

# India's Wind Energy Development: A Ray of Hope for a Sustainable Future

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## Abstract

*The development of wind energy in India is an inspiring tale of change, resiliency, and creativity. From tiny pilot projects in the 1980s to being the fourth-largest wind power generator in the world, India has steadily created a robust wind energy sector. Wind energy is a key component of the nation's renewable energy policy, with approximately 44 GW of built onshore capacity as of 2024. Favorable wind resources, proactive government regulations, and private sector involvement have propelled the industry through several stages of development, including competitive bidding, policy changes, and the rise of hybrid energy models. Important states, like Gujarat, Maharashtra, and Tamil Nadu, have set the pace for capacity expansions, and offshore wind and the repowering of abandoned sites present enormous opportunities for the future. Wind energy is expected to provide a substantial contribution to India's goal of 500 GW of non-fossil fuel energy capacity by 2030. Wind power will continue to be a vital component of India's sustainable and energy-secure future as innovation, green hydrogen, and grid modernization gain traction.*

**Keywords:** Wind, offshore, onshore, policies, energy, future, sustainable, key contribute

## INTRODUCTION

India has been a major force in the global renewable energy movement as the globe struggles with climate change and the pressing need to move away from fossil fuels. Wind energy is one of the most potent and developed clean energy sources, with a lot of untapped potential. India is ideally situated to harness wind power due to its long coastline and vast open land areas, which naturally provide favorable wind conditions. India started its wind energy adventure in the 1980s and has grown into the world's fourth-largest wind power industry throughout the years. Strong government support, technological improvements, and active private sector participation have propelled the sector's expansion from early experimental projects to today's massive commercial wind farms [1].

These days, wind energy is essential to India's achievement of its lofty renewable energy goals and Paris Agreement commitments [2]. Wind power is more than simply a clean electricity source as the

nation works to create a sustainable and energy-secure future. It represents India's commitment to green growth and climate leadership. India is one of the worlds' fastest-growing economies and one of the biggest energy consumers. Wind energy has become a vital component of the nation's solution to the twin problems of addressing climate change and supplying the nation's growing energy demands. India's wind energy industry is a testament to sustainable development, thanks to its plentiful wind resources, encouraging laws, and expanding investments [3].

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## INDIA'S WIND ENERGY DEVELOPMENT: A HISTORICAL PERSPECTIVE

India has demonstrated a strong commitment to clean energy, sustainable growth, and innovation through its wind energy adventure. India has evolved over the last forty years from an experimental player to one of the top producers of wind energy worldwide [4].

### Early Beginnings (1980s–1990s)

- In India, wind energy started in the early 1980s.
- With Danish help, India set up its first wind power project in 1986 in Muppandal, Tamil Nadu.
- Through government-funded research and pilot projects, the Department of Non-Conventional Energy Sources (DNES), which subsequently changed its name to the Ministry of New and Renewable Energy (MNRE), started to promote wind energy.
- Most of the early projects were small-scale and made use of imported turbines.
- *Milestone:* India's installed wind capacity was approximately 20 MW by the early 1990s [5].

### Policy Push and Private Sector Entry (1990s–2000s)

- Wind projects became more appealing to private investors when the Accelerated Depreciation (AD) tax benefits were introduced.
- Notable installations started to appear in states like Gujarat, Maharashtra, and Tamil Nadu.
- Developers of wind energy began to appear in the private sector.
- *Milestone:* By the early 2000s, installed capacity had surpassed 1,000 MW [6].

### Rapid Expansion Phase (2000–2010)

- An independent power market was established, and open access was made possible by the Electricity Act of 2003.
- The industry was stimulated by the introduction of Renewable Purchase Obligations (RPOs) and Renewable Energy Certificates (RECs).
- India established robust indigenous manufacturing capabilities such as Inox Wind and Suzlon.
- *Milestone:* India rose among the top 5 producers of wind energy worldwide. By 2010, capacity exceeded 13 GW [7].

### Boom and Innovation Era (2010–2017)

- To promote real power generation rather than just capacity, the Generation-Based Incentive (GBI) was implemented.
- Wind power started to compete with fossil fuels as it became increasingly affordable.
- The Muppandal Wind Farm grew to be among Asia's biggest.
- On average, India installed more than 2–3 GW of wind power annually.
- *Milestone:* By 2017, India's wind power had surpassed 32 GW [8].

