



Accelerating India's Energy Independence Through Renewable Energy Transition: Challenges, Policy Interventions, and Future Directions

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Abstract

India's increasing energy demand and heavy dependence on imported fossil fuels have made energy independence a national priority. Renewable energy has emerged as the most sustainable solution for reducing import dependence, improving energy security, and supporting economic development. This review examines the role of renewable energy in accelerating India's transition toward energy independence. The paper discusses the growth of renewable energy resources, major government policies, institutional support, and existing challenges affecting renewable energy deployment. It also reviews recent policy initiatives, including the National Solar Mission, Production Linked Incentive (PLI) Scheme, National Green Hydrogen Mission, and PM-KUSUM programme. Finally, the study proposes policy recommendations for strengthening renewable energy adoption, domestic manufacturing, and governance to achieve India's vision of energy independence by 2047. The review concludes that renewable energy, supported by effective policies and institutional reforms, will play the most significant role in India's sustainable energy future.

Keywords: Renewable energy, Energy independence, India, Energy security, Solar energy, Green hydrogen, Renewable energy policy.



1. Introduction

Energy is one of the most important drivers of economic growth and industrial development. As one of the fastest-growing economies in the world, India requires a reliable and affordable energy supply to support industrialization, urbanization, transportation, and improving living standards. However, the country continues to depend heavily on imported crude oil, natural gas, and coal to meet its growing energy demand. This dependence increases India's exposure to international fuel price fluctuations, geopolitical uncertainties, and supply-chain disruptions, making energy security a major national concern [1–4].

To address these challenges, India has adopted renewable energy as a strategic solution for achieving long-term energy independence. Renewable resources such as solar, wind, hydropower, biomass, and green hydrogen are available domestically and can significantly reduce the country's dependence on imported fossil fuels. Over the past decade, India has become one of the world's fastest-growing renewable energy markets through supportive government policies, increased investments, and technological advancements [1,5–8].

The Government of India has launched several flagship initiatives to accelerate renewable energy development, including the National Solar Mission, National Green Hydrogen Mission, PM-KUSUM, Production Linked Incentive (PLI) Scheme, Renewable Purchase Obligations (RPOs), and Green Open Access Rules. These initiatives not only promote clean energy generation but also encourage domestic manufacturing, employment generation, technological innovation, and industrial self-reliance. Such efforts are closely aligned with the vision of Atmanirbhar Bharat, which emphasizes reducing dependence on imports while strengthening domestic industries [1,9–12].

Renewable energy also contributes to environmental sustainability by reducing greenhouse gas emissions, improving air quality, and supporting India's commitments under the Paris Agreement. In addition, renewable energy enhances rural development through decentralized electricity generation, solar-powered agriculture, and distributed energy systems. These multiple benefits make renewable energy a key component of India's sustainable development strategy [5,13–15].

Despite significant progress, several challenges continue to affect India's renewable energy transition. Grid integration, energy storage, financing, land acquisition, domestic manufacturing, critical mineral supply, and policy coordination remain major issues requiring continuous government attention. Addressing these challenges through effective policy interventions and institutional reforms is essential for achieving the goal of energy independence by 2047 [2,5,16].

This review examines the contribution of renewable energy to India's energy independence by analysing the country's renewable energy resources, government policies, institutional initiatives, and future opportunities. The paper also discusses the role of governance, domestic manufacturing, and sustainability in accelerating the renewable energy transition.

Table 1. Major Renewable Energy Policies Supporting Energy Independence in India

Policy	Year	Objective	Contribution
National Solar Mission	2010	Promote solar power	Reduce dependence on fossil fuels
National Biofuel Policy	2018	Promote biofuels	Reduce crude oil imports
PM-KUSUM	2019	Solar-powered agriculture	Replace diesel pumps
Production Linked Incentive (PLI) Scheme	2021	Domestic renewable manufacturing	Improve self-reliance



Updated Nationally Determined Contributions	2022	Expand non-fossil energy	Support clean energy transition
National Green Hydrogen Mission	2023	Promote green hydrogen	Decarbonize industries and reduce fossil fuel use

Objectives of the Review

The objectives of this review are:

1. To examine the importance of renewable energy in achieving India's energy independence.
2. To review major renewable energy policies and government initiatives.
3. To identify the key challenges affecting renewable energy deployment.
4. To propose future policy recommendations for accelerating India's renewable energy transition.

