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DETERMINANTS OF SUCCESS FOR PROMOTING RENEWABLE ENERGY IN RAJASTHAN

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ABSTRACT

The transition towards renewable energy in Rajasthan reflects a confluence of socio-economic priorities, environmental imperatives, and institutional innovation. This paper examines the multifaceted factors that drive the success of renewable energy initiatives in the state, including community engagement, land-use policies, and favorable tariff structures. Rajasthan's natural solar irradiance—exceeding 5.5–6.5 kWh/m²/day—combined with strong policy backing, such as the Rajasthan Renewable Energy Policy 2023, has enabled the state to surpass 25 GW of installed renewable capacity.[1] Investments in solar parks, rooftop systems, and decentralized energy models have empowered rural economies and reduced dependency on fossil fuels. The research further analyses regulatory reforms, including single-window clearance systems and viability gap funding, as critical enablers[3]. Despite logistical and infrastructural constraints, Rajasthan's model highlights how local governance, private sector confidence, and adaptive regulation can collectively shape a sustainable energy future.[4] This case offers valuable insights for scaling renewable energy in other emerging economies.

Keywords: Renewable Energy, Solar Energy, Wind Energy, Biomass Energy, Small Hydro Power, Battery Energy Storage Systems (BESS), Green Hydrogen, Decentralized Energy Solutions, Renewable Energy Policy.

1. INTRODUCTION

Rajasthan's historical energy mix was heavily reliant on non-renewable sources such as coal, lignite, and petroleum, which played a critical role in powering early industrial growth but also raised long-term concerns related to environmental degradation and energy security[5]. Recognizing the central role of energy in economic development and the overall quality of life, both India and Rajasthan gradually shifted focus toward more sustainable energy alternatives[6]. Rajasthan's unique geographical advantages—including high solar irradiance, vast stretches of arid land, and relatively low population density—have positioned it as a prime location for large-scale deployment of solar and wind energy technologies[7].

This transition gained significant momentum following the regulatory reforms introduced by the Electricity Act of 2003 and the subsequent launch of the Jawaharlal Nehru National Solar Mission in 2010, spearheaded by the Ministry of New and Renewable Energy (MNRE) and the Rajasthan Renewable Energy Corporation Limited (RRECL)[8]. These policy shifts laid the foundation for an accelerated shift to renewables, enabling the establishment of flagship projects such as the 2,245 MW Bhadla Solar Park and the 1,064 MW Jaisalmer Wind Park, which have helped cement Rajasthan's leadership in India's clean energy space[9]. The 2023 Renewable Energy Policy set an ambitious goal of achieving 90 GW of solar capacity by 2030, while broader integrated energy planning at the national level has supported coordinated action across sectors and institutions[10].

The latest phase of Rajasthan's renewable energy strategy is encapsulated in the Integrated Clean Energy Policy 2024, which targets a cumulative renewable energy capacity of 125 GW by FY 2029–30, incorporating solar, wind/hybrid systems, and storage-based solutions[11]. Financial and regulatory enablers under the Rajasthan Investment Promotion Scheme (RIPS) 2024—such as exemptions from electricity duty, stamp duty, wheeling charges and pollution board fees—have successfully attracted committed investments totaling ₹4.23 lakh crore through 31 Memorandums of Understanding (MoUs), amounting to 66.4 GW of clean energy projects

including solar, green hydrogen, pump-storage and hybrid systems[12]. Nonetheless, the introduction of revised land-stamp duty rules in early 2025 has raised project implementation costs by an estimated 8–10%, presenting a significant policy hurdle that requires proactive resolution to sustain investment momentum and maintain Rajasthan's leadership in renewable energy development[13].

2. POTENTIAL OF RENEWABLE ENERGY IN RAJASTHAN

Rajasthan's geographical characteristics position it as a powerhouse for renewable energy generation, particularly in the domains of solar and wind energy. The state's vast arid landscapes, coupled with favorable climatic conditions, provide an exceptional resource base for clean energy development[14].

