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Climate Change and Renewable Resources in India: A Comprehensive Analysis for Sustainable Development

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Abstract
India stands at the forefront of global climate and energy transitions, facing the dual challenge of mitigating climate change while meeting the rapidly growing energy demands of its large population. This study provides an integrated analysis of India's vulnerability to climate change, the current status and trajectory of its renewable energy sector, and the effectiveness of policies in achieving sustainable development. Drawing from national and international data, energy system models, and socio-economic indicators, the study identifies key barriers—technical, financial, regulatory, and social—that hinder India's transition to clean energy. Despite notable progress, including significant growth in solar and wind capacity, systemic challenges like grid instability, funding gaps, and land use conflicts remain. The research highlights the need for stronger governance, inclusive planning, and investment in infrastructure to ensure a just and sustainable energy future. Ultimately, the paper proposes actionable policy recommendations aimed at achieving India's net-zero targets while ensuring socio-economic equity and environmental protection.

Keywords: Climate Change Vulnerability, Renewable Energy Transition, Grid Integration Challenges, Socio-Economic Impacts, Just Energy Transition

1. Introduction

1.1 Global Climate Change Context and India's Position

Climate change is a critical global challenge, and India, home to over 1.3 billion people and the third-largest carbon emitter, occupies a central position. Despite low per capita energy use (0.6 tonnes of oil equivalent), its total emissions are high due to population size and development needs. India faces the dual challenge of meeting growing energy demands while reducing emissions. Its climate action is framed by principles of equity and shared responsibility. Notably, India is also among the most climate-vulnerable nations, ranking seventh globally for extreme weather impacts in 2019 (Godara 2025).

1.2 India's Energy Landscape and Renewable Energy Commitment

India has long relied on coal, contributing to economic growth and environmental degradation. In response, it has committed to major renewable energy goals—500 GW non-fossil fuel capacity by 2030 and net-zero emissions by 2070. This study explores the interplay between climate risks and renewable energy development in India, assessing progress, challenges, and future directions.

2. Need for the study

2.1 Urgency of Climate Action in India

India is already experiencing severe climate effects: heatwaves, erratic rains, and frequent disasters. Agriculture and urban poor are especially vulnerable. Rapid urbanization worsens climate risks through unplanned growth, increasing exposure to hazards. Development, if unchecked, can intensify vulnerabilities and threaten long-term sustainability (Ministry of New & Renewable Energy 2025).

2.2 Importance of Renewable Energy Transition

Transitioning to clean energy is vital for emissions reduction, energy security, and environmental health. India's renewable energy goals reflect its strategic shift away from fossil fuels and toward sustainable development.

2.3 Gaps in Understanding

Though many studies address climate impacts or energy policy individually, integrated analysis remains limited. This study fills that gap by offering a synthesized perspective on India's climate risks, renewable energy progress, and socio-economic implications—informing policy and guiding action (Council on Energy, Environment and Water).

3. Objectives

This study aims to:

- Analyze current and projected climate change impacts across India.
- Assess the status and policy framework of renewable energy development.
- Identify challenges such as grid integration, finance, and land conflicts.
- Evaluate renewable energy's role in emission reduction and socio-economic benefits.
- Recommend evidence-based policies for a just and sustainable energy transition.

4. Methodology

4.1 Research Design

The study uses a comprehensive literature review combining qualitative and quantitative analysis. It integrates findings from academic research, government reports, and expert assessments.

4.2 Data Sources

Key sources include:

- Government bodies: MNRE, IMD
- International organizations: IEA, IMF, IRENA, WEF
- Think tanks: CEEW, NREL, WRI India

4.3 Analytical Frameworks

- **Energy Models**
- *IDEEA*: Demonstrates 100% renewable electricity feasibility in India by 2050 using 41 years of weather data.
- *LUT Model*: Projects cost-effective, zero-emissions power sector based on solar, wind, and hydro.
- *NREL Study*: Validates technical feasibility of integrating 175 GW renewables by 2022 into India's grid.

These models show broad consensus on the technical feasibility of India's renewable transition by mid-century.

- **Climate Vulnerability Tools**
    - *CVI*: Maps district-level vulnerability across states.
    - *CHVA*: Used in urban contexts like Mumbai to assess climate risks and equity.
- **Mixed Methods**

Combines statistical data (capacities, emissions) with case studies and policy reviews to capture the energy-climate nexus comprehensively.