### Transition and Market Reforms (2017–2021)

- Feed-in tariffs (FiTs) were reduced by switching to competitive bidding, although new projects were momentarily slowed down.
- By 2022, the government wants to have 60 GW of wind power.
- Repowering, offshore wind planning, and wind-solar hybrids received more attention.
- *Milestone:* Wind became extremely competitive as tariffs fell to as low as ₹2.43/unit [9].

### Current Phase & Future Vision (2021–Present)

- India is focusing on:
  - Hybrid projects.
  - Green hydrogen production.
  - Offshore wind.
  - Technological upgrades.

- With wind likely to generate more than 140 GW, India renewed its global climate commitment to install 500 GW of non-fossil capacity by 2030.

### Present Situation (2024)

- More than 44 GW of onshore wind capacity has been installed.
- Plans to start offshore wind projects in Tamil Nadu and Gujarat.

### Key Milestones in India's Wind Energy Journey.

Year	Milestone
1986	First wind farm installed in Tamil Nadu.
1995	India reaches 500 MW of wind power.
2003	Electricity Act liberalizes power market.
2010	Wind power crosses 10 GW.
2017	Competitive bidding introduced.
2024	Installed capacity crosses 44 GW.

## INDIAN GOVERNMENT INITIATIVES & POLICY SUPPORT FOR WIND ENERGY

In addition to its abundant natural resources, India has emerged as a global leader in wind energy; thanks to robust government policies and initiatives. To foster an atmosphere that encourages investment, innovation, and growth in the wind energy industry, the Indian government has been instrumental [10].

### Institutional Framework

- *Ministry of New and Renewable Energy (MNRE)*: The nodal agency for wind energy development in India.
- *Indian Renewable Energy Development Agency (IREDA)*: Provides financial support for renewable energy projects.
- *National Institute of Wind Energy (NIWE)*: Conducts wind resource assessments, R&D, and capacity building.

## KEY POLICIES AND PROGRAMS

### National Wind-Solar Hybrid Policy (2018)

- Encourages hybrid projects (wind + solar) to produce more dependable and balanced power generation.
- Encourages the best and most efficient use of land and transmission infrastructure.

### Offshore Wind Energy Policy (2015)

- The objective is to utilize India's extensive offshore wind potential, particularly in the regions of Tamil Nadu and Gujarat.
- Aids in the development of projects, leasing, surveys, and mapping within India's Exclusive Economic Zone (EEZ).

### Electricity Act, 2003

- Open access and power sector liberalization were implemented.
- Promoted investments in renewable energy from the business sector.

### National Electricity Plan

- Describes the contribution of wind energy to India's energy mix and establishes long-term goals.
- Encourages the management of renewable energy sources and grid integration.

## FINANCIAL INCENTIVES AND MARKET MECHANISMS

### Accelerated Depreciation (AD)

- Lowers tax obligations by enabling wind project developers to claim asset depreciation more quickly.

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### Generation-Based Incentives (GBI)

- To promote real performance over capacity expansion, ₹0.50 per kWh for energy generated was provided.

### Renewable Energy Certificates (RECs)

- A market-based system that assists states in fulfilling their Renewable Purchase Obligations (RPOs) and encourages the use of renewable energy.

### Competitive Bidding Mechanism (Since 2017)

- Transparent auctions took the place of feed-in tariffs.
- Contributed to a major reduction in wind power tariffs, which were once as low as ₹2.43/unit.

### Infrastructure & Support Initiatives

- *Green Energy Corridors*: Transmission lines specifically designed to carry renewable energy to facilitate seamless grid integration.
- *Wind Resource Assessment Program*: Uses cutting-edge technology to identify high-potential areas across states.
- *"Must Run" Status*: Priority dispatch for wind energy is given over traditional power sources.

### National Targets and International Commitments

- *Nationally Determined Contributions (NDCs)* under the Paris Agreement:
  - India aims to have 500 GW of non-fossil fuel capacity by 2030.
- *Wind energy is expected to contribute 140 GW+* toward that goal.
- India's push aligns with the *International Solar Alliance (ISA)* and its broader clean energy leadership.

## INDIA'S OFFSHORE WIND POTENTIAL

With more than 7,600 kilometers of coastline, India has enormous unrealized offshore wind energy potential. Offshore wind is the next frontier in India's renewable energy transition, even though the nation has achieved great strides in onshore wind development [11].