2.1 Solar Energy

The state is endowed with high levels of solar irradiance, averaging between 6.0–7.0 kWh/m² per day according to earlier assessments, with more recent evaluations estimating a range of 5.72–6.12 kWh/m² per day[15]. Rajasthan enjoys approximately 325 to 355 clear sunny days annually, making it one of the most suitable regions in India for solar power generation. The total estimated solar generation potential stands at an impressive 142 GW[16]. As of early 2024, Rajasthan led the nation in installed solar capacity, reaching 22,860.73 MW[17]. At the national level, India's cumulative solar power capacity rose to 110.83 GW by May 2025 (MNRE, 2025).

2.2 Wind Energy

In addition to solar energy, Rajasthan holds significant potential for wind energy, particularly in its western districts such as Jaisalmer, Barmer, Jodhpur, and Bikaner, where strong and consistent wind speeds prevail. The state's wind energy potential has been assessed at approximately 284 GW[18]. In terms of installed capacity, Rajasthan ranks third in the country, with 5,195.82 MW of wind power as of early 2024[19]. Nationally, India's total wind power capacity reached 51.29 GW by May 2025 (MNRE, 2025).

2.3 Biomass Energy

Biomass energy, though a smaller contributor, also forms part of Rajasthan's renewable energy mix. As of December 2020, the state's installed biomass power capacity was approximately 101.95 MW, with 13 operational projects contributing a total of 120.45 MW[20]. Major sources of biomass include agricultural residues such as mustard husk and plant species like Prosopis juliflora. To support this sector, the state government introduced the "Policy for Promoting Generation of Electricity from Biomass" in 2010. More recently, the Ministry of New and Renewable Energy updated its guidelines for the National Biomass Program for the period 2022–2027[21].

2.4 Small Hydro Power

Although Rajasthan has limited hydroelectric resources due to the scarcity of perennial rivers, small to medium hydropower installations continue to contribute to the state's energy portfolio. Notable projects include the Jakham (5.4 MW), Anas (140 MW), and Indira Gandhi (23.85 MW) hydropower plants[22]. At the national level, India's total small hydro power capacity reached 5,102.05 MW by May 2025 (MNRE, 2025).

2.5 Other Emerging Energy

In response to the growing need for a diversified and resilient energy mix, Rajasthan is increasingly focusing on emerging renewable technologies. The Rajasthan Integrated Clean Energy Policy of 2024 has set a target of achieving 10 GW from hydro, pumped storage projects (PSP), and battery energy storage systems (BESS) by 2029–30[23]. Additionally, the state is actively promoting the development of green hydrogen production facilities and manufacturing units, which are supported through fiscal incentives under the Rajasthan Investment Promotion Scheme[24].

While solar energy has been the primary focus of renewable energy expansion in Rajasthan, the enormous untapped wind potential and the growing strategic interest in hybrid systems, pumped hydro, and BESS technologies indicate a clear shift toward a more balanced and integrated renewable energy strategy[25]. However, realizing this potential is closely tied to the issue of land availability. Rajasthan's extensive barren land is often cited as a key advantage for large-scale renewable energy development. Nonetheless, recent developments have highlighted significant challenges,

particularly regarding land acquisition. Conflicts have emerged over the allocation of common lands, locally known as "Orans" (sacred groves) and lands belonging to Scheduled Caste and Scheduled Tribe communities[26]. These areas are vital for local livelihoods and biodiversity, but are increasingly being allocated to private solar developers, leading to social tensions and legal disputes. Therefore, while Rajasthan's physical potential for renewable energy growth is vast, its practical realization depends on effective and equitable land management policies, as well as robust conflict resolution mechanisms to ensure truly sustainable development.