5. Data analysis: Climate Change Impacts and Vulnerability in India

5.1 Observed Climate Trends and Extreme Events

India has become increasingly vulnerable to extreme weather events, ranking seventh globally in 2019. From 1901 to 2018, average temperatures rose by 0.7°C, and between 1970 and 2021, 573 climate-related disasters claimed over 138,000 lives (IMD, 2021). Recent years saw record heatwaves and prolonged droughts. Monsoon patterns have shifted, leading to erratic rainfall—intensifying both dry and wet spells. Notable events include the 2015 Chennai floods and 2020 flooding in the Ganga-Brahmaputra basin, with Bihar, West Bengal, and Assam most affected (International Energy Agency n.d.).

5.2 Climate Vulnerability and Differential Impacts

CEEW reports that 75% of Indian districts are hotspots for extreme events, with 40% showing a "swapping trend"—flood-prone areas now facing droughts, and vice versa. States like Assam, Maharashtra, and Andhra Pradesh are particularly at risk. Socio-economic vulnerability is high: 363 million Indians live in poverty, and 1.77 million are homeless. Poor and marginalized communities, especially in informal urban settlements, are disproportionately affected due to inadequate access to resources and adaptive capacity.

5.3 Future Projections

By 2050, over a billion people in Asia may face water stress, with 148.3 million Indians living in severe climate hotspots. Sea level rise of up to 50 cm could submerge major coastal cities—Mumbai, Chennai, Goa, and others—putting 35–50 million people at risk of chronic flooding and displacement.

Table 1: Key Climate Change Impacts and Vulnerabilities in India

Indicator	**Value**
Observed Temperature Increase (1901-2018)	0.7°C
Total Climate Disasters (1970-2021)	573 events
Lives Lost due to Climate Disasters (1970-2021)	138,377
Increase in Extreme Events (since 2005)	~200%
Population in Climate-Sensitive Sectors (e.g., agriculture)	~50%
Projected Population in Severe Hotspots (by 2050)	148.3 million
Projected Population at Risk from Sea Level Rise	35-50 million
Highly Vulnerable States (examples)	Assam, Andhra Pradesh, Maharashtra, Karnataka, Bihar

Source: Ministry of New & Renewable Energy 2025

6. Data analysis: india's renewable energy landscape

6.1 Current Status and Growth

As of June 2025, India's total power capacity reached 476 GW, with non-fossil sources contributing 235.7 GW (49%). Renewable energy alone accounts for 226.9 GW, up from 76.4 GW in 2014—a near threefold increase. Solar power has led this growth, rising from 2.82 GW in 2014 to 110.9 GW in 2025, with 23.83 GW added in 2024–25. Wind (51.3 GW), hydro (48 GW), and biopower (11.6 GW) also contribute significantly. Renewables now provide 22.2% of total power generation. The shift to performance-based incentives has accelerated deployment, making India a global RE leader (Ministry of New & Renewable Energy 2025).

6.2 National Targets and Policies

India's updated NDCs target a 45% reduction in emissions intensity by 2030 (vs. 2005 levels) and 50% of installed capacity from non-fossil fuels. Long-term goals include 500 GW of non-fossil capacity by 2030 and net-zero emissions by 2070. Key initiatives include (UNFCCC. 2015):

- *National Action Plan on Climate Change (NAPCC)*
- *Jawaharlal Nehru National Solar Mission*
- *PM-Surya Ghar Programme* (targets 30 GW rooftop solar)
- Shift from CAPEX to OPEX models and enhanced financial incentives.

6.3 Energy Demand and Fossil Fuel Reliance

Despite RE growth, thermal power still dominates with 240 GW (50.52%), including 218 GW from coal. Although coal's share has declined, rising energy demand—projected to grow 35% by 2030—means fossil fuel capacity is still increasing. The core challenge is that renewables are primarily meeting new demand, not yet significantly displacing fossil fuels. Deep decarbonization will require stronger efforts to replace existing fossil-based generation, not just supplement it (National Renewable Energy Laboratory n.d.).

