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RENEWABLE ENERGY IN INDIA: GROWTH TRAJECTORIES, STRUCTURAL CHALLENGES AND FUTURE PATHWAYS

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ABSTRACT

The transition toward renewable energy has emerged as a critical component of sustainable development, particularly in rapidly developing economies such as India. This study examines the growth trajectories, structural challenges and future pathways of renewable energy development, with a specific focus on solar and wind energy. The research is based on secondary data collected from national and international agencies, including MNRE, IEA and IRENA, and employs a trend analysis approach to evaluate capacity expansion and sectoral performance.

The findings indicate that India has achieved significant progress in expanding its renewable energy capacity, driven by supportive government policies, declining technology costs and increased private sector participation. However, the sector continues to face key challenges such as grid integration issues, intermittency of renewable sources, financial constraints and regulatory uncertainties.

The study highlights that while renewable energy offers substantial opportunities in terms of energy security, environmental sustainability and economic development, addressing existing structural and institutional barriers is essential for long-term success. It concludes that a comprehensive policy framework, investment in infrastructure and technological innovation are crucial to ensuring a sustainable and resilient energy transition in India.

Keywords: Renewable Energy, Energy Transition, Sustainability, Solar Power

INTRODUCTION

The transition toward renewable energy has emerged as a critical imperative in the global pursuit of sustainable development, particularly for rapidly developing economies such as India. Accelerated industrial

expansion, demographic pressures, and urban transformation have substantially intensified the nation's energy demand, thereby amplifying concerns related to energy security and environmental sustainability (IEA, 2023). Historically, India's energy architecture has been predominantly anchored in fossil fuel consumption, especially coal, which continues to constitute a significant share of electricity generation. This dependence has not only heightened carbon emissions but has also exacerbated ecological degradation and public health risks (BP Statistical Review, 2022).

In alignment with global climate governance frameworks, including the Paris Agreement and commitments under the United Nations Framework Convention on Climate Change, India has demonstrated an increasing commitment to decarbonizing its energy sector (UNFCCC, 2021). The national pledge to achieve net-zero carbon emissions by 2070, alongside intermediate targets for enhancing non-fossil fuel capacity, underscores a strategic policy shift toward clean energy transitions (Government of India, 2022). These commitments reflect a broader recognition of the need to balance economic growth with environmental stewardship.

Over the past decade, India's renewable energy sector has undergone a transformative expansion, facilitated by proactive policy interventions, technological advancements, and significant cost reductions in renewable technologies (IRENA, 2023). Flagship initiatives such as the National Solar Mission have catalyzed large-scale deployment of solar infrastructure, positioning India among the leading global markets for renewable energy investment and capacity addition (MNRE, 2024). This policy-driven momentum has also fostered increased participation from private and international stakeholders.

Among the various renewable sources, solar energy has assumed a dominant role owing to India's favorable geographical endowment characterized by high solar irradiance and extensive land availability (Sharma et al., 2022). Concurrently, wind energy continues to contribute significantly, particularly in resource-rich regions such as Tamil Nadu and Gujarat, thereby enhancing the diversification and resilience of the national energy mix (GWEC, 2023). This diversification is instrumental in mitigating risks associated with energy supply disruptions and price volatility in global fossil fuel markets.

Notwithstanding these advancements, the renewable energy transition in India is confronted with a range of structural and operational challenges. Key issues include inadequate grid infrastructure, intermittency and variability of renewable power generation, financial constraints, and regulatory inconsistencies (Singh & Kumar, 2023). The integration of variable renewable energy into existing power systems remains a complex technical challenge, necessitating investments in grid modernization and energy storage solutions. Additionally, land acquisition barriers and administrative bottlenecks continue to impede timely project execution (World Bank, 2022).

STATEMENT OF THE PROBLEM

Renewable energy is very important for sustainable development in India. Although the country has made good progress in increasing renewable energy capacity, several problems still exist. The growth of different energy sources is not balanced, as solar energy is growing faster than wind, biomass, and hydropower.

There are also issues such as poor grid infrastructure, which makes it difficult to manage renewable energy. The

intermittent nature of solar and wind energy creates challenges in maintaining a stable power supply. In addition, high investment costs and financial problems of power companies affect the development of the sector.