Table 1: Rajasthan's Renewable Energy (Up to March 2024)

S. No.	Energy Source	Assessed Potential (GW)	Installed Capacity (GW)	Rajasthan's National Rank (Installed Capacity)
1	Solar	142	21.35	1st
2	Wind	284	5.2	3rd
3	Biomass	1.29	~0.12	Not specified
4	Small Hydro	0.51	0.023	Not specified
5	Total RE	427+	27.10	2nd

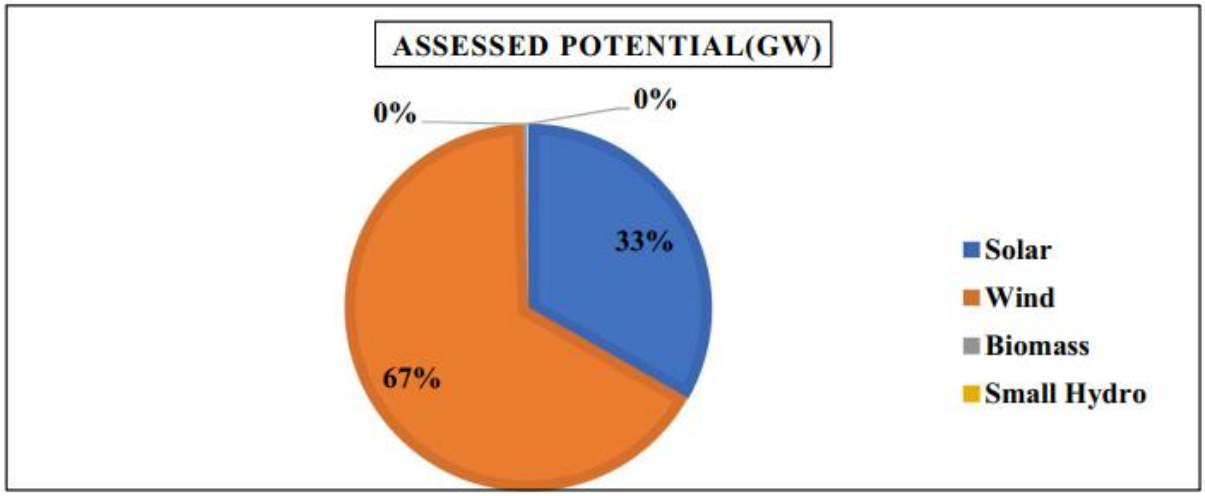

Figure 1.1: Rajasthan's Renewable Energy Potential Up to March 2024 Source: MNRE&CEP

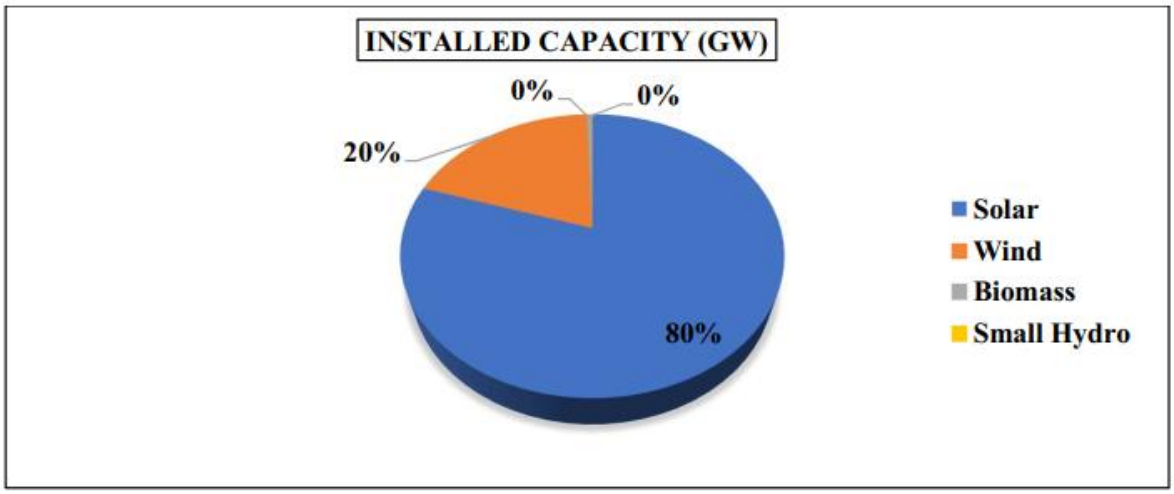

Figure 1.2: Rajasthan's Renewable Energy Installed Capacity Up to March 2024 Source: MNRE&CEP

