Air Energy Potential in India: Ways & Means

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Abstract
There is huge activity in air power, pan-India with the installed capacity increasing to 12,000 MW. India today has the fifth largest installed capacity of air power in the world with 11087MW installed capacity and potential for on-shore capabilities of 68000MW. However the plant load factor (PLF) in air power generation is very low, often in the single digits. The increase in interest in air energy is due to investment subsidies, tax holidays, and government action towards renewable energy playing a big part in nation's energy system. There is a need to generate environment friendly power that not only raises energy efficiency and is sustainable too. The time has come for moving to generation based subsidies and understanding the drawbacks associated with air power in India. The capital cost of air power is third higher than conventional thermal power; further electrical problems like voltage flicker and variable frequency affect the implementation of air farm. However advances in technologies such as offshore construction of air turbines, advanced control methodologies, and simulation of air energy affecting overall grid performance are making a case for air energy.
Key Words: Installed, potential, efficiency, methodologies, implementation, airenergy

1. INTRODUCTION

1.1 Air Energy

The energy that can be extracted from the air is directly proportional to the cube of the air speed, so an understanding of the characteristics of the air (velocity, direction, variation) is critical to all aspects of air energy generation, from the identification of suitable sites to predictions of the economic viability of air farm projects to the design of air turbines themselves, all is dependent on characteristic of air. The most striking characteristic of the air is its stochastic nature or randomness. The air is highly variable, both geographically and temporally. Moreover this variability exists over a very wide range of scales, both in space and time. This is important because extractable energy from air varies with the cube of air velocity. This variability is due to different climatic conditions in the world also the tilt of earth on its axis and its own spinning results in different air distributions across the world. Also within any climatic region, there is a great deal of variation on a smaller scale, which is dictated by several factors such as ratio of land and water, presence of mountains etc. The type of vegetation also affects air distribution through absorption of moisture, temperature moderation and reflection of sun's energy. Generally more air is witnessed on the tops of hills and mountains than in low level areas. Even more locally, air velocities are altered by obstacles such as trees or buildings. For any location there is variation of air pattern, air speed may vary from year to year; also air distribution will change from decade to decade. These long-term variations are not well understood, and thus make it difficult to make predictions of the economic viability of air-farm projects. Air distribution is more predictable over shorter time spans like a year, but on shorter time frame like few days the air energy is difficult to predict. These variations are due to the weather systems. Depending on location, there may also be considerable variations with the time of day (diurnal variations), which are fairly predictable. These variations are important to be considered because they can affect production of large scale air energy and consequent integration into grid, also associated power generation systems must be prepared for these variations. Also we must take into account the fact that short term turbulence cause variations in the quality of power delivered.

1.2 Air Turbines

An air **turbine** is a rotating machine which converts the air kinetic energy into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called an air
Generator, air turbine.

Air turbines can be separated into two types based by the axis in which the turbine rotates as Horizontal Axis Air Turbines and Vertical Axis Air Turbines. The former are more commonly used due to several inherent advantages, the latter being used in small scale.

Major factors that have accelerated the air-power technology development are as follows:

1. Development of high-strength fiber composites for constructing large low-cost blades.
2. Reduction in prices of the power electronics components such as converters.
3. Variable-speed operation of electrical generators to capture maximum energy.
4. Improved plant operation, pushing the availability up to 94 percent.
5. Economy of scale, as the turbines and plants are getting larger in size.
6. Accumulated field experience (the learning curve effect) improving the capacity factor.

The total power generating capacity has grown to about 21089 MW as of March 2025 thus placing India at fifth place in terms of installed capacity.

2. Literature Survey

India's journey in air energy has evolved from modest beginnings in the 1980s to becoming one of the largest producers of air power in the world. This evolution has been marked by policy reforms, technological advancements, and a growing recognition of air energy's role in reducing carbon emissions and ensuring energy security. India's air energy sector has evolved from small-scale demonstration projects to large-scale grid-connected installations. With substantial onshore and offshore potential, India is well-positioned to expand its air energy capacity further, provided that policy consistency, technology innovation, and grid modernization continue. The evolution reflects a blend of public policy, private investment, and international cooperation.

