Prospects and Challenges in Wind Energy:

The Case of Aralvaimozhi Wind Farm

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ABOUT

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In December 2021, the Ministry of Science and Technology, Department of Science and Technology (Policy Research Programme) made an open call for the submission of Expressions of Interest in STI Policy Research towards the Establishment of the Center for Policy Research (CPR) by the academic and research Institutes in India. After multiple rounds of consultations and review, the DST-CPR at NISER received the final sanction order from the Government of India, Ministry of Science & Technology, Department of Science & Technology, bearing the letter No DST/PRC/CPR/NISERBhubaneswar-2023 (G)(PCPM) dated 29/03/2023. The primary focus of the DST-CPR at NISER is to study the Energy Transition, and the secondary focus is to study Tribal Education and Innovations for Tribal Education in Eastern India covering Odisha, Bihar, Chhattisgarh, Jharkhand, and West Bengal.

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List of Abbreviations

EPA	Energy Purchase Agreement
ESI	Employees' State Insurance
EWA	Energy Wheeling Agreement
FDI	Foreign Direct Investment
GBI	Generator based incentive
GOI	Government Of India
GHG	Greenhouse Gas
GW	Gigawatts
IREDA	Indian Renewable Energy Development Agency
ISTS	Inter-State Transmission System
KW	Kilowatts
LC	Letter of Credits
MW	Megawatts
MNRE	The Ministry of New & Renewable Energy
MU	Million Units
O&M	Operations & Maintenance
PMSMs	Permanent Magnet Synchronous Motors
PF	Provident Fund
RPO	Renewable Purchase Obligation
STU	State Transmission Utility
TERC	Tamil Nadu Electricity Regulatory Commission
TANGEDCO	Tamil Nadu Generation & Distribution Corporation Limited
TNEB	Tamil Nadu Electricity Board
UNESCO	United Nations Educational, Scientific and Cultural Organization
WEG	Wind Energy Generator
Y-O-Y	Year-On-Year

Executive Summary

This report examines the evolving landscape of wind energy in Tamil Nadu, with a specific focus on the Aralvaimozhi Wind Farm, one of India's oldest and most iconic wind energy hubs. It situates the case study within the broader context of India's wind energy sector, where the country stands as one of the largest producers globally, supported by a robust domestic manufacturing base. Tamil Nadu has historically led this transition, accounting for a significant share of national wind power capacity. However, its early installations now face technological obsolescence and require systematic repowering to remain efficient and economically viable.

The Aralvaimozhi Wind Farm presents both a symbol of Tamil Nadu's pioneering spirit and a challenge for its future. Most turbines at the site are of low hub height and outdated design, leading to reduced energy output and inefficiencies. The state's current repowering policy places substantial financial burdens on turbine owners, including the costs of dismantling, land acquisition, and evacuation system upgrades. Moreover, delayed payments from the Tamil Nadu Generation and Distribution Corporation (TANGEDCO) and a lack of clear incentives have further discouraged investment in modernization.

This report identifies a range of policy and structural reforms needed to unlock the full potential of wind energy in Tamil Nadu. Key recommendations include offering financial incentives to owners of older turbines, streamlining lease renewals, and increasing public sector participation to reduce the dominance of private contractors. Emphasis is placed on the need for a comprehensive repowering policy that supports the transition to modern, high-capacity turbines with hub heights of 120–150 meters, especially in high-wind regions like Aralvaimozhi.

Finally, the report stresses the importance of local manufacturing, skilled manpower development, and long-term state and central government coordination. By addressing existing challenges and capitalizing on the prospects, Tamil Nadu can not only revitalize its aging wind farms but also reclaim its leadership in India's renewable energy journey. The Aralvaimozhi case offers valuable insights into the practical, policy, and technological shifts required to ensure a sustainable and high-performing wind energy future.