3. CURRENT POLICY, PRACTICE, AND REGULATIONS IN RAJASTHAN

Rajasthan has emerged as a leading state in India for renewable energy development, owing not only to its geographical advantage but also to a progressive and adaptive policy framework. The state's renewable energy governance has evolved through a series of well- defined policies, incentives, and regulatory reforms aimed at maximizing clean energy adoption and integration.

3.1 Evolution of Renewable Energy Policies

Rajasthan's journey toward renewable energy development began with the Policy for Promoting Generation of Power through Non-Conventional Energy Sources, first introduced in 1999 and subsequently revised in 2000, 2003, 2004, 2011, and 2014. A significant leap occurred with the Rajasthan Solar Energy Policy, 2019, which set an ambitious goal of achieving 30 GW of solar capacity by 2024–25. This policy broadened the scope of renewable deployment to include utility-scale solar parks, rooftop solar installations (both net and gross metering), decentralized off-grid systems, and EV charging infrastructure.[27]

Complementing this was the Rajasthan Wind and Hybrid Energy Policy, 2019, which aimed to install 2000 MW of wind and hybrid energy by 2024–25. This policy formally defines hybrid projects as those where the installed capacity of either solar or wind is at least 25% of the other (NIWE, 2024). These developments marked a shift toward integrated renewable systems rather than isolated solar or wind installations.

The most comprehensive and forward-looking framework to date is the Rajasthan Integrated Clean Energy Policy, 2024. This policy outlines a target of 125 GW of total renewable energy capacity by 2029–30, which includes 90 GW from solar, 25 GW from wind and hybrid systems, and 10 GW from hydro, pumped storage (PSP), and battery energy storage systems (BESS). The policy promotes energy security, private sector participation, and technology innovation as pillars for long-term sustainability.[28]

3.2 Key Regulatory Frameworks and Incentives

To attract domestic and foreign investment in renewable energy, Rajasthan has implemented a range of fiscal and regulatory incentives under the Rajasthan Investment Promotion Scheme (RIPS), 2024. These include 100% exemption from electricity duty for seven years, full reimbursement of mandi/market fees for seven years, and 75% exemption with 25% reimbursement on stamp duty and land conversion charges[29].

Additionally, government land is made available at competitive rates for large-scale projects, with a nominal security deposit requirement of ₹100,000 per MW for capacities up to 2000 MW. The state has prioritized project viability and ease of doing business, especially for energy developers. To support grid stability and efficient integration of intermittent renewable energy, the state now offers generous exemptions on transmission and wheeling charges for projects integrated with BESS. These exemptions scale from 75% for projects with 5% storage to 100% for those with over 30% storage capacity.[30]

The recently launched Green Energy Open Access (GEOA) Regulations, 2025, empower commercial and industrial consumers with a minimum sanctioned load of 100 kW to directly procure renewable power. These rules also promote captive generation and encourage BESS integration for reliability.[31]

4. DETERMINANTS OF SUCCESS FOR RENEWABLE ENERGY IN RAJASTHAN

Rajasthan's success in promoting renewable energy is attributable to a combination of factors, including progressive policy frameworks, dedicated institutional support, robust infrastructure development, and a strategic early-mover advantage. However, this success is not without its complexities, particularly concerning environmental governance and social equity.

