

## Green Energy for a Developed India @2047: A Sustainable Roadmap for the Future

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### Abstract

India's transition towards a sustainable, low-carbon future has emerged as a central pillar of its developmental roadmap for a Developed India @2047. Drawing on insights from Government of India policy documents, international agencies such as the IEA, IRENA, UNEP, IPCC, and significant academic works published by Springer, Oxford University Press, TERI, and Routledge, this study examines the evolution, opportunities, and challenges of India's green energy transformation. The trajectory of renewable energy expansion—anchored by the National Solar Mission, National Green Hydrogen Mission, PM-KUSUM, FAME-II, biofuel initiatives, and wind-solar hybrid policies—reveals a steady shift from fossil-fuel dependence to diversified clean energy systems. Literature indicates that India's solar and wind sectors have become globally competitive, supported by declining costs, strong institutional frameworks, and technological innovation.

At the same time, reports from NITI Aayog, RBI, and the Ministry of Power highlight persistent barriers, including grid limitations, financing constraints, storage challenges, and regional disparities in deployment. The reviewed works consistently emphasise the role of green hydrogen, decentralised systems, EV adoption, and sustainable finance as future growth drivers. International analyses, especially from the IEA and the World Bank, project that India will lead global energy demand growth while also having one of the world's highest renewable energy potentials.

Overall, the literature underscores that India's green energy transition is not only an environmental necessity but also a strategic pathway to economic competitiveness, energy security, and social inclusion. Achieving the India @2047 vision will require policy coherence, technological innovation, and strong community participation.

**Keywords:** Green Energy; Renewable Energy Transition; India @2047; Energy Security; Green Hydrogen; Sustainable Development; Climate Resilience.

### Introduction

As India approaches its centenary of independence in 2047, the nation seeks to transition into a developed, inclusive, and environmentally resilient economy. The vision of **Developed India @2047** underscores that sustainable development is inseparable from long-term socio-economic progress (NITI Aayog, 2021). Contemporary development frameworks emphasise that growth in the 21st century must be assessed not only by economic indicators but also by environmental sustainability, renewable energy adoption, and climate resilience (United Nations, 2023).

India remains among the world's most climate-vulnerable regions. The country already experiences intensified heatwaves, erratic monsoon patterns, recurring droughts, glacial retreat in the Himalayas, and rising sea levels that threaten major coastal cities (IPCC, 2021; Ministry of Earth Sciences, Government of India, 2020). These climate-induced pressures demand that India's future developmental path aligns closely with low-carbon strategies and adaptation policies.

A significant step in this direction was India's announcement of the "**Panchamrit**" climate commitments at **COP-26**, which place renewable and green energy at the centre of national climate action (Government of India, 2021). Green energy — comprising solar, wind, hydropower, biomass, geothermal, tidal energy, and

green hydrogen — forms the basis of India's long-term sustainable energy architecture (MNRE, 2022). Beyond environmental benefits, renewable energy offers substantial socio-economic advantages, including employment generation, rural electrification, technological innovation, and reduced dependence on fossil-fuel imports (International Energy Agency, 2023).

Thus, India's aspiration to become a developed nation by 2047 is closely intertwined with its capacity to accelerate renewable energy deployment, strengthen climate policies, and build a resilient, low-carbon economy. Achieving this transformation requires coordinated progress in research, technological innovation, governance, and citizen participation.

## 2. Understanding Green Energy: Concept and Relevance

Green energy refers to power generated from natural, renewable, low-carbon resources that do not harm the ecological balance. Unlike fossil fuels — coal, petroleum, and natural gas — which release harmful greenhouse gases, green energy sources sustain ecosystems while meeting human energy needs. Solar radiation, wind flows, river currents, geothermal heat, agricultural residues, and hydrogen fuel are examples of green energy assets.

For India, green energy has multidimensional relevance:

- It reduces dependence on imported fossil fuels and strengthens **energy sovereignty**
- It supports technological leadership in **electric mobility, hydrogen economy, and micro-grids**
- It enables **clean industrial innovation**, powering steel, cement, fertilisers, and IT infrastructure sustainably
- It offers **inclusive rural development** by empowering local communities with decentralised systems such as solar pumps and biomass plants
- It generates **millions of skilled jobs** in installation, manufacturing, research, and maintenance sectors

In essence, green energy becomes the backbone of a *modern, dynamic and future-ready India*.

