



Green Energy Resources and Clean Environment in India: A Comprehensive Review

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Abstract

India's transition toward green energy represents one of the most significant structural transformations in its modern economic and environmental history. As one of the fastest-growing economies with rapidly increasing energy demand, India faces the dual challenge of ensuring energy security while mitigating climate change and environmental degradation. This comprehensive review critically examines the development, current status, technological advancements, policy frameworks, environmental implications, challenges, and future prospects of green energy resources in India. The study synthesizes developments across solar, wind, hydroelectric, biomass, and emerging green hydrogen sectors. It further evaluates their contribution to carbon emission reduction, air quality improvement, rural electrification, and sustainable development goals. The review highlights India's renewable capacity growth trajectory, policy-driven expansion, investment patterns, and environmental benefits. Despite remarkable progress, challenges such as grid integration, intermittency, land acquisition, financing constraints, and storage limitations persist. The paper concludes that sustained innovation, regulatory stability, technological advancement, and strategic investments are essential to achieve India's long-term clean energy and carbon neutrality ambitions.

Keywords: Green energy; Renewable resources; Solar power; Wind energy; Environmental sustainability; India

Introduction

Energy is fundamental to economic growth, industrial development, and societal progress. India, with a population exceeding 1.4 billion, has witnessed rapid industrialization and urban expansion, leading to a substantial rise in energy demand. Historically, India's energy sector has been dominated by coal and other fossil fuels, contributing significantly to greenhouse gas emissions and environmental pollution. Air pollution in major metropolitan regions, climate variability, and global commitments under international climate agreements have intensified the need for a transition toward cleaner energy systems. Green energy—derived from renewable and environmentally sustainable sources—has emerged as a strategic solution. Solar, wind, hydroelectric, biomass, and green hydrogen technologies form the backbone of India's renewable energy expansion. This review paper evaluates their collective role in promoting environmental sustainability and clean development.

Methods

As this is a comprehensive review paper based on synthesis of existing literature and data, no primary experimental methods were employed. The review draws from secondary sources including government reports, international agency outlooks, and peer-reviewed publications on renewable energy in India.

Results

Renewable Energy Growth in India India has experienced exponential growth in renewable energy capacity over the last decade. Government initiatives, declining technology costs, and global climate commitments have accelerated deployment.

Overview of Green Energy in India India has emerged as one of the fastest-growing renewable energy markets in the world, positioning green energy at the core of its sustainable development strategy. As the world's third-largest energy consumer, India faces a dual challenge: meeting rapidly increasing energy demand while reducing greenhouse gas emissions and environmental degradation. In response, the country has adopted an aggressive

renewable energy expansion strategy aligned with global climate commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement.

Table 1. Renewable Energy Installed Capacity Growth (GW)

Year	Installed Capacity (GW)
2014	35
2016	50
2018	75
2020	110
2022	155
2024	190

2017-2023 Installed Capacity and 2024-2030 IEA Forecast

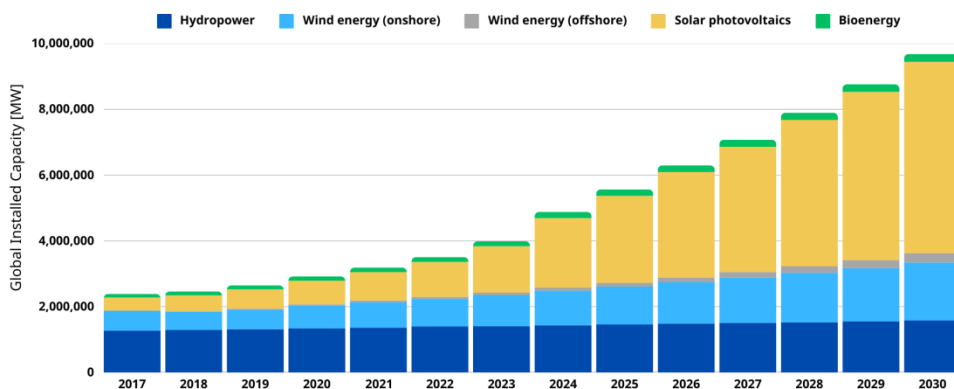


Fig. 1. Renewable Energy Capacity Growth Trend

Renewable Energy Capacity Growth Over the past decade, India has significantly expanded its renewable energy portfolio. The country has set ambitious targets of achieving 500 GW of non-fossil fuel energy capacity by 2030. Renewable energy sources now constitute a substantial share of installed electricity capacity, driven primarily by solar and wind power. The expansion is supported by the Ministry of New and Renewable Energy (MNRE), which coordinates policy formulation, investment facilitation, and implementation of large-scale renewable projects.