4.1 Progressive Policy Frameworks

Rajasthan's policy landscape for renewables was inaugurated in February 2008 with the Generation-Based Incentive scheme, offering ₹12 per kWh for 5 MW solar projects, coupled with a state-mandated Renewable Purchase Obligation of 0.5% for distribution companies that same year, catalyzing the state's capture of 873 MW (79.4% of 1,100 MW) in JNNSM Phase 1st. The Solar Energy Policy, 2019 expanded incentives by introducing a three-tier tariff structure—₹2.50–

3.00/kWh for large-scale, ₹3.20/kWh for rooftop, and accelerated depreciation benefits, targeting 30 GW by March 2025. Building on this, the Integrated Clean Energy Policy 2024 set a comprehensive 125 GW milestone by 2029–30: 90 GW solar, 15 GW wind/hybrid, and 10 GW of storage, pumped hydro, and green hydrogen capacities. The Rajasthan Investment Promotion Scheme ,2024 supplements these goals with fiscal stimuli—seven-year excise and electricity-duty exemptions, 100% reimbursement of mandi fees and stamp-duty waivers up to ₹500 million per project—while stipulating expedited land allotment protocols. Concurrently, central programmes—PM- KUSUM and PM Surya Ghar: Muft Bijli Yojana (up to ₹6,000/kW rooftop subsidy)—have further diversified the state's renewable mix (MNRE, 2025). Despite these strides, the conversion of over 8,000 ha of common lands (Orans and grazing reserves) between 2019– 24 has sparked 27 Public Interest Litigations, exposing tensions between rapid scale-up and community rights[32].

4.2 Institutional Support: RRECL & Single-Window Clearance

Formed in January 2003 through the merger of four departments, the Rajasthan Renewable Energy Corporation Limited (RRECL) acts as the state's single-window nodal agency, orchestrating land acquisition, PPA negotiation, and NOC issuance. Between FY 2018–19 and FY 2023–24, RRECL's total revenue climbed from ₹450 million to ₹800 million (CAGR ~12%), its current ratio averaged 1.8 times, and equity debt remained below 0.4[2]. The Integrated Policy, 2024 enshrines strict timelines: 7 days for project NOCs, 7 days for net-meter commissioning, and 15 days for interconnection approvals. Yet, empirical surveys reveal average grid-tie delays of 90 days (target 30 days) and auction award-to PPA

execution spans of 45 days, highlighting that procedural streamlining must be accompanied by capacity-building in STU departments[33].

4.3 Infrastructure Development: Power Evacuation & Transmission

Anticipating large-scale renewable integration, Rajasthan built a dedicated 400 kV transfer corridor in its desert belt (Jaisalmer–Barmer) between 2012–15, augmented by 220 kV and 132 kV feeders, reducing curtailment losses from 12% to under 8% by 2020[34]. The Rajasthan Electricity Regulatory Commission's ₹6,050 crore capex approval for FY 2025– 26 targets further loss reduction (14% to 11%), grid reinforcement, and dynamic reactive compensation (RERC,2025). The Green Energy Corridor project—comprising four substations and 1,200 km of HV lines—will enable 6,311 MW of solar and wind capacity by 2026. Recognising intermittency, the 2024 policy mandates BESS installations for all plants >5 MW (total target 5 GW by 2030) and drone-based aerial inspection and SCADA retrofits in 50% of substations (CEEW, 2024). Nonetheless, operational reports cite over 35 grid disturbance events in 2023, including voltage tripping at Bhadla, underscoring the need for harmonised physical and digital upgrades.

4.4 Early-Mover Advantage & Diversification

Rajasthan's early solar incentives yielded a 46 times upswing in capacity—from 0.5 GW in 2010 to 23 GW by 2024—earning it 60% of national auctions between 2012–18[7]. However, as of June 2025, Gujarat's cumulative renewables reached 37.5 GW—led by 13.8 GW wind and 8 GW rooftop—compared to Rajasthan's 37.8 GW with only 5.2 GW wind (RERC, 2025). In response, Rajasthan increased wind and hybrid tenders by 60% post-2022 and designated 15% of 2024 auctions for rooftop and storage projects. Moving forward, diversification into green hydrogen (2 GW pilot by 2027) and agrivoltaics (projected 5 GW by 2030) will be critical to counteract technology lock-in[35].