Policy changes, delays in approvals, and land acquisition issues also slow down renewable energy projects. Moreover, lack of advanced technology, skilled workers, and dependence on imports create further challenges.

Therefore, it is necessary to study these problems and find solutions to improve the growth and sustainability of renewable energy in India.

OBJECTIVES OF THE STUDY

- To critically assess the current status and composition of renewable energy capacity in India
- To analyze temporal growth patterns and emerging trends in renewable energy deployment
- To identify structural, financial, and regulatory challenges affecting sectoral expansion
- To evaluate future prospects and policy implications for sustainable energy transition

METHODOLOGY

The study adopts a descriptive and analytical research design, relying exclusively on secondary data. Data sources include reports from the Ministry of New and Renewable Energy (MNRE), International Energy Agency (IEA), International Renewable Energy Agency (IRENA), and other institutional publications.

A trend analysis approach is employed to examine capacity growth over time, while comparative analysis is used to evaluate the contribution of different renewable energy sources. The methodological framework emphasizes interpretative analysis to derive policy-relevant insights.

CURRENT SCENARIO OF RENEWABLE ENERGY IN INDIA

India's renewable energy sector has undergone a significant transformation, positioning the country as a key global actor in clean energy deployment. As of recent estimates, total installed renewable energy capacity has surpassed 250 GW, reflecting sustained growth momentum (MNRE, 2025).

Solar energy constitutes the largest share of this capacity, driven by large-scale solar parks, decentralized installations, and favorable tariff regimes. Wind energy remains the second-largest contributor, although its growth trajectory has been relatively moderate compared to solar expansion. Hydropower continues to provide a stable base, while biomass and other sources contribute marginally.

Importantly, renewable energy now accounts for a substantial proportion of India's total electricity generation capacity, indicating a gradual shift away from fossil fuel dependence. This transition is further reinforced by increasing investments and international collaborations in the clean energy sector.

TREND ANALYSIS OF RENEWABLE ENERGY GROWTH

The growth trajectory of renewable energy capacity in India demonstrates a consistent and accelerating upward trend over the past decade.

S.No	**Year**	**Installed Capacity (GW)**	**Growth Characteristics**
1.	2020	~90 GW	Early expansion phase
2.	2022	~150 GW	Policy-driven acceleration

3.	2024	~220 GW	Rapid solar adoption
4.	2025	~258 GW	Record capacity additions
5.	2026	~267 GW	Consolidation phase

The data indicates a structural shift toward solar energy dominance, supported by declining costs and scalability advantages. The compound annual growth rate (CAGR) reflects strong sectoral expansion, although recent trends suggest the need for infrastructural alignment to sustain growth momentum.

COMPOSITION OF RENEWABLE ENERGY SOURCES

Solar Energy: Solar energy has emerged as the primary driver of India's renewable energy expansion. The declining cost of photovoltaic technology, coupled with policy incentives, has facilitated large-scale deployment. Utility-scale solar projects and rooftop installations have significantly contributed to capacity addition.

Wind Energy: Wind energy continues to play a vital role, particularly in resource-rich states. However, issues related to land availability, transmission infrastructure, and policy uncertainty have moderated its growth relative to solar energy.

Hydropower: Hydropower remains a critical component of India's renewable energy mix, providing base-load support. Nevertheless, environmental concerns and long gestation periods limit its expansion potential.

Biomass Energy: Biomass energy contributes to decentralized energy generation, particularly in rural areas. Despite its potential, its overall share remains limited due to technological and logistical constraints.

OPPORTUNITIES IN RENEWABLE ENERGY DEVELOPMENT

Abundant Renewable Resource Potential: India is endowed with substantial renewable resource potential, particularly in solar and wind energy, which provides a strong foundation for large-scale deployment. The country receives high solar irradiation across most regions, estimated at 4–7 kWh/m²/day, making solar energy one of the most viable options for sustainable electricity generation (IRENA, 2023). Additionally, coastal and inland wind corridors offer significant capacity for wind energy development. This natural advantage not only reduces dependence on imported fuels but also enhances long-term energy sustainability.

Strong Policy and Institutional Support: The growth of renewable energy in India has been significantly driven by proactive government policies and institutional frameworks. Initiatives such as the National Solar Mission have facilitated capacity expansion through incentives, subsidies, and regulatory support (MNRE, 2024). Furthermore, mechanisms like Renewable Purchase Obligations (RPOs) and competitive bidding processes have encouraged private sector participation. Such policy interventions create a stable investment climate and accelerate the transition toward clean energy systems.