2. Renewable Energy as the Foundation of India's Energy Independence

Renewable energy has become the cornerstone of India's strategy to achieve energy independence. Unlike fossil fuels, renewable energy resources are naturally available within the country and can provide a reliable, sustainable, and environmentally friendly source of power. Increasing the share of renewable energy in the national energy mix reduces dependence on imported crude oil, coal, and natural gas while improving energy security and supporting economic growth [1,5,13,17].

India has significant renewable energy potential due to its favorable geographical conditions. High solar radiation, long coastlines suitable for wind power, abundant biomass resources, and extensive hydropower potential provide opportunities for generating clean energy on a large scale. The rapid expansion of renewable energy has already reduced carbon emissions, attracted private investment, and created employment opportunities across various sectors [5,17–19].

2.1 Solar Energy

Solar energy is the largest contributor to India's renewable energy transition. The country receives abundant sunshine throughout the year, making solar power one of the most economical and scalable energy sources. The National Solar Mission and declining photovoltaic costs have significantly increased installed solar capacity over the past decade. Large-scale solar parks, rooftop solar systems, and agricultural solar pumps have reduced dependence on conventional electricity and diesel-based energy systems [1,5,11,20].

Solar energy also supports rural electrification by providing reliable electricity to remote areas where conventional grid expansion is difficult. The PM-KUSUM programme has enabled farmers to adopt solar-powered irrigation systems, reducing diesel consumption while lowering agricultural production costs.

2.2 Wind Energy

India is among the leading countries in wind energy generation. States such as Gujarat, Tamil Nadu, Karnataka, Maharashtra, and Rajasthan possess excellent wind resources that contribute significantly to electricity generation. Wind energy complements solar power because electricity generation often occurs during periods of lower solar output, thereby improving overall grid reliability [17,18,21].



The development of offshore wind projects and modern turbine technologies is expected to further increase wind power generation while reducing dependence on fossil fuel-based electricity.

2.3 Hydropower and Biomass

Hydropower continues to play an important role in India's renewable energy mix by providing stable and flexible electricity generation. Unlike solar and wind energy, hydropower can supply electricity during periods of low renewable generation and helps maintain grid stability.

Biomass and waste-to-energy technologies provide additional opportunities for reducing fossil fuel consumption. Agricultural residues, municipal solid waste, and industrial biomass can be converted into electricity, heat, and biofuels, simultaneously addressing waste management and energy security challenges. Bioenergy also supports rural employment and promotes a circular economy by utilizing locally available resources [7,15,22].

2.4 Green Hydrogen

Green hydrogen has emerged as a promising renewable energy carrier capable of replacing fossil fuels in sectors where direct electrification is difficult. Heavy industries such as steel, fertilizer, cement, and petroleum refining require high-temperature processes that can benefit from hydrogen-based technologies. The National Green Hydrogen Mission aims to develop domestic hydrogen production using renewable electricity, reducing dependence on imported natural gas and fossil fuels [13,23].

Green hydrogen is also expected to support heavy transport, shipping, and long-duration energy storage, strengthening India's long-term energy security.

2.5 Energy Storage and Smart Grids

The increasing share of renewable energy requires efficient energy storage systems and modern electricity grids. Since solar and wind energy are intermittent, battery storage, pumped hydro storage, and smart grid technologies are essential for maintaining reliable electricity supply.

Smart grids improve electricity transmission, demand forecasting, and energy management while reducing transmission losses. Battery storage systems enable surplus renewable electricity generated during peak production periods to be stored and used when demand increases. These technologies improve grid flexibility and accelerate renewable energy integration into the national power system [4,17,24].

