



Solar Energy and Climate Change Mitigation in Rajasthan: Policy, Practice, and Future Prospects

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Abstract

Owing to its consistent sunshine, Rajasthan is positioning itself as a leading region where solar energy significantly aids in climate resilience efforts. This research examines how government policies, vast solar installations, and localized power solutions contribute to climate change mitigation. Despite rapid advancements, critical issues like storage inadequacies, land access disputes, and environmental sensitivities continue to hinder seamless solar adoption, challenges remain — including land acquisition issues, lack of storage, and socio-environmental concerns. The paper concludes with policy recommendations for sustainable solar expansion, emphasizing inclusive growth, technological innovation, and long-term resilience.

Keywords

Solar Energy, Rajasthan, Climate Change Mitigation, Renewable Policy, Sustainable Development, Green Energy, India, Solar Parks.

1. Introduction

Climate change poses a serious and immediate challenge to planetary sustainability. With rising global temperatures, erratic weather patterns, and increased frequency of natural disasters, nations around the world are investing in cleaner energy solutions. In this context, solar energy has gained prominence not only as a renewable source of electricity but also as a tool for reducing dependence on fossil fuels and curbing greenhouse gas emissions.

As a member of the Paris Agreement, India, has set ambitious targets under its Nationally Determined Contributions (NDCs), including achieving 500 GW of non-fossil fuel-based energy capacity by 2030. Rajasthan, with its vast arid terrain, high solar irradiance, and abundant vacant land, holds a unique position in fulfilling this vision.

Benefiting from more than 325 clear sunny days each year and average solar radiation of 5.5–6.0 kWh/m²/day, Rajasthan has emerged as the leading hub for solar energy in India. This research paper critically examines how the development of solar energy in Rajasthan is linked to the larger goal of climate change mitigation. It assesses policies, evaluates on-ground practices, identifies gaps and challenges, and proposes future strategies that can ensure a balanced, efficient, and socially inclusive solar transformation.

2. Climate Change and Renewable Energy Nexus

The relationship between global energy usage and climate change is profound and unavoidable. Fossil fuels remain the leading cause of anthropogenic greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC) estimates that energy production accounts for nearly 73% of global GHG emissions, with coal, oil, and natural gas being the major contributors.

In contrast, renewable energy — especially solar — offers a clean, reliable, and increasingly cost-effective alternative. Electricity from solar energy is produced without releasing CO₂ emissions or other pollutants, making it an essential tool in achieving climate stabilization goals. As technology improves and costs decline, solar energy becomes not just viable but necessary in climate-sensitive regions like Rajasthan.

Rajasthan's geographical vulnerability to climate change — manifested through droughts, water scarcity, crop failures, and desertification — makes renewable energy development all the more critical. Solar infrastructure not only reduces dependency on thermal plants but also provides energy to remote and vulnerable populations, making development both sustainable and equitable.

3. Rajasthan's Solar Energy Potential

Rajasthan is endowed with the highest solar energy potential in India, estimated at more than 142 GW. The state receives over 300 clear sunny days annually, with radiation levels averaging above 5.5 kWh/m²/day. This makes it ideal for both grid-scale solar parks and decentralized, off-grid solar solutions.

The state has taken early leadership in tapping this potential, contributing over 16 GW of installed solar capacity by 2024 — more than any other state. Vast stretches of arid, unused land have been strategically allocated for solar parks, many of which rank among the largest in the world. In parallel, Rajasthan has promoted rooftop solar systems, solar water pumps, and mini-grids to empower agriculture and rural livelihoods.

The Rajasthan Renewable Energy Corporation Limited (RRECL) plays a key role in project facilitation, investor engagement, and policy execution.

4. Major Solar Projects in Rajasthan

Rajasthan is home to several flagship solar installations that have reshaped India's renewable energy landscape. These include:

 **Table 1: Major Solar Projects in Rajasthan**

Project Name	Location	Capacity (MW)	Commissioned	Developers
Bhadla Solar Park	Jodhpur	2,245	2015–2021	ACME, NTPC, SoftBank, Adani
Nokh Solar Plant	Jaisalmer	925	2023	NTPC
Pokhran Solar Park	Jaisalmer	750	2020	Adani Green Energy
Phalodi Solar Project	Jodhpur	250	2018	Azure Power

Project Name	Location	Capacity (MW)	Commissioned	Developers
Bikaner Solar PV Park	Bikaner	1,000	Ongoing	RRECL, THDC India Ltd

These projects demonstrate Rajasthan's capacity for hosting ultra-mega solar parks, achieving some of the lowest tariffs in the world (as low as ₹2.44/kWh). Bhadla, for instance, has attracted global attention for its scale and performance. These parks are interconnected to the Green Energy Corridor, enabling power transfer to other states and reducing grid congestion.