Prospects and Challenges in Wind Energy:

The Case of Aralvaimozhi Wind Farm

1. Introduction

The ever-increasing demand for energy, coupled with the rapid depletion of conventional resources, has compelled the global energy sector to actively pursue renewable alternatives and to significantly curtail carbon emissions associated with traditional energy production methods. As one of the world's major contributors to greenhouse gas (GHG) emissions, India has recognized the urgent need to transition toward a more sustainable energy future. In response, the country has taken decisive steps to combat climate change, most notably by committing to an ambitious target of achieving net-zero carbon emissions by the year 2070.

Among its various renewable energy initiatives, India has emerged as a global leader in wind energy. With more than three decades of experience and innovation in wind energy technology, the country has successfully established a robust onshore wind power infrastructure. As of 2023, India has installed approximately 41.93 gigawatts (GW) of onshore wind energy capacity. This achievement not only reflects India's technical and policy advancements in the sector but also positions the nation as the fourth-largest wind power market in the world (Government of India, 2023). This progress underscores India's commitment to a green energy transition and its potential to lead global efforts in renewable energy deployment.

According to the latest data from Energy Statistics in India, as of May 2023, the estimated wind energy potential at a hub height of 150 meters stands at an impressive 1,163,856 megawatts (MW), accounting for approximately 55.17% of the country's total renewable energy potential (Government of India, 2024). This represents a significant increase from the earlier estimate in March 2021, when the wind energy potential was assessed at 695,509 MW (46.66%) at a hub height of 120 meters (Government of India, 2024; Table 1). The Ministry of New and Renewable Energy (MNRE) also confirms this updated estimate, highlighting the enhanced potential of wind power generation due to advancements in turbine technology and higher hub heights.

This upward revision reflects not only improvements in technological capability but also India's proactive approach toward mapping and harnessing its renewable energy resources more efficiently. As the nation experiences rapid population growth, urban expansion, and industrialization, the demand for electricity is projected to surge, posing a serious challenge for energy planners and policymakers. While coal continues to dominate the energy mix, India has made noteworthy progress in expanding its wind power infrastructure.

Despite the challenges associated with integrating renewable sources into the grid, the consistent increase in wind power installations underscores India's determination to diversify its energy portfolio and reduce its dependence on fossil fuels. This momentum in wind energy development is a critical component of the country's broader strategy to transition to a low-carbon economy and meet its long-term sustainability goals (Sharma et al., 2011).

In this context, a study by Mani and Dhingra (2013) highlighted the pressing need to expand power generation capacity in response to India's rapid economic growth. The study noted that renewable energy accounted for 12% of the total power generation at the time, with wind energy contributing a substantial 67% of this share. Additionally, the growing concerns over environmental degradation and the associated social and economic costs have made it imperative for all nations to transition toward cleaner, more sustainable energy sources. Among these, wind energy stands out as one of the most significant and promising options. India, owing to its favourable geographical conditions, is well-positioned to harness the benefits of wind energy, paving the way for a more sustainable and resilient energy future.

Eight major states contribute significantly to wind energy generation in India: Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Telangana (Table 1). Among these, Tamil Nadu has consistently maintained a leading position in the wind energy sector over the past three decades. The suitability of a location for wind energy installations depends on several key factors, including land availability, wind speed, surrounding terrain, and access to electric transmission lines for grid connectivity.

Technological advancement at the local level is also crucial in the development of wind energy infrastructure, and efforts must be made to ensure that such technologies are accessible and affordable. Several studies, including Goyal (2010), have identified onshore wind farms as a highly effective means of achieving low-carbon energy transitions. However, to fully harness their potential, it is essential to address and overcome the barriers that hinder their implementation.

Tamil Nadu, along with Rajasthan and Gujarat, stands out as one of the top-performing states in wind energy adoption in India. This study aims to provide a comprehensive overview of the status of wind energy in Tamil Nadu, drawing particularly on insights from field experiences at the Muppandal-Aralvaimozhi wind farm sites. It explores the region's wind energy potential, the role of technological advancements, the influence of policy frameworks, and the economic dimensions that shape the state's leadership in wind power development.