Table 2: India's Renewable Energy Installed Capacity and National Targets (GW)

Category	**Value (June 2025)**	**Target (by 2030)**
Total Installed Power Capacity	476 GW	-
Non-Fossil Fuel Capacity	235.7 GW (49% of total)	500 GW (50% of total installed capacity)
Total Renewable Energy Capacity	226.9 GW	-
Solar Capacity	110.9 GW (from 2.82 GW in 2014)	~293 GW (as per CEA projection)
Wind Capacity	51.3 GW	~101 GW (as per job potential)
Hydro Capacity	48 GW	55 GW (by FY 2030)
Bio Power Capacity	11.6 GW	-
Nuclear Capacity	8.8 GW	-
Net-Zero Emissions Year	-	2070

Source: Ministry of New & Renewable Energy 2025

7. Results and findings: challenges and effectiveness of renewable energy transition

7.1 Major Challenges

7.1.1 Transmission and Grid Stability

Rapid RE growth has outpaced grid infrastructure, causing curtailment (5–10%) in solar-rich states like Rajasthan. Grid instability, particularly the "duck curve" (midday oversupply vs. evening shortages), strains India's tightly regulated frequency range. By 2031–32, 79.3 GW / 411.4 GWh of storage will be needed—currently lacking—along with better forecasting and system flexibility (International Energy Agency n.d.).

7.1.2 Financial Constraints

India needs $10.1 trillion for its net-zero goal by 2070, with only $6.6 trillion currently projected—leaving a $3.5 trillion gap. High perceived risks, changing regulations, and long project cycles deter investment. New financing models and strong policy support are essential (International Monetary Fund 2023).

7.1.3 Policy and Regulatory Inconsistencies

Unpredictable changes (e.g., solar import duties, rooftop net metering policies) disrupt the sector. Many awarded projects lack buyers and risk cancellation. Weak environmental enforcement and legal gaps slow progress and erode investor confidence.

7.1.4 Land Use Conflicts

Large-scale RE projects are land-intensive, causing disputes and displacing communities. Over 30 land conflicts affect 41,000 people and Rs 70,738 crore (~$8.5B USD) in investment. The *Oran Land* conflict in Rajasthan highlights the tension between clean energy development and indigenous rights, where sacred community lands are reclassified as "wasteland" for project use—often without consent or proper assessments (Narain et al., 2025).

Key Insight: India's renewable energy expansion, though impressive, is hindered by systemic issues—underdeveloped grid infrastructure, financing gaps, inconsistent policies, and social inequities. The *Oran Land* case exemplifies how aggressive energy targets can undermine the principles of a just transition, disproportionately impacting vulnerable communities and ecological systems.

Table 3: Major Challenges to India's Renewable Energy Transition

Challenge Category	Specific Issues	Quantitative/Qualitative Details
Technical	Transmission Bottlenecks & Grid Stability	Transmission not keeping pace, 5-10% solar curtailment in Rajasthan, "duck curve" instability, tight grid frequency band (49.9-50.05 Hz)
	Energy Storage Requirements	Projected need for 79.3 GW / 411.4 GWh by 2031-32 (currently non-existent large-scale capacity)
Financial	Investment Gaps	$10.1 trillion needed for Net-Zero by 2070, $3.5 trillion funding gap
	Risk Perception	Low-carbon projects perceived as high-risk, longer gestation periods, unpredictable business environment
Policy &	Inconsistencies	Abrupt imposition of customs duties on solar imports,

Challenge Category	Specific Issues	Quantitative/Qualitative Details
Regulatory		frequent changes in rooftop solar net metering rules
	Project Viability	Awarded projects often fail to secure buyers, risking cancellation
	Enforcement Gaps	Gaps in legal framework, issues in enforcing environmental regulations
Social & Land Use	Land Conflicts	At least 30 documented cases, impacting ~41,000 people and ~30,000 hectares, with Rs 70,738 crore investment in limbo
	Human Rights Violations	'Oran Land' case: acquisition without consultation/impact assessments, loss of access/livelihood, environmental damage, displacement
	Lack of Impact Assessments	Government bypassing legislative provisions, EIA exemptions for solar/wind projects
	Land Record Discrepancies	"Banjar" (wasteland) vs. "khatedari" (private) land claims exacerbating conflicts

Source: Ministry of New & Renewable Energy 2025

7.2 Effectiveness of Renewable Energy in Climate Mitigation

Renewable energy, particularly solar PV, offers a low-emission alternative to fossil fuels and is central to India's climate strategy. The country aims to reduce emissions intensity by 45% by 2030 and cut 1 billion tonnes of CO_2 through its renewable targets. Industrial clusters alone may contribute 832 million tonnes of reductions (Pandey & Kumar 2025).

However, while emissions per unit of energy are falling, overall emissions are projected to rise until 2040 due to growing energy demand. Current RE growth is largely meeting new demand rather than replacing existing fossil fuel use. To meet the 2070 net-zero goal, India must adopt more aggressive policies focusing on absolute emission reductions, not just intensity (World Economic Forum 2025).