5. Policy Framework and Government Initiatives

Rajasthan's solar growth has been driven not just by geography but by forward-thinking policies at both central and state levels. India's Jawaharlal Nehru National Solar Mission (JNNSM), launched in 2010, set the stage for large-scale solar development across the country. Rajasthan quickly adapted and led the charge with targeted incentives and state-specific strategies.

Key Initiatives – Elaborated

• Rajasthan Solar Energy Policy (2019):

This state-level policy is a cornerstone of Rajasthan's solar roadmap, aiming to install 30 GW of solar capacity by 2025. It outlines an investor-friendly environment with provisions such as land banks for solar parks, single-window clearance systems to reduce bureaucratic delays, and competitive tariff structures to attract private developers. The policy also encourages solar-wind hybrid models, decentralized applications, and the integration of solar into agriculture and industrial zones.

• PM-KUSUM Scheme (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan):

Launched by the central government, PM-KUSUM is designed to promote the use of solar energy in the agricultural sector. The scheme has three components: (a) installation of standalone off-grid solar pumps, (b) solarization of existing grid-connected pumps, and (c) development of decentralized solar power plants on barren/fallow lands. Rajasthan, with its vast agricultural hinterland, has been one of the leading implementers of this scheme, enabling farmers to reduce dependency on diesel and grid electricity while earning income by selling surplus power.

• Green Energy Corridor Project:

This initiative is jointly funded by the Government of India and international financial institutions like KfW (Germany). It aims to create an efficient transmission infrastructure for renewable energy across high-generation states like Rajasthan. The project includes construction of substations, high-voltage transmission lines, and reactive power management systems. Its main objective is to ensure that solar power generated in remote areas can be evacuated and integrated smoothly into the national grid, minimizing transmission losses and congestion.

• Rooftop Solar Promotion:

To harness the untapped potential of urban rooftops, Rajasthan has encouraged rooftop solar installations across residential, commercial, and institutional sectors. Net-metering policies have been simplified, allowing consumers to feed surplus electricity back into the grid and receive financial credits. DISCOMs and Urban Local Bodies (ULBs) are actively involved in promoting rooftop adoption through awareness campaigns, technical assistance, and subsidy mechanisms. This decentralization also helps reduce grid load and transmission losses in urban areas.

Despite these progressive steps, policy bottlenecks still exist — particularly in areas such as land acquisition, forest clearances, and long-term Power Purchase Agreements (PPAs).

6. Challenges in Implementation

Even with significant advancements, solar energy development in Rajasthan faces multiple implementation hurdles:

- **Land Use Conflicts:** Large solar parks demand vast land areas, often overlapping with pastoral or community lands. This has led to legal disputes and protests.
- **Water Scarcity:** Cleaning solar panels in desert environments requires significant amounts of water, creating ecological stress.
- **Transmission Infrastructure:** Rapid growth in solar capacity has not always been matched with equal investment in grid infrastructure, resulting in curtailments.
- **Delayed Clearances:** Bureaucratic hurdles in approvals for land conversion, environmental assessments, and power purchase contracts lead to project delays.
- **Community Displacement:** Inadequate consultation with local communities has at times led to resistance and delays in project execution.

Addressing these challenges will require an integrated approach that includes policy reform, stakeholder engagement, and infrastructure development.

7. Future Prospects and Innovation

Rajasthan holds immense untapped potential for renewable energy expansion, particularly in its vast western desert regions. As traditional solar parks near saturation, the state's future growth will depend on innovative models and integrated renewable solutions. The following areas represent the next frontier for Rajasthan's clean energy leadership:

- **Hybrid Projects (Solar-Wind Integration):**

Hybrid energy projects combine solar and wind technologies to provide a more stable and continuous power supply. Since solar power peaks during the day and wind energy often peaks at night, their integration ensures 24x7 generation, improving grid stability and capacity utilization. The Nokh Ultra-Mega Renewable Energy Park in Jaisalmer is a pioneering example where such hybrid systems are being deployed on a large scale, with plans to include storage and green hydrogen units as well.

