Exploring Business Models for Decentralised Rooftop Solar in Uttar Pradesh, India: A Focus on Micro-Financing, Public-Private Partnerships, and DISCOM Integration

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Abstract

This paper examines strategic business models to accelerate decentralised rooftop solar adoption in Uttar Pradesh (UP), India—a state with high solar potential but low deployment. Despite India's 11 GW rooftop solar capacity as of 2024, UP contributes less than 7%, highlighting the need for region-specific interventions. Focusing on micro-financing, public-private partnerships (PPPs), and DISCOM integration, the study adopts a policy and management lens, drawing on literature review, stakeholder interviews, and case studies. Micro-financing models leverage Self-Help Groups and MFIs to improve access for low-income users. PPPs facilitate solar deployment in public institutions via BOOT models, Viability Gap Funding, and CSR support. DISCOM integration involves utilities in virtual net metering and digital billing to support grid stability and consumer engagement.

The paper proposes a hybrid framework combining financial innovation, institutional support, and policy alignment. It offers actionable insights for policymakers and practitioners to scale equitable, sustainable solar energy in underserved regions.

Keywords: Decentralised Renewable Energy, Solar Energy, Micro-Financing, Public-Private Partnerships, Sustainability.

1. Introduction

India, as one of the world's fastest-growing economies, is undergoing a rapid and ambitious energy transition to achieve its sustainability, climate, and energy security goals. With a target of installing 500 GW of non-fossil fuel capacity by 2030, as committed under the Paris Agreement, decentralised renewable energy (DRE) solutions, especially rooftop solar photovoltaic (PV) systems, have emerged as vital components of the national energy roadmap (Sethi & Kosmopoulos, 2025). These systems offer transformative potential by addressing chronic power shortages, improving energy access in underserved regions, and reducing dependence on centralised fossil-based power generation (Minas et al., 2024). In this context, Uttar Pradesh (UP)—India's most populous state with over 240 million residents, accounting for nearly 17% of the national population—presents both a compelling opportunity and a policy challenge (Singh et al., 2025). Despite the state's high solar insolation levels, averaging 5.5–6.0 kWh/m²/day, and a technical rooftop solar potential of 11 GWp, actual adoption remains strikingly low (Akter & Bagchi, 2021). As of December 2023, UP had installed only 550 MW of grid-connected rooftop solar, representing less than 5% of India's cumulative rooftop capacity (*NEP_2022_32_FINAL_GAZETTE-1*, n.d.). This underperformance stands in stark contrast to both the state's potential and the urgency of achieving distributed energy equity which is broadly illustrated in Figure.1 below.