2.1 Early Beginnings (1980s – 1990s**)**

- Initial Research & Development**:**

  The first serious exploration into air energy began in the 1980s, with pilot projects supported by the Department of Non-Conventional Energy Sources (DNES), which later became the Ministry of New and Renewable Energy (MNRE).
- First Installations:

  The first demonstration air farms were set up in Tamil Nadu and Gujarat in the late 1980s. These early projects helped assess the viability of air power under Indian conditions.
- Policy Support Begins:

  The Air Energy Programmer was launched in 1983, and in 1993, the Indian Renewable Energy Development Agency (IREDA) began offering financial support for commercial projects.

2.2 Expansion and Private Sector Entry (2000s)

- Introduction of Accelerated Depreciation (AD):

  To attract private investment, the government introduced Accelerated Depreciation (80%) for air power projects, encouraging industrial consumers to invest in air turbines.
- State-Level Initiatives:

  States like Tamil Nadu, Maharashtra, Karnataka, and Rajasthan developed state-specific policies and tariff structures, resulting in a surge of installations.
- Technology Improvements:

  Turbines with higher hub heights and better efficiency began to replace earlier, smaller units. Grid-connected air farms became more common.

2.3 Institutional Framework Strengthens (2010 – 2015)

- Formation of NIWE:

  The National Institute of Air Energy (NIWE**)** was established in Chennai in 2011, taking over from the CWET (Centre for Air Energy Technology), to improve technical expertise and air mapping.
- Renewable Energy Targets:

  India committed to 175 GW of renewable energy capacity by 2022, with 60 GW from **air** energy. This national target added momentum to air sector investments.
- Development of Air Atlas:

  A new air atlas using data at 100m hub height helped reassess India's air potential, revealing it to be over 300 GW at that height.

5.4 Recent Trends (2020s – Present)

- COVID-19 Impact:
  The pandemic temporarily slowed project execution but also encouraged automation and digitalization in operations and maintenance.
- Increased Private Sector Role:
  Companies like Suzlon, ReNew Power, Greenko, and international players like Siemens Gamesa and Vestas are playing key roles in technology and capacity expansion.
- Offshore Air Development:
  The first offshore air energy projects are under preparation, especially off the coast of Gujarat, with support from international partners like Denmark and funding from multilateral agencies.

5.5 Installed Capacity Growth

Year Cumulative Capacity (MW)

2000 ~1,200 MW

2010 ~13,000 MW

2015 ~25,000 MW

2020 ~38,000 MW

2024 ~44,500 MW (approximate)

(Source: MNRE, IREDA, NIWE)

India's Cumulative Air Capacity (MW)
1985: ~10 MW | 2000: ~1,200 MW
2010: ~13,000 MW | 2015: ~25,000 MW
2020: ~38,000 MW | 2024: ~44,500 MW

Air energy, commonly known as **air energy**, is a rapidly developing sector in India's renewable energy portfolio. With its vast landmass and coastline, India possesses significant air potential, both onshore and offshore. The increasing need for sustainable energy and India's commitment to reduce carbon emissions under international frameworks like the Paris Agreement makes air energy a vital area of focus.

Air Energy Potential in India

- According to a report by National Institute of Air Energy (NIWE), the onshore air energy potential at 120 meters hub height is estimated to be over 695 GW.
- The offshore air potential along the Indian coast is also considerable, particularly in Gujarat and Tamil Nadu, with estimates of around 70 GW.

Geographic Distribution

- High-potential states: Tamil Nadu, Gujarat, Karnataka, Maharashtra, and Rajasthan.
- Offshore potential: Gulf of Khambhat, Gulf of Mannar, and coastal areas of Gujarat and Tamil Nadu.

Government Policies and Support

National Air-Solar Hybrid Policy (2018)

- Promotes optimal use of infrastructure and land.
- Encourages hybrid projects that combine air and solar to stabilize power output.

Renewable Energy Targets

- India targets 500 GW of non-fossil fuel-based capacity by 2030, with air expected to contribute significantly.
- Production Linked Incentive (PLI) schemes and Viability Gap Funding (VGF) mechanisms are being developed for offshore air.

Technological Developments

- Higher hub heights and larger rotor diameters are being deployed to improve capacity utilization.
- Hybrid systems (air + solar + storage) to balance intermittency.
- Digitalization and use of AI/ML for predictive maintenance of turbines.

