 2023. DOI: http://dx.doi.org/10.1016/j.esd.2023.101309

[36] Garrod, A., and Ghosh, A. A review of bifacial solar photovoltaic applications. *Frontiers in Energy*, 17(6):704-726, 2023. DOI: https://doi.org/10.1007/s11708-023-0903-7

[37] Shi, Y., Berry, J. J., and Zhang, F. Perovskite/silicon tandem solar cells: insights and outlooks. *ACS Energy Letters*, 9(3):1305-1330, 2024. DOI: 10.1021/acsenergylett.4c00172

[38] Shanmugam, N., Pugazhendhi, R., Madurai Elavarasan, R., Kasiviswanathan, P., and Das, N. Anti-reflective coating materials: A holistic review from PV perspective. *Energies*, 13(10):2631, 2020. DOI: https://doi.org/10.3390/en13102631

[39] Choudhury, S. (2022). Review of energy storage system technologies integration to microgrid: Types, control strategies, issues, and future prospects. *Journal of Energy Storage*, 48:103966, 2022. DOI: https://doi.org/10.1016/j.est.2022.103966

[40] Ziegler, M. S., and Trancik, J. E. Re-examining rates of lithium-ion battery technology improvement and cost decline. *Energy and Environmental Science*, 14(4):1635-1651, 2021. DOI: https://doi.org/10.1039/D0EE02681F

[41] Ralon, P., Taylor, M., Ilas, A., Diaz-Bone, H., and Kairies, K. Electricity storage and renewables: Costs and markets to 2030. *International Renewable Energy Agency: Abu Dhabi, United Arab Emirates*, 164*,* 2017.

[42] Kolawole, M. I., and Ayodele, B. L. Smart electronics in solar-powered grid systems for enhanced renewable energy efficiency and reliability, 2024. DOI: http://dx.doi.org/10.30574/ijsra.2024.13.2.2512

[43] Garg, S., and Arun, J. B. (2016). High temperature effect on multicrystalline photovoltaic module in Western Rajasthan, India. *High Temperature*, 4(2):44-48, 2016. DOI: http://dx.doi.org/10.5120/cae2016652055

[44] Dubey, S., Sarvaiya, J. N., and Seshadri, B. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world–a review. *Energy procedia*, 33:311-321, 2013. DOI: http://dx.doi.org/10.1016/j.egypro.2013.05.072

[45] Ghosh, S., Roy, J. N., and Chakraborty, C. Exploring the merits of geographical diversification of solar PV power plants for a resilient PV-dominated electricity grid in India. *Clean Energy*, 7(4):885-910, 2023. DOI: https://doi.org/10.1093/ce/zkad024

[46] Senthil Kumar, J., Charles Raja, S., Srinivasan, D., and Venkatesh, P. Hybrid renewable energy-based distribution system for seasonal load variations. *International Journal of Energy Research*, *42*(3):1066-1087, 2018. DOI: https://doi.org/10.1002/er.3902

[47] Gohain, M., Mahanta, D. K., and Baishya, K. Micro-Hydro and Solar Synergy: A Review of Hybrid Power Solutions for Assam's Energy Challenges. In *2024 6th International Conference on Energy, Power and Environment (ICEPE)*. IEEE, 2024. DOI: https://doi.org/10.1109/ICEPE63236.2024.10668891

[48] Smart platform for promotion of renewable energy in Assam. State Innovation & Transformation Aayog (SITA). Department of Energy, Tezpur University, Assam, 2022.

[49] Groh, S., and Taylor, H. (2015). The role of microfinance in energy access: changing roles, changing paradigms, and future potential. *Enterprise Development and Microfinance*, (4):307-324, 2015. DOI: http://dx.doi.org/10.3362/1755-1986.2015.026

[50] Sarangi, G. K. *Green energy finance in India: Challenges and solutions*. Asian Development Bank Institute. Retrieved on March 22, 2022 from https://www.adb.org/publications/green-energy-finance-india-challenges-and-solutions

[51] International Renewable Energy Agency. 2020. *Pay-as-you-go models: Innovation landscape brief*. International Renewable Energy Agency, Abu Dhabi. Retrieved on October 13, 2023 from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Pay-as-you-go_models_2020.pdf