## 3. Green Energy and National Development

Energy systems have historically shaped the economic trajectories of nations, and contemporary development theory recognises energy security as a foundational determinant of national growth. For India, the transition to green energy is not merely an environmental aspiration but a structural necessity anchored in economic, strategic, and geopolitical considerations. As the world's fastest-growing major economy, India is projected to experience the highest absolute increase in energy demand by 2040 (IEA, 2023). Meeting this demand with conventional fossil fuels would significantly increase carbon emissions, accelerate ecological degradation, and deepen import dependency.

India currently imports nearly 85% of its crude oil and more than 50% of its natural gas (Ministry of Petroleum & Natural Gas, 2024), thereby exposing it to significant global price volatility and geopolitical risks. In FY 2023–24 alone, fossil fuel imports exceeded USD 165 billion, underscoring the urgent need for domestic, low-carbon alternatives. In this context, renewable energy emerges as a strategic pillar for economic modernisation, energy independence, and long-term resilience.

India has already made notable progress in expanding its renewable energy portfolio, with installed capacity surpassing 190 GW in 2024 (MNRE, 2024), placing the nation among the top four renewable energy producers globally. Empirical studies further indicate that renewable energy represents a significant source of green employment, with projections suggesting 3–4 million jobs in solar, wind, battery storage, and green hydrogen sectors by 2030 (IRENA, 2023). Moreover, the launch of the National Green Hydrogen Mission and India's

COP-26 “Panchamrit” commitments reflect an integrated policy approach that links the energy transition to climate mitigation targets and to industrial competitiveness.

Thus, the expansion of green energy is central to India’s vision of becoming a developed nation by 2047. It reinforces national energy security, enhances economic diversification, reduces fiscal burdens associated with imports, and supports India’s global leadership in climate action.

#### 4. Evolution of Renewable Energy in India

India’s renewable energy sector has undergone a remarkable transformation over the past decade, emerging as one of the world's fastest-growing clean energy markets. The evolution of this sector reflects a series of policy innovations, international collaborations, and long-term strategic commitments aimed at strengthening energy security and meeting global climate responsibilities. A chronological overview of key milestones highlights the progressive maturity of India’s renewable energy landscape.

##### 4.1 Table 1 Milestones in India’s Renewable Energy Transition

| Year | Milestone   |
|------|---|
| 2010 | Launch of the <i>National Solar Mission</i> , marking India’s first significant step toward large-scale solar deployment.             |
| 2015 | Establishment of the <i>International Solar Alliance (ISA)</i> , positioning India as a global leader in solar diplomacy.             |
| 2017 | India emerges as the 4th-largest renewable energy market, reflecting rapid expansion in solar and wind installations.                 |
| 2022 | Achievement of the 175 GW renewable energy target, as announced under the National Action Plan on Climate Change.                     |
| 2023 | Introduction of the <i>National Green Hydrogen Policy</i> , initiating India’s transition toward hydrogen as a clean industrial fuel. |
| 2030 | National commitment to achieve 500 GW of non-fossil fuel capacity and align development with the net-zero trajectory.                 |
| 2047 | Vision of becoming an energy-independent and net-zero developed nation under the <i>Viksit Bharat @2047</i> framework.                |

These developments collectively demonstrate India’s sustained policy momentum and its long-term strategy to build a diversified and resilient energy ecosystem.

#### 4.2 India’s Current Global Standing

India holds a prominent position in the global renewable energy market, ranking among the leading nations in clean-energy deployment:

- 4th in solar energy capacity
- 4th in wind energy capacity
- 5th in total renewable energy capacity

These achievements underline India’s rapid progress in scaling renewables and its emergence as a major contributor to global clean energy transitions.

#### 4.3 India’s Progress in Green Energy Transition

Over the past decade, India has emerged as one of the world’s fastest-growing renewable energy markets. With a total renewable capacity exceeding 180 GW and ambitious plans to reach 500+ GW by 2030, the country has showcased strong global leadership. India currently ranks among the top nations in solar and wind

installation. Mega solar parks across Rajasthan, Gujarat, Madhya Pradesh, Tamil Nadu, and Karnataka symbolise the dawn of a clean energy revolution. Furthermore, hybrid renewable systems, rooftop solar schemes, floating solar plants, and solar-powered agricultural systems represent innovative models of sustainable energy distribution. The International Solar Alliance, spearheaded by India, is a historic diplomatic achievement that unites over 100 nations to accelerate solar adoption worldwide. Meanwhile, large-scale hydropower infrastructure and emerging pumped-storage systems help stabilise renewable energy output. Additionally, the digital revolution, innovative metering programs, and smart grids are strengthening energy efficiency. Moreover, grassroots approaches — such as solar charkhas, community-based biogas plants, solar street lighting in villages, and tribal energy empowerment projects — demonstrate that India's green transition embraces both macro- and micro-level strategies

## 5. Types of Green Energy in India

India's green energy landscape comprises diverse renewable resources that collectively strengthen the nation's energy security, reduce carbon emissions, and support sustainable development. Each resource plays a distinct role in India's transition towards a low-carbon economy.

