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India's Renewable Energy Transition: Evaluating Sustainable Solar Sector Growth, Governance, and Future Prospects

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Abstract:

India's solar sector has undergone rapid expansion over the past decade, emerging as a central pillar of the country's clean energy transition. With cumulative installed capacity reaching 116.25 GW by mid-2025, solar power now constitutes the largest share of India's renewable energy portfolio. This paper examines the policy architecture, growth trajectory, state-level performance, and structural challenges shaping India's solar expansion. It evaluates the role of institutional initiatives such as the 'National Solar Mission' and industrial measures including domestic manufacturing incentives in strengthening the sector. The analysis also highlights financial constraints, grid integration gaps, land acquisition complexities, and regional disparities that influence implementation outcomes. By situating solar development within the broader goals of sustainability, 'Viksit Bharat', and global climate commitments, the study argues that India's solar transition represents both an economic opportunity and a governance challenge requiring coordinated policy reform and long-term institutional capacity building.

Key Words: Solar Energy, Renewable Energy Sustainability, SDG

Introduction:

India's expansion of solar energy has become central to its broader development vision, including the aspiration of achieving Viksit Bharat by 2047. Rising energy demand, climate variability, and pressure on agricultural resources have compelled a shift toward cleaner and more decentralised power systems. Solar energy offers a practical route to reduce fossil fuel dependence while strengthening energy access in rural and urban regions. In agriculture, where irrigation remains closely tied to subsidised electricity and diesel use, solarisation can lower production costs and improve income stability for farmers. At the national level, it contributes directly to sustainability goals and supports India's commitments under the 'Sustainable Development Goals (SDGs), particularly affordable and clean energy, climate action, and responsible resource use. The expansion of domestic solar manufacturing under initiatives such as Make in India has further linked renewable deployment with industrial growth and employment generation. Emerging start-ups are also reshaping service delivery through innovative financing, digital monitoring, and decentralised maintenance models. Yet progress is uneven across states, and concerns remain regarding grid readiness, groundwater use, and financial viability. India's solar journey therefore

reflects both technological advancement and the continuing challenge of building institutions capable of sustaining long-term transformation.

Growth Trajectory and Policy Architecture of India's Solar Sector:

It is essential to situate India's solar expansion within its institutional and developmental context. Over the past decade, solar power has transitioned from a niche renewable option to a dominant contributor within the national energy mix. As of June 2025, India's installed solar capacity reached 116.25 GW, representing the largest share of the country's 234 GW renewable energy portfolio. This rapid growth reflects structured policy planning, competitive procurement mechanisms, and steady cost reductions in photovoltaic technology. The launch of the 'National Solar Mission (2010)' marked a turning point by establishing phased capacity targets and providing fiscal incentives to reduce investor risk. Successive policy measures, including solar park development and programs like PM Surya Ghar Muft Bijli Yojna, PM KUSUM, strengthened institutional confidence. Competitive reverse auctions significantly reduced tariffs, making solar electricity cheaper than coal in several states such as Rajasthan, Gujarat, and Karnataka. India now ranks among the leading global solar markets alongside China and the United States.

The composition of installed capacity highlights the sector's structural depth. Ground mounted solar plants account for 89.29 GW, grid connected rooftop systems contribute 18.84 GW, off grid installations provide 5.05 GW, and hybrid projects add 3.06 GW. While utility scale projects dominate capacity additions, decentralised solutions are expanding in rural and urban regions, supporting households, irrigation systems, and small enterprises. The national target of achieving 500 GW of renewable energy capacity by 2030, including 280 GW from solar, reflects long term policy continuity and commitment to sustainability. This ambition is closely tied to the vision of Viksit Bharat, which emphasises economic strength, technological capability, and environmental responsibility. Solar expansion contributes directly to 'Sustainable Development Goals (SDGs)' related to affordable energy, climate action, and sustainable industrialisation.

Industrial policy has also become central to solar growth. The 'Production Linked Incentive (PLI)' scheme promotes domestic manufacturing of solar modules and cells under the 'Make in India' initiative, reducing import dependence and strengthening supply chains. At the same time, start-ups are entering the sector with innovations in storage integration, digital performance monitoring, and decentralised service delivery models. Together, these developments indicate that India's solar expansion is not limited to capacity addition but represents a broader transformation of energy governance, industrial development, and sustainable growth strategy.