Declining Cost of Renewable Technologies: Technological advancements and economies of scale have led to a substantial decline in the cost of renewable energy technologies, particularly solar photovoltaic systems. Over the past decade, solar tariffs in India have reached historically low levels, making them competitive with conventional fossil fuel-based power generation (IEA, 2023). This cost competitiveness enhances the economic feasibility of renewable energy projects and attracts both domestic and international investors.

Energy Security and Reduced Import Dependence: The expansion of renewable energy contributes

significantly to national energy security by reducing reliance on imported fossil fuels such as coal, oil, and natural gas. Given the volatility of global energy markets, increasing domestic renewable capacity provides greater stability and resilience (NITI Aayog, 2023). This transition also mitigates risks associated with supply disruptions and fluctuating fuel prices, thereby strengthening India's macroeconomic stability.

Employment Generation Potential: The renewable energy sector has emerged as a major source of employment, offering opportunities across various stages of the value chain, including manufacturing, installation, operation, and maintenance. According to IRENA (2022), the sector has the potential to create millions of jobs, particularly in rural and semi-urban areas. This employment generation contributes to inclusive economic growth and supports skill development initiatives.

Attraction of Foreign Direct Investment (FDI): India's renewable energy sector has attracted significant foreign direct investment due to its high growth potential and supportive policy environment. International investors are increasingly participating in large-scale solar and wind projects, contributing to capital inflows and technological transfer (World Bank, 2022). This inflow of foreign capital enhances the financial capacity of the sector and accelerates infrastructure development.

Technological Innovation and Digital Integration: The integration of advanced technologies such as artificial intelligence, smart grids, and energy storage systems has significantly improved the efficiency and reliability of renewable energy systems. These innovations enable better demand-supply management, grid stability, and predictive maintenance (IEA, 2023). As digitalization continues to evolve, it is expected to play a crucial role in optimizing renewable energy operations.

Decentralized Energy Access and Rural Development: Renewable energy technologies facilitate decentralized power generation, which is particularly beneficial for rural and remote areas with limited access to grid infrastructure. Off-grid and mini-grid solutions powered by solar and biomass energy enhance energy accessibility and improve living standards (UNDP, 2022). This contributes to rural development, poverty alleviation, and social inclusion.

Climate Change Mitigation Commitments: The expansion of renewable energy is closely aligned with India's international climate commitments under the Paris Agreement. By reducing greenhouse gas emissions, renewable energy plays a critical role in mitigating climate change and achieving sustainable development goals (UNFCCC, 2021). This alignment enhances India's global standing in climate governance.

Industrial Growth and Green Economy Transition: The renewable energy sector acts as a catalyst for the development of green industries, including manufacturing of solar panels, wind turbines, and energy storage systems. This transition supports the emergence of a low-carbon economy and fosters innovation (OECD, 2023). The development of domestic manufacturing capabilities also reduces dependence on imports and strengthens industrial competitiveness. **CHALLENGES IN RENEWABLE ENERGY TRANSITION**

Grid Integration and Infrastructure Constraints: The rapid expansion of renewable energy capacity has placed significant pressure on existing grid infrastructure, which is often inadequate for handling variable power inputs. The lack of modern transmission systems and grid flexibility limits the efficient integration of renewable energy (IEA, 2023). Addressing these infrastructural gaps requires substantial investment in grid modernization and smart

technologies.

Intermittency and Variability of Renewable Sources: Renewable energy sources such as solar and wind are inherently intermittent, as their generation depends on weather conditions. This variability poses challenges for maintaining grid stability and ensuring a continuous power supply (IRENA, 2023). The absence of adequate storage solutions further exacerbates this issue, necessitating advancements in energy storage technologies.

High Initial Capital Investment: Renewable energy projects are capital-intensive, requiring significant upfront investment for infrastructure development. Although operational costs are relatively low, the high initial expenditure can act as a barrier for investors, particularly in developing economies (World Bank, 2022). Access to affordable financing remains a critical challenge for scaling renewable energy projects.