[52] Kumar, A., and Bhaskar, A. *Rooftop solar PV in India: Looking back, looking ahead*. Climate Investment Funds. Retrieved from https://www.cif.org/sites/cif_enc/files/rooftop_solar_pv_in_india_ctf_pwc._v8pdf_0.pdf

[53] Ministry of New and Renewable Energy. *Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM)*. Government of India. Retrieved on May 06, 2024 from https://mnre.gov.in/en/pradhan-mantri-kisan-urja-suraksha-evam-utthaan-mahabhiyaan-pm-kusum

[54] Ministry of New and Renewable Energy. *Guidelines for PM-Surya Ghar: Muft Bijli Yojana Central Financial Assistance to Residential Consumers*. Government of India. Retrieved on May 08, 2024 from https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2024/07/202407021768035484.pdf

[55] Bose, D., Saini, D. K., Yadav, M., Shrivastava, S., and Parashar, N. Decentralized solar energy access and assessment of performance parameters for rural communities in India. *Sustainability and Climate Change*, 14(2):103-114, 2021. DOI: https://doi.org/10.1089/scc.2020.0050

[56] Rathore, P. K. S., Chauhan, D. S., and Singh, R. P. Decentralized solar rooftop photovoltaic in India: On the path of sustainable energy security. *Renewable energy*, 131:297-307. DOI: https://doi.org/10.1016/j.renene.2018.07.049

[57] Ramírez, F. J., Honrubia-Escribano, A., Gómez-Lázaro, E., and Pham, D. T. Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: Comparative economic assessment and policy implications for European countries. *Energy Policy*, 102:440-452, 2017. DOI: https://doi.org/10.1016/j.enpol.2016.12.040

[58] Thakur, J., and Chakraborty, B. Impact of compensation mechanisms for PV generation on residential consumers and shared net metering model for developing nations: A case study of India. *Journal of cleaner production*, 218:696-707, 2019. DOI: https://doi.org/10.1016/j.jclepro.2019.01.286

[59] Williams, N. J., Jaramillo, P., Taneja, J., and Ustun, T. S. Enabling private sector investment in microgrid-based rural electrification in developing countries: A review. *Renewable and Sustainable Energy Reviews*, 52:1268-1281, 2015. DOI: https://doi.org/10.1016/j.rser.2015.07.153

[60] Cedeno, R. C. B., and Wei, J. Investigating factors to promote energy: Socio-political barriers to renewable energy sector in India. *The Electricity Journal*, 37(2):107366, 2024. DOI: https://doi.org/10.1016/j.tej.2024.107366

[61] Joshi, G., and Yenneti, K. Community solar energy initiatives in India: A pathway for addressing energy poverty and sustainability?. *Energy and Buildings*, 210:109736, 2020. DOI: https://doi.org/10.1016/j.enbuild.2019.109736

[62] Bose, D., Saini, D. K., Yadav, M., Shrivastava, S., and Parashar, N. Review of sustainable grid-independent renewable energy access in remote communities of India. *Integrated Environmental Assessment and Management*, 17(2):364-375, 2021. DOI: https://doi.org/10.1002/ieam.4373

[63] Brooks, C., and Urmee, T. Importance of individual capacity building for successful solar program implementation: A case study in the Philippines. *Renewable energy*, 71:176-184, 2014. DOI: https://doi.org/10.1016/j.renene.2014.05.016

[64] Joshi, L., Choudhary, D., Kumar, P., Venkateswaran, J., and Solanki, C. S. Does involvement of local community ensure sustained energy access? A critical review of

a solar PV technology intervention in rural India. *World Development*, 122:272-281, 2019. DOI: https://doi.org/10.1016/j.worlddev.2019.05.028

[65] Bera, R., Mishra, P., and Patnaik, P. Renewable energy for women empowerment: Experiences from rural West Bengal. *Renewable and Sustainable Energy Reviews*, 198:114446, 2024. DOI: https://doi.org/10.1016/j.rser.2024.114446

[66] Chaurey, A., Krithika, P. R., Palit, D., Rakesh, S., and Sovacool, B. K. New partnerships and business models for facilitating energy access. *Energy policy*, 47:48-55, 2012. DOI: https://doi.org/10.1016/j.enpol.2012.03.031