3. Methods and Materials

METHODS

To evaluate and harness the air (air) energy potential in India, a multi-disciplinary methodological framework is adopted:

3.1.1 Air Resource Assessment

- Site Survey & Mapping:

Use of meteorological and geospatial tools to identify high air potential zones.
Application of GIS software and Air Atlas databases (e.g., NIWE Air Atlas).

- Measurement of Air Parameters:

Use of anemometers and air vanes installed at various hub heights (typically 50–120 meters).
Parameters measured: air speed, air direction, air temperature, pressure.

3.1.2 Data Collection & Analysis

- Real-time Monitoring Stations:
  Data from NIWE and regional weather stations are collected over 12–24 months to establish air consistency.
- Remote Sensing Techniques:

Use of LiDAR (Light Detection and Ranging) and SODAR (Sonic Detection and Ranging) for vertical air profiling.

- Statistical Analysis:

Weibull distribution used to estimate air speed frequency.
Power density calculations to assess energy output potential.

3.1.3 Technology Assessment

- Air Turbine Selection:

Based on air class, terrain type, and energy needs (e.g., onshore vs. offshore turbines).

- Simulation and Modeling:

Software tools like WAsP, AirPRO, and HOMER used for system design and yield prediction.

3.1.4 Environmental and Economic Assessment

- EIA Studies:

Conducted to evaluate ecological impact and ensure compliance with environmental regulations.

- Cost-Benefit Analysis:

Life-cycle cost, payback period, and Levelized Cost of Energy (LCOE) are computed.

3. MATERIALS

The following materials, tools, and technologies are typically used in air energy assessment and development:

3.2.1 Measuring Instruments

- Anemometers: For air speed measurement.
- Air Vanes: To measure air direction.
- LiDAR/SODAR Devices: For vertical air profiling.
- Data Loggers: To record long-term air data.

3.2.2 Technical Resources

- Air Turbines:
  Onshore: Horizontal-axis turbines of varying capacities (250 kW to 3 MW).
  Offshore: Larger turbines (up to 8–12 MW capacity).
- Tower Structures:
  Lattice towers, tubular steel towers, or hybrid types depending on height and terrain.

3.2.3 Software Tools

- Air Simulation Tools: WAsP, AirPro, RETScreen
- GIS Software: ArcGIS, QGIS for mapping air zones and terrain.

- Energy Modeling Tools: HOMER, SAM (System Advisor Model)

3.2.4 Infrastructure

- Meteorological Towers: Installed at heights of 50m, 80m, or 100m for air measurement.
- Transmission Infrastructure: For grid integration and distribution of generated power.

3.2.5 Support Systems

- Battery Storage: For hybrid air-solar systems.
- SCADA Systems: For real-time monitoring and control of air farms.

4. Results & Discussions

4.1 Results

4.1.1 Air Resource Availability

- Geographical Variation:

Coastal Areas: States like Tamil Nadu, Gujarat, and Maharashtra show the highest air potential due to their coastal proximity.

Highland Regions: Rajasthan, Madhya Pradesh, and certain parts of Karnataka exhibit substantial air energy resources.

Offshore Air: India has significant offshore air potential, particularly off the coasts of Gujarat and Tamil Nadu. Early studies suggest an offshore air potential of over 70 GW.

- Air Speed Data:

The average air speeds in India range between 4.5 to 7.5 m/s, with areas in Tamil Nadu and Gujarat reaching speeds of 7-8 m/s, ideal for large-scale air power projects.

Data from the National Air Resource Map indicates a high potential for air energy generation in the western and southern regions.

4.1.2 Air Energy Potential

- Estimated Total Potential:

According to the National Institute of Air Energy (NIWE), India's total onshore air potential is estimated at around 302 GW (at 100m hub height). However, due to land and infrastructure constraints, a more practical development potential is estimated at 60-100 GW.

Offshore air resources are also promising, with an estimated potential of 30 GW along the coasts of Gujarat and Tamil Nadu.

- Current Installed Capacity:

As of 2023, India's cumulative air energy installed capacity is around 42 GW, primarily from onshore air farms, making it the 4th largest in the world. However, India has the potential to scale up significantly in the coming decades.