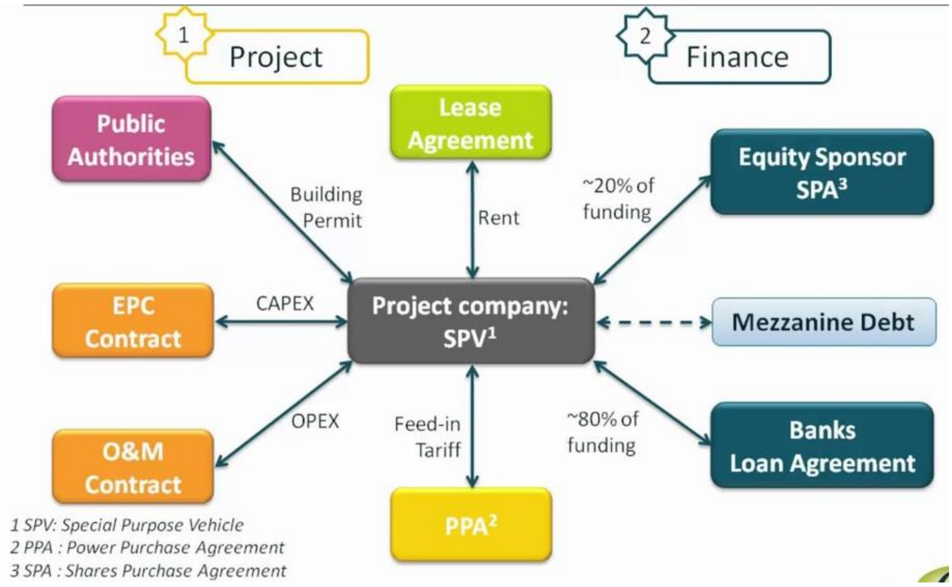

Figure 1: Project finance stakeholder's overview

The broader solar trajectory in UP, however, shows promise. Solar power capacity in the state grew from 288 MW in 2017 to 4,230 MW by March 2025, with an ambitious target of reaching 22,000 MW by 2026–27 under the Uttar Pradesh Solar Energy Policy – 2022 (*Uttar-Pradesh-Significant_220324*, n.d.). Yet, the bulk of this growth has been in large-scale solar parks, with decentralised rooftop adoption lagging due to persistent barriers such as high upfront costs, fragmented financing mechanisms, institutional inertia, and DISCOM reluctance. Electricity reliability continues to be a pressing issue in UP, particularly in rural and peri-urban regions, where consumers face frequent outages, voltage fluctuations, and poor service quality (Perera et al., 2021). In such areas, decentralised solar systems can provide both primary and backup energy for critical uses—ranging from lighting and refrigeration to agricultural water pumping and mobile charging (Dhingra et al., 2023). Rooftop solar is not just a clean energy solution but a socio-economic enabler. A simple solar plant is illustrated as given below in Figure 2.

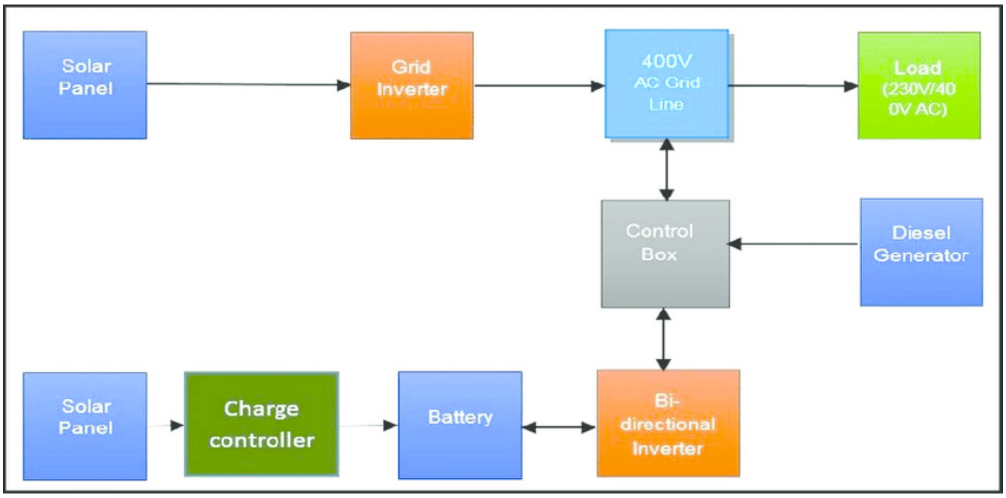

Figure 2. Solar power plant operation

This paper posits that the key to unlocking rooftop solar adoption in UP lies in context-specific, stakeholder-aligned business models that are financially viable, institutionally supported, and socially inclusive. Specifically, it investigates three scalable models:

1. Micro-Financing: Leveraging Self-Help Groups (SHGs), Microfinance Institutions (MFIs), and pay-as-you-go (PAYG) models to overcome capital barriers and enable low-income households to invest in solar systems.

2. Public-Private Partnerships (PPPs): Facilitating deployment in public and semi-public spaces via Build-Own-Operate-Transfer (BOOT) models, Viability Gap Funding (VGF), and CSR-backed infrastructure.