[67] Urmee, T., and Md, A. Social, cultural and political dimensions of off-grid renewable energy programs in developing countries. *Renewable Energy*, 93:159-167, 2016. DOI: https://doi.org/10.1016/j.renene.2016.02.040

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

[69] Farrukh, A., Ayubi, S., and Sajjad, A. Investigating the barriers and mitigation strategies for biogas adoption in a developing economy: A multi-stakeholder networks perspective. *Process Safety and Environmental Protection*, 188:559-572, 2024. DOI: https://doi.org/10.1016/j.psep.2024.05.104

[70] 1kW Solar Panel System Price in India with Subsidy. Amplus Solar. Retrieved on February 04, 2025, from, https://amplussolar.com/blog/1kw-solar-system-price-in-india-with-subsidy/.

[71] Walker, H., Lockhart, E., Desai, J., Ardani, K., Klise, G., Lavrova, O., Tansy, T., Deot, J., Fox, B., and Pochiraju, A.,. *Model of operation-and-maintenance costs for photovoltaic systems* (No. NREL/TP-5C00-74840). National Renewable Energy Lab.(NREL), Golden, CO (United States), 2020.

[72] Chaudhari, R.H., Chaudhari, B.H., Chavda, P.D., and Aal, V.L. To study the temporal variation of capacity utilization factor (CUF) of PV based solar power plant with respect to climatic condition. *Current World Environment*, 11(2):654, 2016.

[73] Tan, V., Dias, P.R., Chang, N., and Deng, R. Estimating the lifetime of solar photovoltaic modules in Australia. *Sustainability*, 14(9):5336, 2022.

[74] Guno, C. S., & Agaton, C. B. Socio-economic and environmental analyses of solar irrigation systems for sustainable agricultural production. *Sustainability*, 14(11):6834, 2022. DOI: https://doi.org/10.3390/su14116834.

[75] Ouyang, X. and Lin, B. Levelized cost of electricity (LCOE) of renewable energies and required subsidies in China. *Energy policy*, 70:64-73, 2014.

[76] García-Gusano, D., Espegren, K., Lind, A. and Kirkengen, M. The role of the discount rates in energy systems optimisation models. *Renewable and Sustainable Energy Reviews*, 59:56-72, 2016.

[77] Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM Scheme). National Portal of India, Central financial assistance (CFA)/ state government support. Retrieved on 3 May, 2023, from https://www.india.gov.in/spotlight/pm-kusum-pradhan-mantri-kisan-urja-suraksha-evam-utthaan-mahabhiyan-scheme, 2023.

[78] PM Surya Ghar: Muft Bijli Yojana. National Portal. Retrieved on 5 November, 2024, from https://pmsuryaghar.gov.in/#/

[79] Thanawala, H., 2023. FD rates go up: These banks offer up to 8% interest on three-year fixed deposits. Money Control. Retrieved on 25 April, 2023, from, https://www.moneycontrol.com/news/photos/business/personal-finance/fd-rates-go-up-these-banks-offer-up-to-8-interest-on-three-year-fixed-deposits-10300981.html

[80] Central Electricity Authority. CO_2 Baseline Database for the Indian Power Sector, 2024.

[81] Assam Electricity Regulatory Commission (AERC). Retrieved on 5 July, 2024 from, https://aerc.gov.in/orders/1719487800.pdf.

[82] MNRE Standard, Specification & Benchmark Cost. Retrieved on 20 September, 2024 from https://mnre.gov.in/en/solar-standard-specification-benchmark-cost/

[83] Indian Solar Manufacturers Association (ISMA). Retrieved on 21 September, 2024 from https://indiansma.in/

[84] Solar Energy Corporation of India Limited(SECI). Retrieved on 21 September, 2024 from https://www.seci.co.in/

[85] EPC contracts in the solar sector. Retrieved on 21 September, 2024 from https://www.pwc.com/m1/en/blogs/pdf/epc-contracts-in-solar-sector.pdf, 2024.

[86] National Institute of Solar Energy (NISE). Retrieved on 21 September, 2024 from https://nise.res.in/

[87] The Energy and Resources Institute. Retrieved on 21 September, 2024, from https://www.teriin.org/

[88] Supply Chain Issues: Transportation Cost. Retrieved on 21 September, 2024