### 5.1 Solar Energy

Solar power *is at the core of India's renewable energy expansion*, given the country's favourable geographical conditions. India receives approximately 300–320 sunny days annually, enabling high solar potential across most regions (MNRE, 2024). This has positioned solar energy as the *most significant* contributor to India's clean-energy capacity.

Major initiatives and installations include:

- Bhadla Solar Park, Rajasthan – with a capacity of over 2.2 GW, it is one of the world's largest operational solar parks.
- Pradhan Mantri Suryodaya – Rooftop Solar Initiative (2024) – aims to provide rooftop solar installations to one crore households, enhancing decentralised power generation and lowering household electricity expenditure.
- Expansion of solar parks in Gujarat, Karnataka, and Andhra Pradesh has further accelerated utility-scale deployment.

### 5.2 Wind Energy

Wind energy forms the second-largest component of India's renewable energy capacity. The country has several high-wind-potential corridors, particularly along coastal and elevated regions.

Key wind zones include:

- Tamil Nadu, Gujarat, Karnataka, and Maharashtra, which together account for more than 80% of installed wind capacity (MNRE, 2024).
- Ongoing development of offshore wind projects in Gujarat and Tamil Nadu marks a significant step towards diversifying India's wind portfolio.

Wind energy plays *an essential* role in balancing solar-based generation due to its complementary seasonal patterns.

### 5.3 Hydropower

Hydropower remains a vital renewable source, offering reliable base-load power and grid stability. India's diverse river systems enable both large hydropower stations and run-of-the-river projects.

Hydropower is primarily concentrated in:

- The Himalayan region (Uttarakhand, Himachal Pradesh, Jammu & Kashmir)
- The Northeastern states (Arunachal Pradesh, Sikkim, Meghalaya)

New pumped-storage hydropower facilities are being prioritised under the Government of India's 2023 guidelines to support renewable intermittency and grid balancing.

#### 5.4 Biomass and Biofuels

Biomass energy plays a significant role in rural energy systems and supports waste-to-wealth objectives. India's bioenergy sector includes:

- Bio-CNG plants, which convert agricultural waste, municipal solid waste, and cattle dung into compressed biogas.
- The GOBARdhan scheme, promoting rural bio-gasification and scientific waste management.
- Ethanol blending programmes—including 1G (molasses-based) and 2G (agricultural residue-based) ethanol—to achieve the national target of 20% ethanol blending in petrol by 2025–26.

Biomass energy strengthens rural economies, reduces *stubble burning*, and promotes *circular resource* utilisation.

#### 5.5 Green Hydrogen

Green hydrogen represents the next frontier in India's clean energy strategy, especially for hard-to-abate sectors such as steel, fertilisers, refining, heavy transport, and chemicals. It is produced using renewable-powered electrolysis and therefore has near-zero carbon emissions.

Under the National Green Hydrogen Mission (2023), India has set ambitious goals:

- Production target: 5 million tonnes (MMT) of green hydrogen per year by 2030
- Development of domestic electrolyser manufacturing
- Creation of green hydrogen hubs in Gujarat, Rajasthan, and Tamil Nadu

Green hydrogen is expected to play a transformative role in reducing industrial emissions and enhancing India's global competitiveness.