3. DISCOM Integration: Aligning utility operations with decentralised generation through net metering, virtual net metering, demand aggregation, and digital billing platforms.

Through detailed case studies from Lucknow, Varanasi, and Gorakhpur, this study evaluates the operational, financial, and socio-political dimensions of each model. It further draws insights from existing initiatives like the Saur Urja Yojana, which offers capital subsidies but suffers from fragmented implementation. The objective is to develop an integrated business framework that can guide policymakers, DISCOMs, developers, and community stakeholders in scaling rooftop solar solutions in one of India's most energy-challenged states.

2. Literature Review

The potential of decentralised solar energy in India has garnered significant scholarly and policy attention over the past decade, particularly as a dual response to climate imperatives and energy poverty. Decentralised renewable energy (DRE) systems, especially rooftop solar PV, are increasingly recognised as key instruments in achieving inclusive, sustainable electrification. Despite notable advancements, deployment across Indian states remains uneven. India's rooftop solar capacity reached approximately 11.08 GW by the end of 2023, yet Uttar Pradesh (UP) contributed less than 7%—highlighting a stark underutilisation relative to its population and solar potential (Matcha & T R, 2024). Researchers have repeatedly underscored the importance of finance, policy clarity, stakeholder coordination, consumer awareness, and technical capacity as critical determinants of rooftop solar adoption (Ashok et al., 2018; Das, 2021; Mandal & Singh, 2017). These dimensions are particularly sensitive to regional socio-economic contexts and institutional readiness. Bhatia and Angelou (2015), through the Multi-Tier Framework (MTF) developed under the World Bank's "Beyond Connections" initiative, expanded the concept of energy access to encompass affordability, reliability, and quality. They emphasized the relevance of micro-financing and pay-as-you-go (PAYG) models to overcome financial constraints in low-income households—a recurring theme in the literature.

GIZ and TERI (2021) explored Public-Private Partnerships (PPPs) in states like Gujarat and Rajasthan, revealing the success of BOOT and Viability Gap Funding (VGF) models in accelerating community-scale rooftop solar projects. Their findings underscored that successful PPPs rely on transparent contracts, efficient public-private coordination, and policy alignment—all of which are inconsistently present in UP. Utility engagement has also been identified as a pivotal factor. Brookings India (2019) critiqued India's DISCOMs, suggesting that without incentives for grid integration and technical modernization, utilities would remain reluctant to support rooftop solar due to revenue loss concerns. These insights directly apply to UP's energy ecosystem, where DISCOMs face deep financial and operational challenges.

(Purohit et al., 2024) identified five systemic barriers to rooftop adoption: high upfront costs, low awareness, limited access to credit, inconsistent net metering, and minimal DISCOM cooperation. The main thrust while national programs such as PM-KUSUM have helped, localised business models are essential to reach the last mile in states like UP. (TERI, n.d.) extended the conversation by highlighting the socio-economic co-benefits of decentralised energy, particularly in boosting rural livelihoods and supporting micro-enterprises. The study emphasized that interventions must be user-centric and include robust post-installation support.

Additional studies such as UPNEDA's State Solar Policy, (Renewable Energy Agency, 2024), on the socio-economic impacts in rural UP, further reinforce the need for integrated, scalable, and equitable models. However, a persistent gap in the literature lies in granular, state-specific analyses tailored to complex regions like UP. While states such as Karnataka and Maharashtra have developed replicable frameworks, UP's unique socio-economic, bureaucratic, and infrastructural challenges remain underexplored. Studies have called for cross-sectoral linkages between energy, gender empowerment, and digital inclusion, yet these remain under-prioritized in UP's solar discourse.

This paper aims to address these gaps by evaluating three business models—Micro-Financing, PPPs, and DISCOM Integration—through case studies in UP, offering practical insights for replication across other underperforming states.