2.6 Renewable Energy and Domestic Manufacturing

Renewable energy deployment should be accompanied by strong domestic manufacturing to achieve true energy independence. Importing solar panels, batteries, and other clean energy equipment creates new forms of dependence. Therefore, India has introduced policies such as the Production Linked Incentive (PLI) Scheme to encourage domestic manufacturing of solar photovoltaic modules, battery systems, and other renewable energy technologies [11,16].

Developing indigenous manufacturing capabilities strengthens supply chains, creates employment opportunities, promotes technological innovation, and improves industrial competitiveness. Domestic



production also supports the vision of **Atmanirbhar Bharat** by reducing dependence on imported clean energy equipment.

Table 2. Contribution of Renewable Energy Sources to Energy Independence

Renewable Source	Energy	Major Contribution	Impact on Fossil Fuel Dependence
Solar Energy		Electricity generation, agricultural pumps	Reduces coal and diesel consumption
Wind Energy		Utility-scale electricity generation	Reduces coal-based power generation
Hydropower		Grid stability and peak power supply	Supports renewable electricity integration
Biomass and Bioenergy		Electricity, heat, and biofuels	Reduces dependence on petroleum and coal
Green Hydrogen		Industrial fuel and transport	Replaces natural gas and fossil fuels
Battery Storage		Renewable energy integration	Improves reliability of renewable electricity
Smart Grids		Efficient electricity management	Supports large-scale renewable deployment

The rapid expansion of renewable energy demonstrates that India possesses sufficient natural resources and technological capability to reduce dependence on imported fossil fuels. However, the success of this transition depends on supportive government policies, institutional coordination, financial incentives, and effective implementation mechanisms. Therefore, the next section examines the major policy interventions and governance frameworks that are accelerating India's renewable energy transition toward long-term energy independence.

3. Policy Interventions Supporting Renewable Energy Transition

Government policies have played a crucial role in accelerating renewable energy development in India. Over the last decade, several national programmes have encouraged renewable energy generation, domestic manufacturing, energy efficiency, and clean technology adoption. These policy interventions aim not only to increase renewable energy capacity but also to reduce dependence on imported fossil fuels, strengthen energy security, and promote sustainable economic growth [1,5,11].

3.1 National Solar Mission

The National Solar Mission is one of India's flagship renewable energy programmes. It has significantly increased solar power generation by promoting utility-scale solar parks, rooftop solar systems, and decentralized solar projects. The mission has attracted both domestic and international investment, making India one of the fastest-growing solar energy markets in the world [1,5,17].

3.2 Production Linked Incentive (PLI) Scheme

The Production Linked Incentive (PLI) Scheme was introduced to strengthen domestic manufacturing of high-efficiency solar photovoltaic modules and other clean energy technologies. The programme encourages industries to manufacture renewable energy equipment within India, thereby reducing dependence on imported



technologies and supporting the vision of Atmanirbhar Bharat. Domestic manufacturing also generates employment, improves supply-chain resilience, and enhances India's global competitiveness [11,16].

3.3 National Green Hydrogen Mission

Green hydrogen is expected to become an important component of India's future energy system. The National Green Hydrogen Mission promotes domestic production of hydrogen using renewable electricity, particularly for industries such as steel, fertilizer, petroleum refining, and heavy transportation. The policy also encourages research, innovation, and infrastructure development for hydrogen production and utilization [13,23].

3.4 PM-KUSUM and Agricultural Solarization

The PM-KUSUM scheme supports the installation of solar-powered irrigation pumps and decentralized solar power plants. The programme reduces farmers' dependence on diesel pumps, lowers agricultural energy costs, and increases the use of renewable energy in rural areas. Solar-powered agriculture also contributes to rural development while reducing greenhouse gas emissions [15].

3.5 Renewable Purchase Obligations and Green Open Access

Renewable Purchase Obligations (RPOs) require electricity distribution companies and large consumers to procure a specified percentage of electricity from renewable energy sources. Similarly, the Green Open Access Rules encourage industries to directly purchase renewable electricity, thereby increasing renewable energy consumption and attracting private investment in clean energy projects [11,20].