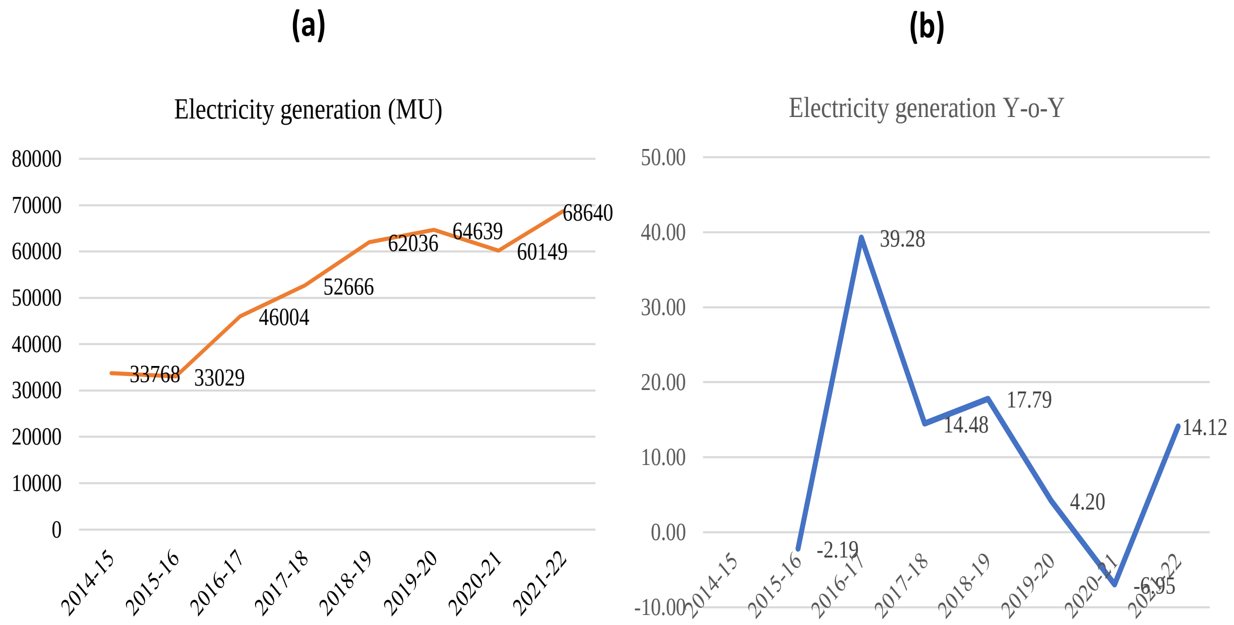
2. Wind Power Growth in India

Figure 1, Panel (a), illustrates the steady rise in annual electricity generation from wind energy sources in India, increasing from 33,768 MW in 2014–15 to 68,640 MW in 2021–22. However, the year-on-year (Y-o-Y) growth rate, shown in Panel (b), presents a more nuanced picture. Initially, the growth rate rose from a negative -2.19% in 2015–16 to a remarkable 39.28% in 2016–17, marking the highest annual increase in wind energy generation in the country's history.

Following this peak, the sector experienced a consistent downward trend in growth, culminating in a significant decline between 2018–19 and 2020–21, where the growth rate dropped to -6.9%. This sharp decline is largely attributed to the global COVID-19 pandemic, which disrupted infrastructure development, supply chains, and investment flows. Notably, the growth rate had already begun to slow, falling from 17.89% in 2018–19 to negative territory by 2020–21.