Table 2. Major Renewable Energy Sources in India

Energy Source	Key Regions	Contribution Trend	Environmental Benefit
Solar Power	Rajasthan, Gujarat, Tamil Nadu	Rapidly increasing	Zero operational emissions
Wind Energy	Tamil Nadu, Gujarat, Maharashtra	Stable growth	Reduces fossil dependency
Hydropower	Himachal Pradesh, Uttarakhand	Moderate	Clean baseload supply
Biomass	Punjab, Haryana, UP	Expanding	Waste-to-energy conversion
Green Hydrogen	Emerging nationwide	Early-stage	Future decarbonization driver

Solar Energy Dominance

Solar power represents the fastest-growing renewable sector in India. The launch of the National Solar Mission under the National Action Plan on Climate Change accelerated solar capacity deployment. Large-scale solar parks such as the Bhadla Solar Park have positioned India among global leaders in utility-scale solar installations. Declining photovoltaic (PV) module costs, improved grid integration, and favorable government incentives have significantly improved solar energy competitiveness compared to conventional coal-based power.

Wind Energy Expansion

India is one of the largest wind power producers globally. Wind corridors in southern and western states provide strong capacity factors. Technological improvements in turbine efficiency and hybrid renewable projects (solar-wind hybrids) are enhancing output reliability.

Major Green Energy Resources

Solar energy has emerged as the dominant renewable source in India due to high solar irradiance and declining photovoltaic costs. Large-scale solar parks and rooftop installations have significantly expanded capacity. Wind energy plays a crucial role in coastal and high-wind states. Hydropower ensures grid stability, while biomass supports rural electrification and waste-to-energy initiatives.

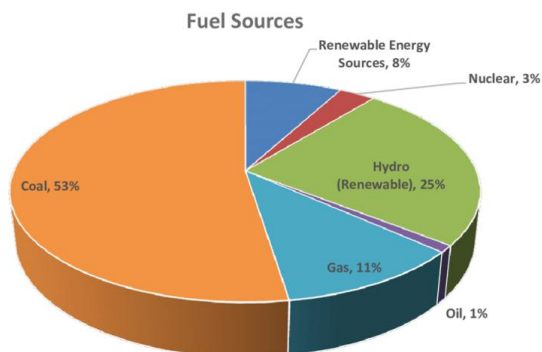


Fig. 2. Share of Renewable Energy Sources in India

Environmental Impact and Clean Environment The environmental benefits of renewable energy adoption are substantial. Transitioning from coal-based power generation to renewable energy significantly reduces carbon dioxide emissions, sulfur dioxide emissions, and particulate matter concentrations. This shift contributes to improved air quality, reduced respiratory illnesses, and lower climate-related risks.



Fig. 3. CO₂ Emission Intensity Trend

Policy and Institutional Framework India’s renewable energy expansion has been driven by strong policy support. Key programs include the National Solar Mission, Renewable Purchase Obligations (RPO), Production-Linked Incentive schemes, Green Hydrogen Mission, and various fiscal incentives. Regulatory reforms and competitive bidding have attracted domestic and foreign investments.

Table 3. Major Renewable Energy Policies in India

Policy	Purpose	National Solar Mission	Large-scale solar deployment
Wind-Solar Hybrid Policy	Optimize land & grid use	Renewable Purchase	Obligation Mandate renewable consumption Green Hydrogen Mission Promote hydrogen fuel PLI Scheme Boost domestic manufacturing

Policy and Institutional Framework India’s renewable energy growth is supported by strategic frameworks such as:
 National Action Plan on Climate Change (NAPCC) ·
 Renewable Purchase Obligations (RPOs) ·
 Production-Linked Incentive (PLI) Scheme for solar manufacturing ·
 Green Hydrogen Mission ·
 State-level renewable energy policies

Financial mechanisms such as viability gap funding, green bonds, and international climate finance have further accelerated deployment.

Environmental and Economic Significance

Green energy development contributes to:

- Reduction in carbon emissions
- Improved air quality in urban centers
- Energy security and reduced import dependence
- Employment generation in renewable manufacturing and installation
- Rural electrification and decentralized power access

The integration of renewables also supports India's broader commitment to achieving net-zero emissions by 2070. Emerging Trends India is now transitioning from capacity expansion toward: · Energy storage systems · Smart grid integration · Offshore wind projects · Green hydrogen production · Electrification of transport These developments indicate a structural transformation of India's energy ecosystem from fossil-dominant to sustainability-driven.

Discussion

Challenges and Constraints Despite rapid expansion, renewable energy deployment faces challenges including intermittency, storage limitations, financial barriers, transmission infrastructure gaps, land acquisition conflicts, and regulatory uncertainties. Addressing these issues requires integrated planning, technological advancement, and stakeholder collaboration.

Future Prospects and Technological Innovations Future growth will depend on advancements in battery storage, smart grids, artificial intelligence-driven energy management, green hydrogen production, offshore wind development, and decentralized energy systems. India's long-term objective of achieving net-zero emissions will require sustained renewable expansion and policy stability.

Conclusion

Green energy resources play a transformative role in ensuring a clean environment and sustainable economic growth in India. The country has made remarkable progress in renewable energy expansion; however, long-term sustainability will depend on technological innovation, robust policy frameworks, financial investments, and coordinated institutional efforts. A comprehensive transition toward renewable energy is essential for achieving environmental protection, energy security, and climate resilience.

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Author Contributions

Subramanyam M, Shanthikumar V conceived the concept, wrote and approved the manuscript.

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Competing interest

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Ethics approval

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