3. Methodology

This study employs a mixed-methods approach to evaluate the feasibility, scalability, and socio-economic impact of three decentralised solar business models—Micro-Financing, Public-Private Partnerships (PPPs), and DISCOM Integration—in the state of Uttar Pradesh (UP). Given the complex interplay of policy, institutional, and consumer dynamics in decentralised renewable energy (DRE) adoption, a combination of quantitative data analysis, field-based case studies, and stakeholder interviews was deemed appropriate to capture both breadth and depth.

3.1. Research Design

The research followed a comparative case study design, focusing on three urban and peri-urban districts in UP: Lucknow, Varanasi, and Gorakhpur. These districts were selected based on diversity in electricity access, demographic composition, and prior rooftop solar activity under

UPNEDA programs. The objective was to explore how local socio-economic and infrastructural factors influence the operationalization of business models for rooftop solar.

3.2. Data Sources and Collection

a. Secondary Data Analysis

Secondary data was sourced from:

- UPNEDA's solar project database (2022–2024)
- MNRE and IREDA reports (2021–2023)
- India's national and state solar policies
- Employment and capacity statistics from IRENA and the Ministry of Statistics and Programme Implementation (MoSPI) These data sources were used to benchmark UP's progress relative to national and state-level solar targets, and to estimate the technical and financial viability of the selected business models.

b. Primary Data Collection

Primary data was collected using:

- Semi-structured interviews with 38 stakeholders, including:
    - Residential and institutional consumers
    - Microfinance institutions (MFIs)
    - Energy service companies (ESCOs)
    - DISCOM officials
    - UPNEDA officers
    - Solar developers
- Focus group discussions (FGDs) with local communities and SHGs to assess household-level perceptions, adoption barriers, and gender impacts.
- On-site project observations and documentation of 12 rooftop installations under varying financing and implementation schemes.

3.3. Analytical Framework

The data analysis was guided by an Integrated Energy Access Model, adapted from Bhatia and Angelou's Multi-Tier Framework, with custom metrics for:

- Affordability (cost-to-income ratio)
- Reliability (downtime, outage frequency)
- Institutional viability (CAPEX, OPEX recovery, payback period)
- User satisfaction (via Likert-scale surveys)
- Socio-economic impact (livelihood enhancement, gender inclusion)

The study acknowledges limitations in generalizability due to the small geographic scope. Also, some financial and performance data were self-reported and may carry response biases. Nonetheless, by combining multiple data streams and ground-truthing with stakeholders, the study maintains high contextual relevance. This methodology enables a holistic evaluation of how decentralised solar models perform in Uttar Pradesh and provides actionable insights for replication in other underserved regions. Three solar rooftop projects were selected as in-depth case studies to assess on-ground realities. The field investigation covered three diverse decentralised solar projects in Uttar Pradesh, each illustrating a unique implementation model. In Lucknow, a 100-kWp rooftop solar installation was commissioned in 2022 on a government building through collaboration between UPNEDA, the Public Works Department (PWD), and the local DISCOM. This project is notable for its seamless integration with net metering infrastructure and strong adherence to state policy frameworks. In Varanasi, a larger 250 kW system was commissioned in 2021 on the campus of IIT-BHU, spearheaded by a private EPC contractor in partnership with the institution. The installation features a research-led design with a hybrid solar-plus-storage configuration, enabling energy optimization and academic research. Meanwhile, in Gorakhpur, a 60 kWp residential solar cluster was developed in 2023 through cooperation between Resident Welfare Associations (RWAs), women-led Self-Help Groups (SHGs), and private developers. This community-owned model stands out for its social inclusion and grassroots coordination, particularly the active leadership of women in planning and implementation.

The study focuses on three distinct business models—Micro-Financing, Public-Private Partnerships (PPPs), and DISCOM Integration—each addressing specific barriers to decentralised rooftop solar adoption in Uttar Pradesh.