Despite these setbacks, the sector demonstrated resilience and recovery. In 2021–22, the growth rate rebounded to 14.2%, indicating a renewed momentum in wind energy development. Although the highest growth was recorded in 2016–17, the sector's ability to bounce back from a negative phase suggests strong potential for future expansion. The transition from negative to positive growth between 2015–16 and 2016–17 serves as a historical precedent for the sector's capacity to overcome challenges and continue progressing.

Figure 1: Year wise Electricity generation from Wind sources in India



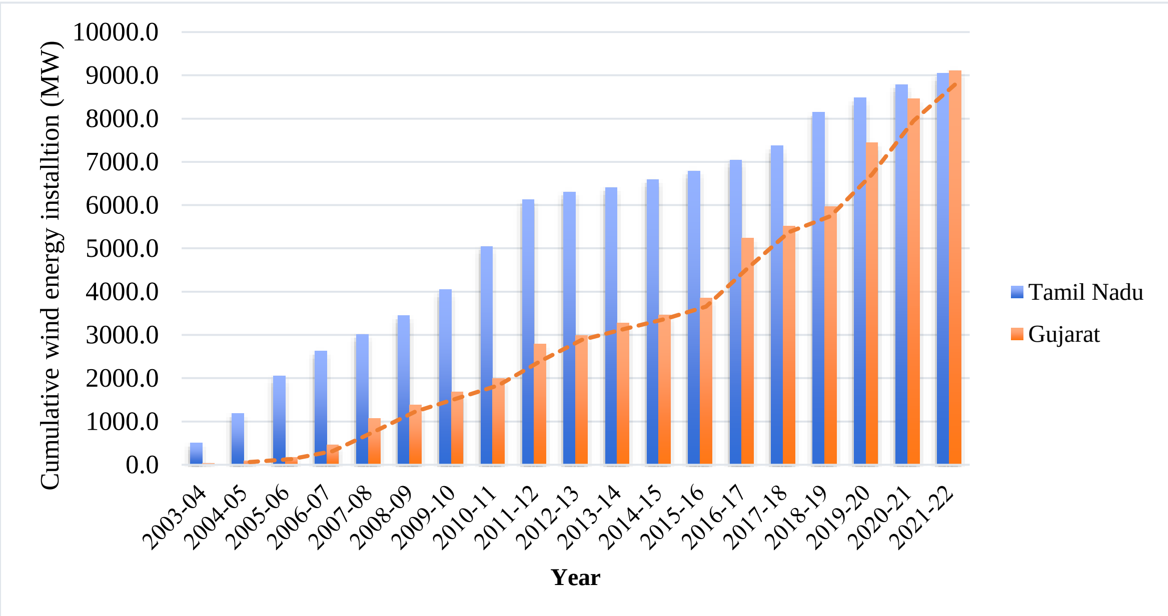
Source: Ministry of New Renewable Energy (MNRE), Government of India, 2023.

The growth of the wind energy sector carries significant implications for the environment, the economy, and the broader energy landscape. By reducing dependence on fossil fuels, wind energy plays a crucial role in mitigating climate change. In addition to its environmental benefits, the sector generates economic opportunities through job creation and increased investment in local communities. As technological advancements continue, wind energy is expected to become even more viable and competitive, further strengthening its contribution to the global energy mix.

India has made remarkable progress in wind turbine generator technology and now possesses advanced capabilities in wind turbine manufacturing. A strong domestic manufacturing sector supports the local production of approximately 75% of wind turbine components. Numerous global industry leaders have established operations in India, and more than 14 companies are currently manufacturing over 35 different wind turbine models. These achievements are facilitated through joint ventures, licensed production agreements, subsidiaries of foreign companies, and Indian firms developing their own technologies. The maximum available unit size for wind turbines in the country has increased to 3.60 MW (Government of India, 2023), reflecting significant technological progress and a maturing industry.

Tamil Nadu and Gujarat are the leading states in India for wind energy installations. As of 2021–22, they recorded the highest cumulative installed capacities—9,109.97 MW in Tamil Nadu and 9,405.71 MW in Gujarat. Together, these two states accounted for approximately 47% of the total wind energy capacity installed in the country during that period.