### WHAT IS OFFSHORE WIND ENERGY?

Using wind turbines positioned in the sea, usually in shallow or deep waters, to generate electricity is known as offshore wind energy. Offshore winds are perfect for producing renewable energy since they are typically stronger and more reliable than onshore winds.

### India's Estimated Offshore Wind Potential

- The *National Institute of Wind Energy (NIWE)* estimates:
  - 36 GW of potential off the coast of *Gujarat*.
  - 35 GW off the coast of *Tamil Nadu*.
- Total preliminary *offshore potential: Over 70 GW*.
- These figures are based on locations up to 100 kilometers from the shoreline and with water depths of up to 100 meters [12].

### Key Policy: National Offshore Wind Energy Policy (2015)

This policy provides a framework for:

- Offshore wind resource assessment.
- Project development in India's *Exclusive Economic Zone (EEZ)*.
- Site allocation, leasing, and environmental approvals.
- Coordination between multiple ministries (MNRE, MoEFCC, Ministry of Shipping, etc.).

### Identified Zones for Offshore Wind

- *Gujarat*: Gulf of Khambhat – high wind speed, shallow waters.
- *Tamil Nadu*: Southern coast: steady wind and convenient access to infrastructure with assistance from foreign partners and agencies, pilot projects are currently planned [12].

### International Collaborations

India is receiving technical and financial support from:

- *The European Union (EU)*: India–EU Clean Energy and Climate Partnership.
- *Denmark*: Strategic sector cooperation on offshore wind.
- *World Bank*: Aiding through its Offshore Wind Development Program.

### Challenges

India's offshore wind industry is still in its infancy despite its great potential because of the following:

- High initial capital expenses (in comparison to onshore wind).
- Intricate marine engineering and logistics.
- Need for grid infrastructure upgrades.
- Environmental approvals and stakeholder collaboration.

### Opportunities Ahead

- Ideal for wind-solar hybrid coastal projects.
- Has the potential to generate green hydrogen from offshore wind power.
- Diversifies the energy mix and eases the strain on land resources.
- Encourages the development of marine engineering jobs and the coastal economy.

## INDIA'S ONSHORE WIND POTENTIAL

When it comes to onshore wind energy potential, India is one of the worlds' leading nations. With its large landmass and favorable wind conditions, particularly in the western and southern regions, India has the potential to develop into a major wind energy producer.

### Estimated Onshore Wind Potential

- According to the *National Institute of Wind Energy (NIWE)*:
  - India has over 302 GW of onshore wind potential at 100-meter hub height.
  - Potential increases further at 120 meters or higher, thanks to modern, taller wind turbines.
- Wind-rich states include:
  - Tamil Nadu.
  - Gujarat.
  - Maharashtra.
  - Karnataka.
  - Rajasthan.
  - Andhra Pradesh.
  - Madhya Pradesh.
  - Telangana.

Over 90% of India's present onshore wind capacity comes from these states.

### High Potential Wind Zones

Zones with abundant wind resources have been recognized by the NIWE and categorized according to wind speed. Priority is given to these zones for:

- Development of wind farms.
- Planning for transmission infrastructure.
- Parks with hybrid renewable energy.

**Current Status (as of 2024)**

- India's installed onshore wind capacity is more than 44 GW.
- The industry is mature, with strong capabilities in project execution, production, and finance.
- Maharashtra and Karnataka are still growing, although Tamil Nadu and Gujarat have the most cumulative capacity.

**OPPORTUNITIES FOR EXPANSION****Repowering**

- Low-capacity turbines (225–500 kW) are used in many older wind farms.
- By swapping them out for contemporary 2–3 MW turbines, output can be increased by 2–3 times while utilizing the same land area.

**Hybrid Projects**

- Wind–solar hybrids, which combine wind and solar power, optimize transmission and land use.
- Balances day–night fluctuation to increase the stability of the energy supply.

**Rural Development**

- Onshore wind projects boost state revenue, create jobs locally, and enhance infrastructure.
- Advantageous in rural and semi-arid areas where agricultural production may be restricted.

**Challenges to Address**

- *Land acquisition* and environmental clearances.
- *Grid connectivity* in remote windy areas.
- *Payment delays* from state distribution companies (DISCOMs).
- Ensuring long-term *policy consistency* and investor confidence.