4.5 Environmental Governance & Social Equity

The Rajasthan State Pollution Control Board's 'tatkal' consent scheme expedites 90% of solar and wind project approvals within 15 days, while mandating 12 ML/day of treated effluent reuse for module cleaning[36]. Nonetheless, judicial records indicate that 35% of Oran allotments (2,800 ha) and 40% of pumped-storage sites (PSPs) were legally contested over afforestation and displacement concerns; only 45% of the required 1:10 afforestation ratios were met, leading to Supreme Court orders to suspend non-

compliant projects. Water-energy-land nexus analyses reveal CSP plants consume 4 m^3/MWh and PSPs 2 m^3/MWh in regions averaging 5 m^3/capita/day water availability. Pilot robotic cleaning systems have cut water use by 60% and solar-driven RO units supply 0.5 L/s to local communities, yet robust participatory planning—incorporating Free, Prior & Informed Consent (FPIC)—remains essential to ensure just transitions.

5. ENVISIONING THE FUTURE OF RENEWABLE ENERGY IN RAJASTHAN

Rajasthan stands at a pivotal moment in its renewable energy transition. With ambitious state-level targets and comprehensive policy frameworks, the state is poised to become a

national leader in clean energy. According to the Rajasthan Integrated Clean Energy Policy, 2024, the state aims to achieve 125 GW of renewable energy capacity by FY 2029–30. This includes 90 GW from solar energy, 25 GW from wind and hybrid sources, and 10 GW from pumped storage projects (PSPs) and Battery Energy Storage Systems (BESS). This vision aligns with India's broader commitments under the National Green Hydrogen Mission, 2023[37], and the Panchamrit pledges made at COP26, positioning Rajasthan as a key player in India's low-carbon transition. Large-scale solar parks remain central to Rajasthan's renewable strategy. Operational facilities such as the Bhadla Solar Park and upcoming high- capacity parks in Jodhpur, Bikaner, Barmer, and Phalodi exemplify the state's emphasis on utility-scale clean energy development[38].

5.1 Emerging Opportunities for a Scalable and Equitable Energy Transition

Rajasthan's clean energy future presents several transformative opportunities, each grounded in global and national clean energy paradigms:

5.1.1 Green Hydrogen Economy

Green hydrogen represents a strategic frontier in Rajasthan's energy diversification agenda. With vast solar potential and policy incentives under RIPS-2023, the state is emerging as a prospective hub for green hydrogen production and export. This development aligns with the Hydrogen Economy theory, which positions hydrogen as a critical solution for decarbonizing hard-to-abate industrial sectors[39].

5.1.2 Battery Energy Storage Systems (BESS)

Effective energy storage is vital for integrating intermittent renewable sources into the grid. Rajasthan's target of 5 GW BESS capacity marks a significant step toward flexible and resilient grid infrastructure. Prioritizing BESS over conventional PSPs, especially in arid zones, reflects water-conserving innovation essential to Rajasthan's water-scarce environment[40].

5.1.3 Decentralized Renewable Energy (DRE) and Energy Access

Decentralized solutions such as rooftop solar, off-grid systems, and solar mini-grids are gaining momentum. Supported by national programs like PM-KUSUM and PM Surya Ghar Muft Bijli, these initiatives promote energy equity and rural empowerment. Rajasthan's DRE expansion aligns with the Just Energy Transition framework, which seeks to deliver clean energy access without exacerbating social inequalities[41]. The Green Energy Open Access (GEOA) Regulations, 2025, further support consumer rights and encourage energy democratization.

5.2 Persistent Challenges and Knowledge Gaps

Despite progress, Rajasthan's energy transition faces several structural and environmental barriers:

5.2.1 Dust Deposition on PV Modules

High dust loads in the Thar Desert substantially reduce photovoltaic (PV) efficiency. While robotic cleaning technologies are in use, tailored R&D is required to optimize cleaning cycles while minimizing water consumption[42].