1. Micro-Financing Models are designed to tackle the affordability challenge faced by low-income households and small businesses. These models leverage partnerships with Self-Help Groups (SHGs), Microfinance Institutions (MFIs), and cooperatives to offer lease-to-own or pay-as-you-go (PAYG) financing structures. Such approaches allow users to install rooftop solar systems with minimal upfront investment and repay through manageable, usage-aligned instalments. In districts with active SHG networks, repayment rates have exceeded 90%, demonstrating both financial viability and community buy-in.
2. Public-Private Partnerships (PPPs) harness the strengths of both the private and public sectors to facilitate large-scale rooftop deployments on public infrastructure. This model includes arrangements like Build-Own-Operate-Transfer (BOOT), Viability Gap Funding (VGF), and CSR-backed funding. PPPs have been effective in installing systems on schools, hospitals, and administrative buildings, reducing public energy expenditure while creating demonstration effects for wider adoption.
3. DISCOM Integration models engage power distribution companies directly in the deployment and management of rooftop solar systems. By using mechanisms such as virtual net metering, demand aggregation, and digital billing platforms, these models help maintain grid stability while encouraging decentralised generation. DISCOMs can play a pivotal role in streamlining approvals, aggregating demand, and offering long-term maintenance contracts, as seen in pilot projects by Purvanchal Vidyut Vitaran Nigam Ltd.

4. Case Studies in Uttar Pradesh

4.1 Lucknow – SHG-Driven Microfinancing Model: In Lucknow, a decentralized solar project piloted in 2022 demonstrated the transformative potential of microfinancing through community-based models. A total of 100 rural households were equipped with 2 kW rooftop solar systems under a partnership involving a local Microfinance Institution (MFI), a grassroots Non-Governmental Organization (NGO), and a certified solar technology vendor. The project followed a lease-to-own financing model with repayments structured over a five-year period.

Empirical data from the field revealed that households reported an average monthly saving of INR 500 on electricity expenditures, which they redirected toward essential needs like education and healthcare. Impressively, the loan repayment rate stood at 94%, indicating strong community ownership and financial discipline. The use of Self-Help Groups (SHGs) as facilitators proved especially effective, with women playing a pivotal role in awareness building, system maintenance, and repayment tracking. This model underscored the potential of gender-inclusive financial structures in expanding energy access.

4.2 Varanasi – PPP Model on Public Buildings: Varanasi implemented a large-scale Public-Private Partnership (PPP) model for rooftop solar deployment across public buildings in 2021. The project targeted schools, hospitals, and administrative offices, installing a cumulative capacity of 1 MW. Key stakeholders included the Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA), Tata Power Solar as the execution partner, and a corporate entity that provided CSR funding for initial capital costs.

The impact has been multifaceted. First, the project has generated 1.3 GWh of clean energy annually, significantly reducing reliance on grid power. Second, it has contributed to an estimated reduction of 1,100 tons of CO_2 emissions per year, aligning with India's climate commitments under the Paris Agreement. Importantly, these installations also serve as educational tools for students and community members, fostering broader awareness and acceptance of solar technology. The success of this initiative provides a scalable model for institutional solar adoption under structured PPP frameworks.

4.3 Gorakhpur – DISCOM-led Virtual Net Metering Model: In Gorakhpur, the deployment of rooftop solar systems across three apartment complexes in 2023 showcased the feasibility and efficiency of DISCOM-led virtual net metering (VNM). This project was facilitated by the PVVNL. in collaboration with certified local contractors. Under the VNM model, power generated from rooftop systems is credited proportionally to each flat owner’s electricity account, eliminating the need for individual meters.

The results have been substantial. Households reported an annual reduction of INR 8,000 in electricity bills, enhancing affordability and reducing energy-related financial stress. Additionally, the project contributed to a 15% reduction in peak-hour grid load, improving supply reliability and grid stability during high-demand periods. This model demonstrates how DISCOMs can play a proactive role in integrating decentralised solar solutions while ensuring financial and operational benefits for all stakeholders. Together, these case studies illustrate the diverse yet converging paths through which Uttar Pradesh can accelerate decentralised solar adoption by tailoring business models to specific socio-economic contexts.