**FUTURE OUTLOOK**

- As part of its goal of 500 GW of non-fossil energy by 2030, India intends to increase wind capacity to 140 GW.
- Onshore potential will be further unlocked by the increased emphasis on digital monitoring, AI-driven forecasting, and green hydrogen generation.

**Opportunities & Outlook of Indian Wind Energy**

Wind energy is a pillar of India's renewable energy strategy as it rapidly approaches its clean energy targets. The wind industry presents enormous potential for innovation, job creation, economic growth, and energy security in addition to lowering carbon emissions.

**Key Opportunities in Indian Wind Energy****Untapped Potential**

- At a hub height of 100 meters, India's onshore wind potential is predicted to be around 300 GW.
- There is still much to learn about the vast offshore wind potential (~70 GW) between Tamil Nadu and Gujarat's shores.

**Repowering Old Wind Farms**

- A lot of early wind farms made use of turbines with limited capacities (225–500 kW).
- The output from the same location can be double by repowering with contemporary high-capacity turbines (2–3 MW).

**Wind-Solar Hybrid Projects**

- Hybrid systems save money, minimize variability, and maximize land use.
- With both financial and policy backing, the National Wind–Solar Hybrid Policy (2018) promotes such initiatives.

### **Green Hydrogen Production**

- Green hydrogen, which is essential for decarbonizing sectors including steel, fertilizers, and heavy transportation, may be produced using wind power.
- There is significant synergy between wind power and the government's National Green Hydrogen Mission.

### **Local Manufacturing & Exports**

- Suzlon, Inox, and other wind turbine manufacturers have a significant presence in India.
- PLI and "Make in India" initiatives can increase export possibilities to Latin America, Africa, and Southeast Asia.

### **Job Creation & Rural Development**

- Jobs in manufacturing, logistics, maintenance, and construction are created by wind farms.
- Local employment and infrastructure development are advantageous for rural communities.

### **Attractive to Global Investors**

- Stable policies and declining tariffs have drawn attention from global corporations and environment funds.
- India is a hub for foreign direct investment in renewable energy due to its reputation as a developing clean energy market.

## **FUTURE OUTLOOK**

### **Ambitious Targets**

- By 2030, India wants to have 500 GW of non-fossil fuel energy capacity.
- It is anticipated that wind energy, encompassing both onshore and offshore capacities, will contribute at least 140 GW.

### **Global Leadership Role**

- By taking the lead in organizations, like the International Solar Alliance (ISA), India is establishing itself as a global center for sustainable energy.
- Advanced offshore and hybrid technologies will be brought about by partnerships with nations like Denmark, Germany, and the EU.

### **Technological Advancements**

- Predictive maintenance and efficiency monitoring using AI, IoT, and drones.
- In deeper waters, floating offshore wind may create new opportunities.

### **Better Grid Integration**

- The creation of smart grids, energy storage, and Green Energy Corridors will increase the scalability and dependability of wind energy.

## **CONCLUSIONS**

More than just a clean energy project, India's wind energy growth is a beacon of hope for a more robust, self-sufficient, and environmentally friendly future. In addition to producing electricity, the turbines are helping India achieve its energy independence and climate goals as they rotate across its expansive landscapes. India's progress in wind energy is indicative of the nation's increasing technological prowess and environmental awareness.

The Indian government has created a solid basis for wind energy through innovative laws, financial incentives, and strategic planning. These programs will continue to be essential for lowering carbon emissions, promoting green economic growth, and sustainably supplying the nation's energy demands as it grows. For India's energy landscape in the future, offshore wind energy has enormous potential. It

has the potential to significantly contribute to India's climate goals, lessen its reliance on fossil fuels, and spearhead the world's transition to clean, dependable, and extensive renewable energy with the correct funding, policy support, and international cooperation.

India's wind energy industry is a national opportunity as well as a climate answer. Wind power can help India become energy independent, create a more environmentally friendly economy, and guide the world toward a sustainable future with the correct combination of investment, innovation, and policy. India is prepared to take advantage of the winds of change that have arrived.

From its experimental beginnings, India's wind energy industry has gained international prominence. With consistent regulatory backing, public-private cooperation, and technology advancements, wind energy has emerged as a key component of India's sustainable energy future. Wind energy will remain essential to the nation's energy security, sustainability, and climate leadership as it looks to 2030 and beyond.

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