5.2.2 Water Scarcity and Usage

Water-intensive operations such as solar module cleaning and PSPs pose challenges in arid regions. Although policy initiatives promote rainwater harvesting and wastewater reuse, a holistic water-energy nexus approach is necessary for sustainable[43].

5.2.3 Land Use Conflicts

Land acquisition, particularly of common and

tribal lands, remains contentious. These conflicts highlight the need for participatory planning and adherence to Free, Prior, and Informed Consent (FPIC) principles to ensure equitable development[44].

5.2.4 Grid Integration and Stability

The intermittent nature of renewable sources demands smart grid solutions, AI-based forecasting, and responsive demand-side mechanisms. Without such modernization, high renewable energy penetration risks destabilizing the grid[45].

5.2.5 Underutilized Carbon Market Potential

While large-scale projects generate carbon credits, smaller systems such as biogas units and solar pumps remain excluded. Expanding carbon market participation to include these decentralized systems is crucial for inclusive climate finance[46].

5.3 Policy-Implementation Gaps and Equity Concerns

Top-down energy policies often fail to resonate with on-the-ground realities. Implementation of schemes like PM-KUSUM is hindered by issues in land tenure, financial accessibility, and local capacity. According to the Energy Justice Theory, energy transitions must be not only distributively fair but also procedurally inclusive, ensuring that marginalized communities are active stakeholders rather than passive recipients.

5.4 Recommendations for Sustainable and Inclusive Growth

- To ensure a just and sustainable energy transition in Rajasthan, the following policy and implementation measures are recommended:
- Integrated Land-Use Planning: Develop community-led frameworks that balance ecological sensitivity with traditional land rights and biodiversity conservation.
- Arid-Zone R&D Acceleration: Invest in dust-resilient PV materials, waterless module cleaning systems, and dry cooling technologies for thermal-hybrid plants.
- Smart Grid and Storage Infrastructure: Accelerate deployment of smart grid technologies integrated with real-time load balancing, AI forecasting, and BESS.
- Energy Portfolio Diversification: Reduce reliance on solar by incorporating wind, hybrid, geothermal, and bioenergy technologies.
- Community Engagement and Conflict Mitigation: Institutionalize benefit- sharing mechanisms and grievance redress systems within project approval processes.
- Decentralized Solutions for Rural Equity: Expand access to mini-grids, solar cookers, biogas systems, and off-grid technologies through targeted technical and financial support.

6. CONCLUSION

Rajasthan's success in renewable energy development is a result of its abundant solar and wind resources, visionary policy frameworks, and strong institutional mechanisms. The Rajasthan Integrated Clean Energy Policy 2024, along with the proactive role of agencies like RRECL, has significantly boosted investment, project execution, and infrastructure development. Strengthening of grid integration, power evacuation systems, and streamlined single-window clearances have positioned the state as a leader in India's energy transition. However, this progress is accompanied by critical socio-environmental challenges. Issues related to land acquisition, water scarcity, and the integration of variable renewable energy sources reveal that technical and financial achievements must be supported by inclusive and equitable approaches.

According to contemporary energy transition theories, ensuring a Just Energy Transition is essential, where the benefits of clean energy are distributed fairly and local community participation is prioritized. Addressing the water-energy-land nexus, particularly in this arid region, requires innovative solutions like Battery Energy Storage Systems (BESS), decentralized energy models, and the promotion of green hydrogen. Rajasthan's future energy roadmap must integrate social equity, ecological sustainability, and technological advancement. The state's continued leadership in renewable energy will depend on its ability to embed these principles into its planning and governance structures. If implemented effectively, Rajasthan can emerge not only as a model for India but also as a global example of how a green energy transition can be achieved in a manner that is just, inclusive, and truly sustainable.

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