5. Comparative Analysis of Business Models

The three business models—Microfinancing via SHGs, Public-Private Partnerships (PPPs), and DISCOM-led Virtual Net Metering (VNM)—each offer distinct pathways for accelerating rooftop solar adoption in Uttar Pradesh. A comparative assessment of these models reveals insights into their financial sustainability, institutional alignment, scalability, and socio-economic impact.

5.1. Financial Viability and Consumer Affordability

- SHG-driven microfinancing in Lucknow showed strong repayment behavior (94%) and meaningful household savings (INR 500/month). By leveraging local MFIs and NGOs, the model significantly reduced the upfront cost barrier and allowed low-income users to access clean energy through small, manageable repayments.
- PPP models, as seen in Varanasi, required minimal user-level financial contribution due to CSR funding and public-sector backing. This model is financially robust for institutions, but not easily replicable for residential consumers without external funding.
- The DISCOM-led VNM model in Gorakhpur offered substantial annual bill savings (INR 8,000/household) yet required higher upfront investment and more regulatory coordination. Affordability is strong once systems are installed, but initial costs and policy clarity remain challenges.

5.2. Institutional and Stakeholder Alignment

- The PPP model showcased the best alignment among stakeholders—UPNEDA, Tata Power, and CSR funders—with clear roles, streamlined contracts, and project oversight. This clarity enabled timely implementation and operational efficiency.
- Microfinancing models, while grassroots-driven and inclusive, faced moderate challenges with technical support and long-term system maintenance. However, their community-led structure fostered ownership and trust.

- In contrast, the VNM model faced hurdles in regulatory clarity and approval delays. However, its direct integration with DISCOMs positioned it as a promising model for long-term grid-compatible deployment.

5.3. Scalability and Replicability

- SHG microfinancing is highly replicable in rural and peri-urban areas, particularly in states with strong MFI or SHG networks. However, scaling this model requires standardised loan products, training, and vendor partnerships.
- PPP models offer high scalability for institutional buildings but are dependent on sustained CSR or public funding and effective public procurement processes. Their replication in weaker institutional environments (e.g., smaller towns) is limited.
- The DISCOM-led VNM model has high scalability potential in urban residential sectors where DISCOMs are willing to innovate. This model could be integrated into smart grid planning but depends heavily on DISCOM capacity and regulatory backing.

5.4. Socio-economic and Environmental Outcomes

- SHG-based microfinancing models contribute significantly to women's empowerment, community cohesion, and energy equity.
- PPPs deliver strong institutional energy savings, carbon reduction, and public awareness, with limited direct social impact on low-income households.
- VNM models improve grid efficiency, consumer autonomy, and load management, but lack direct community development components unless bundled with awareness and service initiatives.

6. Conclusion

This study explores the transformative potential of decentralized rooftop solar (DRTS) systems in Uttar Pradesh by evaluating three tailored business models: SHG-based microfinancing, public-private partnerships (PPPs), and DISCOM-led virtual net metering (VNM). The SHG model, effective in rural areas, promotes inclusive adoption via local MFIs and NGOs, though its success hinges on technical support and maintenance. The PPP model, demonstrated in Varanasi, efficiently leverages public infrastructure and private capital but remains limited to institutional settings due to high initial costs and CSR funding dependency. Meanwhile, the DISCOM-led VNM model enables urban solar integration and consumer bill savings, but its scalability depends on DISCOM innovation and supportive regulation. Findings suggest that a hybrid model integrating financial, institutional, and technical innovations offers the most robust pathway for DRTS adoption. This approach addresses affordability, policy alignment, and infrastructure constraints—bridging UP's solar potential with deployment—while supporting India's clean energy goals and socio-economic equity.

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