Figure 2: Wind Power installed capacity (MW)



Source: National Institute of Wind Energy, Government of India. (As on March 2022)

Since 2020–21, both states have added around 80 MW of cumulative wind energy capacity. However, Gujarat soon overtook Tamil Nadu, reaching a total installed capacity of 9,405.71 MW. This milestone marked the first time that Tamil Nadu lost its long-held top position in wind power capacity, with Gujarat emerging as the new leader in 2021–22.

Figure 3: Wind Power Share (in %): Tamil Nadu vs Gujarat

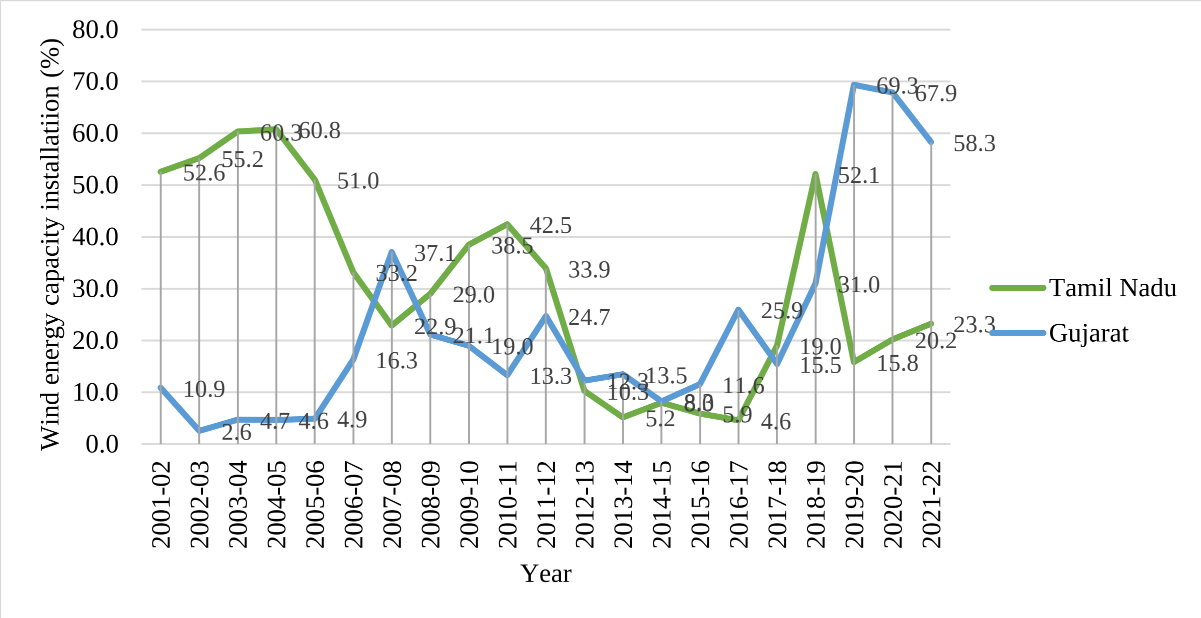


Figure 2 illustrates the percentage share of installed capacity in total wind energy installations for each year in the states of Tamil Nadu and Gujarat. In the early 2000s, Tamil Nadu held a higher share of wind energy installations, primarily due to its early adoption and substantial base of wind projects. As one of the pioneering states in wind energy development—having initiated wind farming in the 1980s—Tamil Nadu contributed a significant portion of the country's wind energy production during that time. Between 2001–02 and 2005–06, it maintained a higher installation rate than Gujarat, although this trend gradually declined.

In the post-2018–19 period, Gujarat surpassed Tamil Nadu in terms of wind energy capacity share, eventually reaching approximately 69.3%. This shift highlights Gujarat's rapid expansion in wind energy infrastructure and its emergence as the new leader in India's wind energy sector.