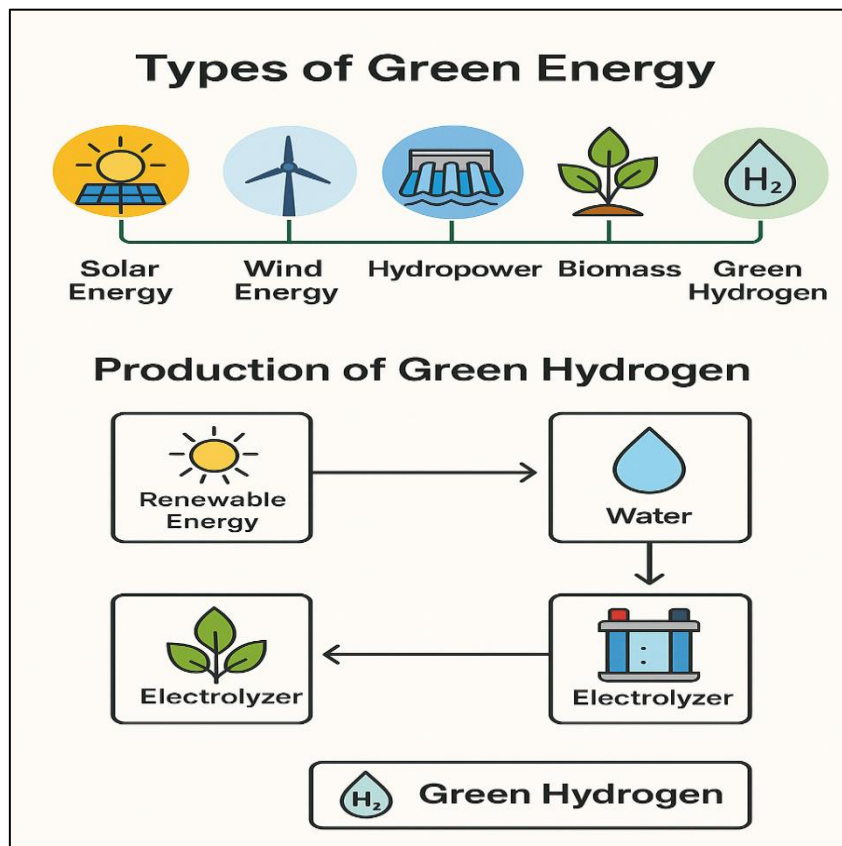


Fig-1

6. Table 2 Policy Support and Government Initiatives

| Scheme/Policy                     | Objective                                |
|-----------------------------------|--|
| National Solar Mission            | 100 GW solar goal                        |
| International Solar Alliance      | Global solar cooperation                 |
| PM-KUSUM                          | Solar pumps for farmers                  |
| Green Hydrogen Mission            | Hydrogen economy development             |
| FAME-II                           | Electric vehicles promotion              |
| National Biofuel Policy           | Ethanol blending target 20%              |
| Production-Linked Incentive (PLI) | Domestic solar manufacturing is boosting |

The government targets:

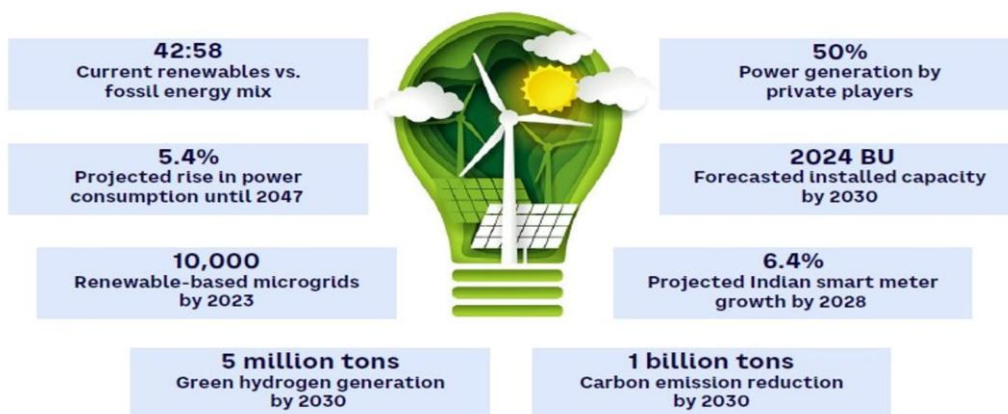
**Net-zero emissions by 2070**

**50% electricity from renewable sources by 2030**

Further, progressive carbon market frameworks, innovation grants, green credit systems, municipal climate action plans, and ESG investment policies strengthen the ecosystem for long-term sustainability. India's presidency of the G-20 highlighted "One Earth, One Family, One Future," reinforcing global environmental stewardship.

7. Table 3 Role of Green Energy in the India@2047 Vision

| Dimension     | Contribution of Green Energy                                    |
|---------------|---|
| Economic      | Low energy cost, export potential, and industry competitiveness |
| Environmental | Lower carbon footprint, cleaner air & water                     |
| Social        | Rural jobs, improved health, and access to electricity          |
| Strategic     | Energy independence from fossil fuel imports                    |



Source: Arthur D. Little, Government of India Ministry of Power, Central Electricity Authority of India, Government of India Ministry of New and Renewable Energy, Report Ocean, Mitsui & Co., India Prime Minister Narendra Modi, and NITI Aayog