3.6 ESG Governance and Sustainable Energy Policies

Renewable energy expansion should be accompanied by strong governance and environmental accountability. Environmental, Social, and Governance (ESG) principles help governments and industries evaluate sustainability performance while ensuring transparency and responsible decision-making. Effective ESG implementation strengthens investor confidence and improves the credibility of renewable energy programmes.

Patyrykin and Vasyukova emphasized that weak ESG implementation often results in symbolic compliance rather than measurable environmental improvements. Therefore, transparent ESG reporting and accountability mechanisms are essential for ensuring that renewable energy policies achieve their intended sustainability objectives [32].

3.7 Digital Governance and Renewable Energy Management

Digital technologies have become important tools for improving renewable energy planning, monitoring, and policy implementation. Artificial intelligence, automation, smart meters, cloud computing, and data analytics enable governments to monitor renewable energy projects more efficiently and improve decision-making.

Patel and Patyrykin reported that digital automation enhances organizational efficiency, improves information management, and supports better strategic decision-making. Similar digital approaches can strengthen renewable energy governance by improving transparency, reducing administrative delays, and facilitating faster implementation of renewable energy projects [30].



3.8 Sustainability Assessment for Renewable Energy Projects

As renewable energy investments continue to grow, systematic evaluation of project performance becomes increasingly important. Sustainability assessment frameworks help policymakers compare renewable energy projects based on environmental, economic, and operational performance.

The Environmental–Efficiency–Economic (EEE) Impact Model developed by Jena et al. provides an integrated framework for evaluating alternative energy systems by considering economic viability, operational efficiency, and environmental performance [24]. Similarly, the Plant Overall Performance (POP) Index offers a practical approach for monitoring operational performance and continuous improvement of industrial systems [23]. Furthermore, sustainability initiatives positively influence stakeholder confidence and public acceptance, supporting wider adoption of renewable energy programmes [27].

Table 3. Major Renewable Energy Policies Supporting Energy Independence

Policy	Main Objective	Contribution to Energy Independence
National Solar Mission	Expand solar power generation	Reduce coal dependence
Production Linked Incentive (PLI) Scheme	Domestic manufacturing	Reduce technology imports
National Green Hydrogen Mission	Promote green hydrogen	Reduce fossil fuel consumption in industries
PM-KUSUM	Solar-powered agriculture	Replace diesel irrigation pumps
Renewable Purchase Obligation (RPOs)	Increase renewable electricity use	Accelerate renewable energy deployment
Green Open Access Rules	Encourage renewable electricity procurement	Promote private investment
ESG Governance	Improve sustainability and accountability	Strengthen environmental performance
Digital Energy Management	Smart monitoring and automation	Improve policy implementation efficiency

The progress achieved through these policy interventions demonstrates India's strong commitment to renewable energy development. Nevertheless, achieving complete energy independence requires overcoming several technical, financial, and institutional challenges. The following section discusses these challenges and presents future policy recommendations for accelerating India's renewable energy transition by 2047.

4. Challenges, Future Directions

4.1 Challenges to Renewable Energy Transition

Although India has made remarkable progress in renewable energy development, several challenges continue to influence the pace of the energy transition. One of the major challenges is the intermittent nature of renewable energy sources such as solar and wind power. Electricity generation from these resources depends on weather conditions, making efficient energy storage systems and modern grid infrastructure essential for ensuring a reliable power supply [4,17,26].



Another significant challenge is the expansion of transmission infrastructure. Many renewable energy projects are located in remote regions where grid connectivity is limited. Strengthening transmission networks and developing smart grids are necessary to efficiently transfer renewable electricity from generation sites to consumption centers [17,20].

Financing also remains an important concern. Although renewable energy costs have declined considerably, large-scale investments are still required for solar parks, offshore wind projects, battery storage, hydrogen production, and transmission infrastructure. Expanding green finance, public-private partnerships, and climate investment funds will help accelerate renewable energy deployment [2,8].

Domestic manufacturing presents another challenge. India continues to depend on imports of solar photovoltaic modules, batteries, and critical minerals required for renewable energy technologies. Strengthening domestic manufacturing under the Production Linked Incentive (PLI) Scheme and encouraging research and innovation can improve supply-chain resilience and reduce import dependence [11,16].