Table 1: Potential of Wind Energy in India

SI. No	State	Wind Potential at 120 m (GW)	120 m (%)	Wind Potential at 150 m (GW)	150 m (%)
1	Andhra Pradesh	74.9	10.8	123.3	10.6
2	Gujarat	142.56	20.5	180.8	15.5
3	Karnataka	124.15	17.9	169.3	14.5

4	Madhya Pradesh	15.4	2.2	55.4	4.8
5	Maharashtra	98.21	14.1	173.9	14.9
6	Rajasthan	127.75	18.4	284.2	24.4
7	**Tamil Nadu**	**68.75**	**9.9**	**95.1**	**8.2**
8	Telangana	24.83	3.6	54.7	4.7
	Total 8 windy states	676.55	97.3	1136.7	97.7
9	Others	18.95	2.7	27.1	2.3
	Total	695.5		1163.9	

Source: Ministry of New and Renewable Energy (MNRE), as on March 2023. https://mnre.gov.in/wind-overview/

Table 1 presents wind energy capacities across various Indian states, highlighting their potential at different hub heights. Based on the analysis of wind energy potential at a height of 120 meters, Gujarat emerges as the leading state, with a substantial capacity of 142.56 gigawatts (GW), accounting for 20.5% of the total wind potential in this category. Karnataka follows with a capacity of 124.15 GW, contributing 17.9% to the total, while Rajasthan also demonstrates significant potential, with 127.75 GW, representing 18.4% of the overall wind energy capacity at this height.

When assessing wind energy capacity at a higher hub height of 150 meters, Gujarat continues to lead with an impressive potential of 180.8 GW, accounting for 15.5% of the total potential. Karnataka also maintains a strong position, with a capacity of 169.3 GW, representing 14.5% of the total. Notably, Rajasthan's wind energy potential shows a significant increase, reaching 284.2 GW, which constitutes 24.4% of the total potential at this altitude.

The combined wind energy potential of the eight leading states—Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, and Telangana—amounts to 676.55 GW at a height of 120 meters, making up 97.3% of the country's total wind potential at that elevation. At 150 meters, their cumulative potential rises to 1,136.7 GW, accounting for 97.7% of the overall national potential.