4.1.3 Technological Insights

- Air Turbine Efficiency:

Advances in turbine design, such as high-efficiency blades and variable-speed turbines, have resulted in improved capacity factors in air farms, particularly in Tamil Nadu, Rajasthan, and Gujarat.

Offshore air technology is progressing, with pilot projects demonstrating the feasibility of larger turbines (8-12 MW) that can harness stronger and more consistent airs.

- Energy Storage:

Integration with battery storage systems and hybrid air-solar solutions has demonstrated significant potential for addressing intermittency challenges and ensuring a more reliable energy supply.

3.1.4 Economic and Social Impact

- Job Creation:

The air energy sector has the potential to create millions of direct and indirect jobs, ranging from manufacturing to installation and maintenance. Training programs and skill development initiatives are essential to meet the growing demand.

- Rural Development:

Air farms, particularly in semi-arid and rural regions, have provided opportunities for land leasing and local employment, contributing to economic growth in remote areas.

- Reduction in Carbon Emissions:

Air energy significantly contributes to reducing the carbon footprint, with every MW of air energy offsetting around 2,500 tons of CO_2 per year.

3.2. Discussions

3.2.1 Challenges in Expanding Air Energy in India

- Land Acquisition Issues:

One of the primary barriers to scaling up air energy is the challenge of acquiring land for large-scale projects, particularly in air-rich areas where agriculture and other land uses are prevalent.

Government policies to ease land acquisition for renewable energy projects are essential to accelerate growth.

- Grid Infrastructure and Transmission Bottlenecks:

While air energy potential is high, integrating this energy into India's existing grid infrastructure remains a challenge. Regions with high air potential (e.g., Tamil Nadu) often lack sufficient transmission lines to evacuate power to high-demand regions like Delhi and Mumbai.

The development of green energy corridors and grid upgrades are needed to facilitate smoother transmission of renewable power.

- Intermittency and Variability:

Air energy is intermittent, and its variability can affect grid stability. While storage solutions like batteries and hybrid systems (air-solar) can help, they are still in the developmental phase and require further investment.

3.2.2 Policy Support and Regulatory Framework

- Government Initiatives:

Policies like the National Air Energy Mission (NLEM) aim to promote air energy development. Additional incentives such as Generation-Based Incentives (GBI), accelerated depreciation, and tax exemptions have helped foster growth.

The Air-Solar Hybrid Policy has great potential to enhance grid stability by integrating these two intermittent resources.

- Future of Offshore Air:

The offshore air energy potential remains largely untapped, though early steps have been taken with pilot projects like the Gujarat Offshore Air Energy Project.

International collaboration and technology transfer will be critical to accelerating offshore air adoption.

3.2.3 Technological Advancements and Innovation

- Hybrid Air-Solar Systems:

  The integration of air with solar photovoltaic (PV) systems has proven effective in providing a more reliable energy mix, especially in areas with fluctuating weather patterns. This system can optimize land usage while enhancing energy reliability.

- Digitalization of Air Farms:

  Technologies like Artificial Intelligence (AI) and Internet of Things (IoT) are helping optimize operations and predictive maintenance in air farms, improving efficiency and reducing downtime.

3.2.4 Environmental Considerations

- While air farms provide significant environmental Wildlife Impact:

  Benefits, there are concerns about their impact on wildlife, particularly bird and bat populations. Careful site selection and environmental assessments are required to minimize ecological disruption.

- Water Conservation:

Unlike thermal power plants, air energy requires no water for cooling, making it an excellent option for water-scarce regions of India, such as Rajasthan.

3.3. Conclusion

India has significant potential to expand its air energy sector, with large resource availability both onshore and offshore. However, several challenges need to be addressed, including land acquisition, grid infrastructure, intermittency issues, and regulatory hurdles. With the right policies, technological innovations, and infrastructure investments, air energy can play a crucial role in India's renewable energy future. The shift toward hybrid systems, offshore air, and improved grid integration holds the key to achieving the nation's ambitious renewable energy goals.

India's diverse geography offers a strong base for air energy deployment. Through systematic air resource assessments, advanced measurement tools, and supportive technology, the nation can effectively utilize its air energy potential. The methods and materials outlined above are crucial in evaluating feasibility, optimizing design, and scaling air power generation for a sustainable future.

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