7.3 Socio-Economic and Environmental Benefits

- **Job Creation**: The RE sector created ~1 million jobs in 2023. With expansion, it could generate 3.4 million jobs by 2030, including 1.2 million in solar alone. Projects like solar irrigation in Uttar Pradesh demonstrate how RE boosts rural employment and productivity (Singh 2015).
- **Rural Electrification**: Decentralized RE, supported by schemes like *Saubhagya*, has improved electricity access in remote areas, enabling education, healthcare, and small businesses (WRI India n.d.).
- **Energy Security**: RE reduces dependence on imported fossil fuels, shielding India from volatile global energy markets and improving energy independence.
- **Health and Environment**: RE reduces air pollution, especially in urban areas. The WHO projects a 20% drop in pollution-related health issues with reduced coal use over the next decade.

Key Takeaway: Beyond emission reductions, India's renewable transition delivers significant developmental co-benefits—jobs, rural empowerment, energy access, and health improvements—

aligning the climate agenda with national growth priorities and increasing public and political support for a just energy transition.

Table 4: Socio-Economic and Environmental Benefits of Renewable Energy in India

Benefit Category	Specific Impacts	Quantitative/Qualitative Details
Economic & Employment	Job Creation	~1 million jobs created in 2023 (solar, wind, bioenergy); potential for ~3.4 million jobs by 2030 (solar, wind)
	Rural Productivity	Solar irrigation pump sets improved rural productivity and created jobs across socio-economic classes in Uttar Pradesh
	Economic Growth	Attracting foreign investment, fostering technological innovation, increasing production efficiency, and reducing costs
Social & Access	Rural Electrification	Decentralized RE systems provide stable electricity, reducing reliance on costly diesel generators
	Socio-Economic Upliftment	Saubhagya Scheme (aided by RE) facilitates education, healthcare, small business growth in remote areas
	Energy Security	Reduces dependence on imported fossil fuels, mitigating risks from global oil price fluctuations
Environmental & Health	Emission Reduction	Large potential to displace GHG emissions; solar PV has significantly lower CO_2 emissions than conventional energy
	Air Quality Improvement	Shift to RE reduces air pollution, leading to significant health benefits in metropolitan areas
	Health Improvements	Anticipated 20% drop in air pollution-related health problems over next decade due to reduced coal consumption

8. Policy recommendations and future outlook

To enable a just and sustainable energy transition, India must adopt a comprehensive approach across finance, infrastructure, governance, and research.

8.1 Strengthen Financing

Bridge the $3.5 trillion funding gap by mobilizing international climate finance, encouraging private investment, and adopting innovative tools like green bonds. Introduce financial incentives and flexible tariffs (e.g., for grid flexibility) to support technologies like green hydrogen.

8.2 Improve Grid Integration

Invest in transmission infrastructure and energy storage (target: 79.3 GW/411.4 GWh by 2031–32) to manage RE variability. Expand time-of-use tariffs, mandate rooftop solar registration, and improve national coordination of dispatch systems to enhance reliability and cost efficiency.

8.3 Address Land Conflicts and Ensure Just Transition

Mandate thorough Environmental and Social Impact Assessments (EIAs), ensure meaningful consultation with local communities, and secure land tenure. Prioritize renewable projects on degraded lands. Develop fair rehabilitation and resettlement plans including skills training for displaced populations.

8.4 Promote Collaboration and Awareness

Build capacity among local governments, foster cross-sectoral planning that integrates climate goals, and run awareness campaigns to promote public engagement and community-driven solutions.

8.5 Advance Research

Prioritize R&D on scalable energy storage, land acquisition impacts, and financing models. Enhance energy system models with localized data. Comparative policy studies can inform best practices from similar developing nations.

9. Conclusion

India faces the dual challenge of combating severe climate impacts while meeting the energy demands of a growing economy. The country is highly vulnerable to climate extremes, which disproportionately affect poor and marginalized communities.

India's strong renewable energy progress—especially in solar and wind—supported by ambitious goals (500 GW by 2030, net-zero by 2070), showcases its global leadership. Beyond emissions reduction, the transition delivers major socio-economic benefits, including jobs, rural electrification, energy security, and health improvements.

However, critical challenges persist: underdeveloped transmission and storage infrastructure, a $3.5 trillion investment gap, inconsistent policies, and rising land conflicts, especially in indigenous and ecologically sensitive areas. These issues reveal a pressing need for stronger governance, social equity, and community-inclusive planning.

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