Policy implementation also requires better coordination among central and state governments. Differences in regulations, approval procedures, and electricity tariffs sometimes delay renewable energy projects. Simplified regulations and improved institutional coordination can accelerate project implementation and improve investor confidence [5,11].

4.2 Future Directions

India has significant opportunities to become one of the world's leading renewable energy economies. Future policy efforts should focus on increasing renewable electricity generation while simultaneously strengthening domestic manufacturing, digital energy systems, and research capacity.

The National Green Hydrogen Mission should be expanded to support industrial decarbonization and reduce fossil fuel consumption in sectors such as steel, fertilizer, petroleum refining, and heavy transportation [13,36]. Similarly, continued investment in battery energy storage and smart grid technologies will improve renewable energy reliability and facilitate large-scale renewable integration.

Artificial intelligence, digital monitoring systems, and data analytics can improve renewable energy forecasting, project monitoring, and electricity demand management. Digital governance will enable better policy implementation and increase the efficiency of renewable energy infrastructure [30].

Environmental governance should also receive greater attention. Strong ESG reporting frameworks, transparent sustainability assessment, and continuous performance monitoring can improve policy accountability and enhance investor confidence. Effective environmental governance ensures that renewable energy projects deliver measurable environmental and social benefits rather than symbolic compliance [32].

Research and development should remain a national priority. Universities, research institutions, industries, and government agencies should collaborate to develop advanced renewable energy technologies, battery systems, hydrogen production, recycling technologies, and smart energy management systems. Such collaboration will strengthen India's innovation ecosystem while promoting long-term industrial competitiveness.



4.3 Policy Recommendations

Based on the review, the following recommendations are proposed to accelerate India's renewable energy transition:

- Increase investment in solar, wind, biomass, and green hydrogen projects.
- Strengthen domestic manufacturing of renewable energy technologies through continued support for the PLI Scheme.
- Expand battery energy storage and modernize transmission infrastructure.
- Improve coordination between central and state governments for faster policy implementation.
- Promote green finance through sovereign green bonds and climate investment funds.
- Encourage artificial intelligence and digital technologies for renewable energy management.
- Strengthen ESG reporting and sustainability assessment for renewable energy projects.
- Support research, innovation, and university-industry collaboration in clean energy technologies.
- Develop policies for critical mineral security and recycling of renewable energy equipment.
- Encourage public awareness and community participation in renewable energy adoption.

5. Conclusion

Renewable energy has become the most important pillar of India's strategy to achieve long-term energy independence. The country's abundant solar, wind, hydropower, biomass, and green hydrogen resources provide significant opportunities to reduce dependence on imported fossil fuels while supporting sustainable economic growth. During the past decade, government initiatives such as the National Solar Mission, PM-KUSUM, the Production Linked Incentive Scheme, and the National Green Hydrogen Mission have accelerated renewable energy deployment and strengthened India's clean energy transition.

The review demonstrates that renewable energy contributes not only to energy security but also to industrial development, employment generation, environmental protection, and climate change mitigation. Domestic manufacturing, supported by policy initiatives such as the PLI Scheme, is equally important for reducing dependence on imported renewable energy technologies and strengthening industrial self-reliance.

Despite these achievements, challenges related to grid integration, energy storage, financing, domestic manufacturing, critical minerals, and institutional coordination remain. Addressing these issues through stable policies, technological innovation, digital governance, and effective environmental accountability will further accelerate India's renewable energy transition.

The review also highlights the importance of integrating sustainability assessment and transparent governance into renewable energy planning. Strong ESG practices, digital monitoring systems, and comprehensive performance evaluation frameworks can improve policy implementation, attract sustainable investment, and enhance public confidence in renewable energy programmes.

Overall, renewable energy represents the most practical and sustainable pathway for achieving India's vision of energy independence by 2047. With continued policy support, technological advancement, domestic manufacturing, and institutional cooperation, India can establish a resilient, low-carbon, and self-reliant energy system that supports economic development while contributing to global climate goals.



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