Land Acquisition and Regulatory Barriers: Large-scale renewable energy projects require extensive land, which often leads to conflicts related to land acquisition and environmental clearances. Regulatory complexities and bureaucratic delays further hinder project implementation (MNRE, 2024). These challenges increase project costs and extend timelines, affecting overall efficiency.

Policy Uncertainty and Regulatory Inconsistencies: Frequent changes in policies, tariffs, and regulatory frameworks create uncertainty for investors and developers. Inconsistent policy implementation across states further complicates the investment landscape (NITI Aayog, 2023). Ensuring policy stability and transparency is essential for fostering long-term investment in the sector.

Limited Energy Storage Infrastructure: The lack of adequate energy storage systems limits the ability to store excess renewable energy for later use. This constraint reduces the overall efficiency of renewable energy utilization and affects grid reliability (IEA, 2023). Investment in battery storage and other technologies is crucial for addressing this challenge.

Financial Risks and Funding Constraints: Financial challenges such as delayed payments by distribution companies (DISCOMs) and high levels of debt impact the viability of renewable energy projects. These risks discourage investment and affect the financial sustainability of the sector (World Bank, 2022). Strengthening the financial health of power utilities is therefore essential.

Technological and Skill Gaps: Despite advancements, the renewable energy sector faces shortages of skilled labor and technical expertise. The lack of adequate training and capacity-building initiatives hampers efficient project implementation (IRENA, 2022). Addressing skill gaps is critical for sustaining sectoral growth.

Environmental and Social Concerns: While renewable energy is environmentally beneficial, large-scale projects can have localized ecological and social impacts, including habitat disruption and displacement of communities. Balancing environmental sustainability with development objectives remains a complex challenge (OECD, 2023).

Dependence on Imported Components: India's renewable energy sector, particularly solar manufacturing, remains dependent on imported components such as photovoltaic modules. This dependence exposes the sector to supply chain disruptions and geopolitical risks (IEA, 2023). Developing domestic manufacturing capabilities is essential for long-term sustainability.

POLICY FRAMEWORK AND INSTITUTIONAL SUPPORT

India's renewable energy expansion is underpinned by a comprehensive policy framework, including:

- National Solar Mission
- Renewable Purchase Obligations (RPO)
- Production Linked Incentive (PLI) Scheme
- Green Energy Corridor Initiative These policies aim to facilitate capacity expansion, enhance domestic manufacturing, and improve grid infrastructure. However, effective implementation and policy stability remain critical for long-term success.

FINDINGS OF THE STUDY

- Renewable energy capacity in India has expanded significantly, with solar energy leading growth
- Policy interventions and technological advancements have been primary drivers
- Structural challenges, particularly in infrastructure and financing, persist
- Renewable energy is increasingly central to India's energy security strategy
- Sustained growth requires integration of technological, financial, and policy measures

SUGGESTIONS

- Improve electricity grid infrastructure to support renewable energy growth. This will help manage power supply efficiently and reduce transmission losses.
- Promote energy storage systems such as batteries and pumped storage. This will help store excess energy and ensure continuous power supply.
- Ensure stable and clear government policies for investors. Consistent policies will increase confidence and attract more investments in India.
- Provide easy and affordable loans for renewable energy projects. Financial support will encourage both public and private sector participation.
- Encourage domestic production of solar panels and equipment. This will reduce dependence on imports and strengthen the local industry.
- Support rooftop solar and small-scale renewable systems. This will improve electricity access, especially in rural and remote areas.
- Improve coordination between government departments and agencies. Better coordination will speed up project approvals and implementation.
- Invest more in research and development of new technologies. Innovation will improve efficiency and reduce the cost of renewable energy.
- Provide training and skill development programs for workers. Skilled manpower will ensure better installation and maintenance of systems.

CONCLUSION

Renewable energy has become a key driver of sustainable development in India. The country has made significant progress in expanding its renewable energy capacity, especially in solar energy, supported by government policies and technological advancements. This growth has contributed to improving energy security and reducing environmental impact.

However, several challenges such as inadequate grid infrastructure, financial constraints, policy uncertainties, and dependence on imported components continue to affect the sector's growth. Issues related to intermittency and energy storage also need to be addressed to ensure a stable power supply.

Therefore, a balanced approach involving strong policy support, investment in infrastructure, promotion of domestic manufacturing, and technological innovation is essential. By overcoming these challenges, India can achieve a sustainable, reliable, and long-term energy transition.

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