- **Battery Energy Storage Systems (BESS):**

One of the major limitations of solar power is its intermittency. To address this, Battery Energy Storage Systems are being introduced to store excess electricity generated during peak sunlight hours for use during low generation periods or high demand. NTPC, SECI, and private developers are piloting several BESS projects in Rajasthan, including utility-scale lithium-ion battery installations. These systems will play a critical role in reducing curtailment, managing frequency, and improving dispatchability of solar energy.

- **Agri-Photovoltaics (Agri-PV):**

Agri-photovoltaics refers to the practice of using the same plot of land for both solar photovoltaic generation and agricultural activities. In a land-constrained country like India, this dual-use approach offers a sustainable alternative. Rajasthan, with its semi-arid land and dispersed farming, is well-suited to Agri-PV. By elevating solar panels and allowing crop cultivation underneath, farmers can benefit from both electricity generation and agricultural income. This also helps reduce land conflicts often associated with large solar farms.

- **Solar-Powered Green Hydrogen Production:**

Green hydrogen is produced through electrolysis powered by renewable energy. With Rajasthan's abundant solar irradiance, the state has the potential to become a green hydrogen hub for India and international markets. Ongoing policy discussions at the central and state levels aim to establish green hydrogen corridors, pilot production units, and export infrastructure. This can help decarbonize sectors like steel, cement, fertilizers, and transport — areas that are hard to electrify directly with solar.

8. Recommendations

1. Develop transparent land acquisition norms

Land conflicts are a leading cause of solar project delays in Rajasthan. The government must create clear, transparent, and fair land acquisition laws specific to renewable energy. Local communities must be properly consulted, compensated fairly, and offered participation in the benefits of such projects. Land banks or wasteland mapping can be used to avoid fertile or disputed zones.

2. Promote community-owned solar models

Ownership by local cooperatives or panchayats can increase public acceptance and distribute benefits. Community solar gardens, village-level microgrids, or public-private partnerships where locals hold equity stakes can improve sustainability and reduce resistance to large projects.

3. Encourage innovation in waterless panel cleaning

In Rajasthan's arid climate, using water to clean solar panels is environmentally unsustainable. Investment should be made in robotic dry cleaning systems, electrostatic cleaning, or nano-coatings that repel dust. Government-supported R&D and startup funding can accelerate the deployment of such technologies.

4. Expand grid infrastructure and storage support

Solar energy is variable. To avoid curtailment, Rajasthan must upgrade its grid and integrate Battery Energy Storage Systems (BESS). Smart grids, AI-based forecasting tools, and flexible power purchase contracts are also needed to absorb surplus and manage load.

5. Strengthen rooftop solar promotion in rural areas

Despite policy incentives, adoption of rooftop solar in villages and small towns remains low. Awareness campaigns, technical training, financing schemes like RESCO models, and streamlined net-metering should be introduced. Gram panchayats and SHGs can play a big role in this decentralization.

6. Foster collaboration with academia and industry.

Collaborative innovation hubs in partnership with IITs, universities, and solar companies should be established in Rajasthan. This can boost skill development, local entrepreneurship, and bring global innovations closer to implementation.

9. Conclusion

Rajasthan's solar energy journey stands as a testament to what visionary policy, geographic advantage, and technological innovation can achieve in unison. It has transformed from a power-deficit region into a clean energy leader, driving India's renewable targets forward. However, this transformation is not merely a development achievement — it is a climate imperative. In the face of rising global temperatures, ecological degradation, and growing energy demands, Rajasthan's solar mission serves as a critical pillar of India's climate resilience strategy.

Yet, installed capacity alone does not equate to long-term success. The real test lies in ensuring that solar expansion is socially inclusive, environmentally sensitive, and economically adaptive. Equitable land acquisition, community participation, innovation in storage, and sustainable water use must be integral to

the next phase of solar policy. As the impacts of climate change become more severe, Rajasthan's solar model must evolve beyond just generation — toward a decentralized, just, and circular energy economy.

With its proactive government, engaged private sector, and growing technological ecosystem, Rajasthan is well-positioned to not only meet national goals but also inspire similar transitions across the Global South. Its experience can shape international narratives on how emerging economies can align clean energy growth with social justice and environmental stewardship.

In conclusion, Rajasthan's solar mission offers more than just electricity — it offers a blueprint for sustainable development in the age of climate crisis. If pursued wisely and inclusively, it can become a shining model not only for India but for the world.

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