India's Solar Sector: Key Data at a Glance (June 2025)	
Metric / Milestone	**Figure / Status**
Installed Solar Capacity	116.25 GW
Ground Mounted Solar Plant	89.29 GW
Grid Connected Solar Rooftop	18.84 GW
Off-Grid Solar	5.05 GW
Hybrid Projects(Solar Component)	3.06 GW
Renewable Energy Target for 2030	500 GW (including 280 GW solar)
Year National Solar Mission Launched	2010
Leading Solar States	Rajasthan, Gujarat, Karnataka
Falling Solar Tariffs	Cheaper than coal in several regions
Emerging Innovations	Floating solar, agrivoltaics, hybrids
Policy Support	PLI for manufacturing, solar parks, etc.
Global Standing in Solar Deployment	Among top 5 globally
Cost Trend	Cheaper than coal in many areas
Key Government Incentive	Production-Linked Incentive (PLI)

Source: Compiled by Author from various source

Structural and Institutional Constraints in India's Solar Expansion:

While India's solar sector has achieved rapid capacity growth and policy momentum, the expansion process remains shaped by several structural and institutional constraints. The transition from target setting to sustained implementation requires robust financial systems, reliable grid infrastructure, transparent regulatory practices, and coordinated action across central and state agencies. Few of the constraints are discussed briefly-

- Access to affordable finance remains a critical concern. Large utility-scale projects have attracted international capital due to predictable revenue streams and sovereign-backed frameworks. However, small and medium developers often encounter high domestic interest rates, shorter loan tenures, and strict collateral conditions. These factors increase capital costs and extend payback periods. Payment delays from state distribution companies and instances of renegotiated power

purchase agreements in certain states have further introduced regulatory uncertainty, affecting investor confidence.

- Land acquisition presents another significant constraint. Utility-scale solar parks require large contiguous land parcels, which are difficult to assemble in regions marked by fragmented ownership patterns and competing agricultural uses. Disputes, local resistance, and lengthy approval processes add to project timelines and transaction costs. In some cases, concerns about ecological impact and livelihood displacement have also surfaced, requiring more transparent compensation and consultation mechanisms.

- Grid infrastructure has not expanded at the same pace as generation capacity. States such as Rajasthan have experienced instances of solar curtailment due to transmission bottlenecks and limited storage facilities. The growing share of variable renewable energy demands investment in transmission corridors, grid-scale storage, and digital load management systems. Without such upgrades, installed capacity may not translate into reliable supply.

- Regional disparities are equally visible. While Gujarat and Karnataka have created relatively predictable policy environments, other states lag in procedural efficiency and grid preparedness. Reducing these disparities is essential to avoid overconcentration of solar projects in a few high-resource regions.

- Industrial capacity also requires sustained attention. The 'Production Linked Incentive' scheme has strengthened domestic manufacturing under the Make in India initiative, yet dependence on imported components persists. Greater supply chain integration and technology development are necessary to shield the sector from global price volatility and geopolitical risk.

Long-Term Sustainability and Global Leadership:

India now stands at a critical juncture where its solar strategy can shape both domestic development and international climate engagement. As one of the world's largest carbon emitters and a rapidly growing economy, the country faces the dual responsibility of expanding energy access while limiting emissions growth. Experiences from China demonstrate the benefits of early manufacturing investments, while the United States and the European Union illustrate the importance of grid modernization and market flexibility in managing high renewable penetration. India's leadership in establishing the 'International Solar Alliance' reflects its intention to extend solar cooperation to other developing countries. Strengthening research in next-generation photovoltaic technologies, battery storage, and digital grid solutions will be crucial for sustaining competitiveness. Public-private partnerships and green financing instruments such as climate bonds can mobilize additional capital, while targeted skill development programs can build a workforce capable of managing advanced renewable systems.

Solar expansion also presents an opportunity to integrate climate action with inclusive development. Agri-voltaic systems can supplement farm income, and decentralised solar micro-grids can enhance energy reliability in rural regions. Urban rooftop programs can help cities address rising demand without increasing local pollution. These approaches contribute not only to emission reduction but also to employment creation and regional equity. In the context of the broader national aspiration of Viksit Bharat, solar growth is intertwined with industrial capability, technological self-reliance, and environmental stewardship. The path forward requires stable regulation, institutional coordination, and sustained investment in innovation. If these elements

are maintained, India's solar expansion can serve as a model for emerging economies seeking growth pathways that are economically viable and environmentally responsible.

Conclusion:

India's solar expansion reflects a significant transformation in its energy landscape, driven by consistent policy support, falling technology costs, and growing investor participation. The progress achieved in installed capacity demonstrates the feasibility of large-scale renewable deployment in a diverse federal system. However, sustaining momentum requires addressing structural bottlenecks related to finance, land, grid modernization, and regulatory certainty. Regional disparities in implementation underscore the importance of strengthening state-level institutions and infrastructure. Domestic manufacturing initiatives and innovation ecosystems must continue to evolve to reduce import dependence and enhance resilience. Solar energy also holds potential for inclusive development through decentralised applications that support rural livelihoods and energy access. If institutional reforms keep pace with technological growth, India can consolidate its position as a leading solar market while advancing economic development and climate responsibility in a balanced and sustainable manner.

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