Fig 2

8. Challenges in India's Green Energy Transition

Despite impressive progress, challenges persist. Financial investment expectations remain massive, technology transfer from developed countries is inconsistent, and domestic manufacturing capacity must scale further to reduce reliance on foreign technology. Additionally, intermittent renewable supply requires advanced storage solutions and grid modernisation. Land availability, environmental clearances, public

awareness, and skill development are also significant barriers. Social acceptance and behavioural transition pose conceptual challenges — sustainability is not only technological but cultural. Similarly, industrial decarbonization, clean transportation networks, and urban waste management require sustained commitment. Addressing these challenges demands coordinated policy execution, public participation, and academic-industry collaboration.

| Challenge                 | Description                          |
|---------------------------|--------------------------------------|
| Infrastructure gap        | Grid integration, transmission lines |
| Financial barriers        | High initial investment              |
| Technological limitations | Battery storage, domestic tech       |
| Land acquisition issues   | Solar farms require land.            |
| Awareness gap             | Slow adoption in rural regions       |
| Intermittency             | Solar & wind output variability      |

## 9. Proposed Solutions & Strategies

### 9.1 Strengthen Domestic Manufacturing

- Expand solar module & battery production
- Invest in research institutes & green energy startups

### 9.2 Boost Financing & Incentives

- Low-interest loans
- Subsidies for households & MSMEs

### 9.3 Promote Decentralised Energy

- Rooftop solar for homes & schools
- Solar villages, solar irrigation community models

### 9.4 Skill Development

- Green energy training programs
- Renewable engineering in universities

### 9.5 Digital Innovations

- AI-based energy forecasting
- Smart grids & energy storage technologies

### 9.6. Role of Youth and Society

- Green entrepreneurship
- Energy-efficient lifestyles
- EV adoption
- Eco-clubs in schools & colleges
- Swachh Bharat & waste-to-energy participation

Youth are climate champions — they will drive innovation, awareness & public engagement.

## 10. India @2047 Vision and Climate Imperative

India's 2047 vision frames sustainability as a fundamental development priority. The NITI Aayog vision document emphasises clean growth, circular economy, green industrialisation, decarbonised transport systems, energy security, and climate-resilient agriculture. This long-term vision aligns with global commitments, including the Paris Agreement, Mission LiFE (Lifestyle for Environment), and the Sustainable Development Goals (SDGs). The philosophy behind India's climate strategy echoes the nation's ancient environmental ethos — living in harmony with nature (Prakriti Purush Samvad) — while adopting cutting-

edge modern technology. However, the urgency is undeniable. India faces rising heatwaves, declining groundwater, erratic monsoons, desertification, sea-level rise threatening coastal cities, and public health risks from pollution. According to global climate assessments, India is among the most climate-vulnerable nations. Therefore, the developmental model cannot repeat the environmentally destructive patterns of industrialised countries. A green growth pathway is not merely ideal — it is essential for survival, competitiveness, and dignity on the world stage.

Imagine India in 2047:

- Every home with rooftop solar
- 100% electric mobility
- Hydrogen trains & industries
- Zero-waste, zero-carbon smart cities
- Farmers producing energy along with crops
- India is exporting renewable technology globally

This is not a dream — it is a **policy-driven, citizen-powered, technology-enabled future**.

#### 11. Future Strategies for a Green India @2047

India's pathway towards becoming a developed, climate-resilient nation by 2047 rests on integrating science, innovation, and social inclusivity. Strategic focus areas include expansion of domestic manufacturing, affordable financing, universal energy access, and investments in breakthrough sectors such as green hydrogen propulsion, battery technology, bio-energy parks, renewable micro-grids, carbon capture systems, and AI-enabled energy forecasting.

Equally important is skill development to prepare a green-energy workforce. Academic and vocational institutions must integrate renewable energy courses, entrepreneurship programs, and climate research modules. Public awareness campaigns, youth participation, women's empowerment in green industries, community solar clusters, and climate-smart agriculture initiatives will broaden the socio-economic benefits. Therefore, India's green future cannot be constructed solely in laboratories or government offices—it must be co-created by farmers, industries, youth, researchers, innovators, and citizens at every level.

#### Conclusion

A developed India @2047 is one where innovation fuels growth, equity defines progress, and sustainability protects future generations. Green energy lies at the heart of this national transformation. From solar fields in deserts to wind corridors along coasts, from hydrogen innovation labs to bio-fuel startups, from electric highways to climate-resilient villages — India is scripting a new developmental paradigm rooted in environmental responsibility. The journey ahead demands perseverance, vision, and unity. If guided by a shared sense of purpose, India will not only achieve energy independence and climate security but also emerge as a global torch-bearer of sustainable civilisation. This is not just an economic mission; it is a moral and cultural calling—an opportunity to create a planet-friendly, prosperous, and dignified future for all.

**Green Energy is India's passport to a prosperous, secure and sustainable 2047.**

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