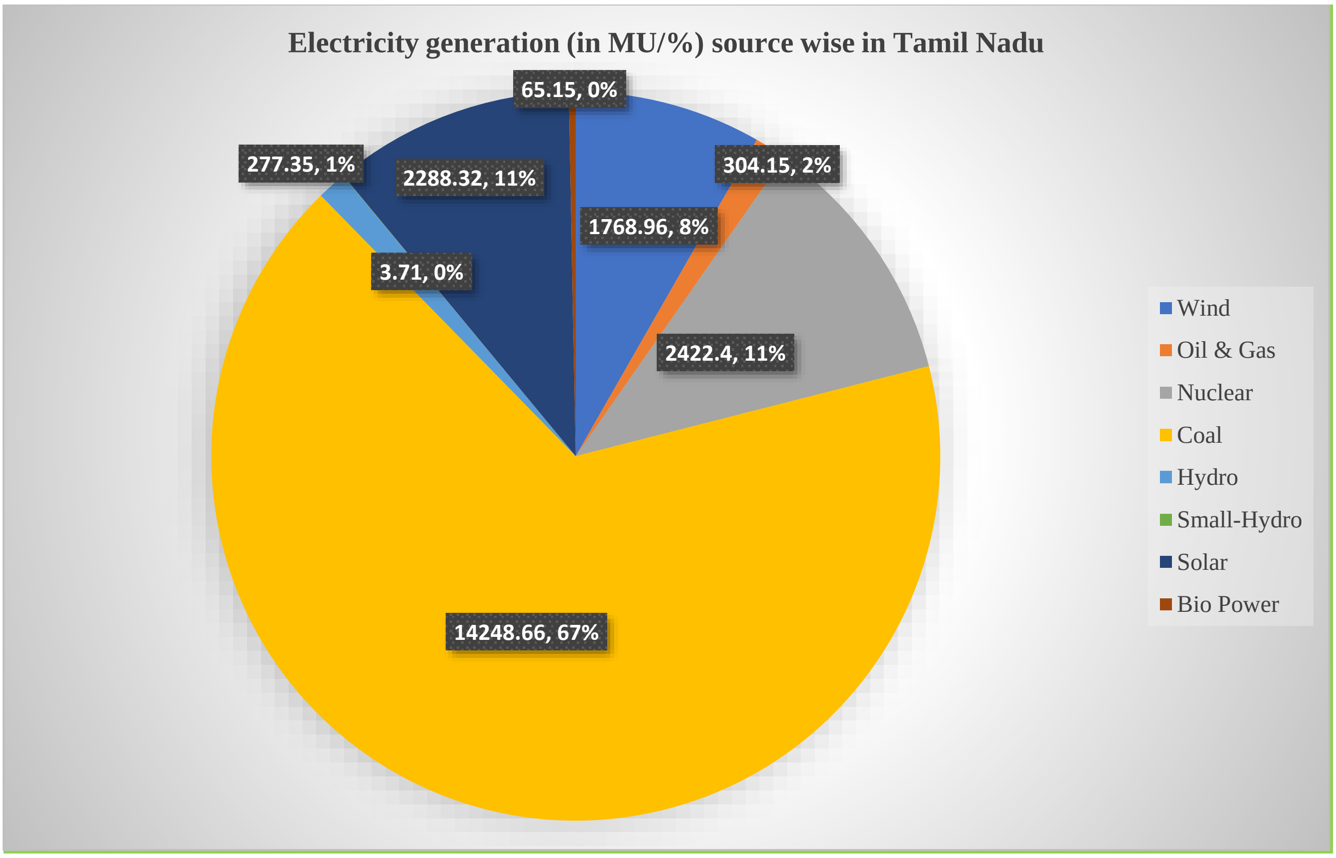
In contrast, the remaining states categorized as "others" contribute a relatively small share. At a height of 120 meters, they possess a combined potential of 18.95 GW (2.7% of the total), which increases modestly to 27.1 GW (2.3%) when the hub height is raised to 150 meters.

Gujarat, Karnataka, and Rajasthan hold the majority of India's wind energy resources due to their substantial wind potential. The data underscores the critical role these states play in advancing India's wind energy capacity and suggests the need for a targeted strategy to effectively harness these resources in order to meet the nation's renewable energy goals.

3. Wind Energy Status in Tamil Nadu

The wind energy sector comprises several critical components, including site selection, turbine installation, operation and maintenance, and fault detection. Each of these elements plays a vital role in ensuring the efficient and successful functioning of wind energy projects. The sector's growth is fueled by technological advancements, supportive government policies, and the growing awareness of the need for sustainable energy solutions. In addition to reducing greenhouse gas emissions, wind energy also generates economic benefits by creating jobs and promoting local development.

Figure 4: Electricity generation from different sources in Tamil Nadu.



Source: India Climate Energy Dashboard, 2024. NITI Aayog, Government of India.

Coal-based electricity generation dominates in Tamil Nadu, accounting for 67 percent of the state's total electricity production. The second-largest contributions come from nuclear and solar energy sources, each providing around 11 percent. Wind energy ranks third, generating approximately 1,768.96 million units (MU), which represents about 8 percent of the total electricity produced from various sources. Most wind farms are situated in the southern part of Tamil Nadu, where the terrain and wind conditions are more favourable for wind energy generation.

Wind speed is the primary factor to consider before installing wind turbines in any region. Tamil Nadu has four major wind corridors that enable consistent wind energy production throughout the years. These are the Aralvaimozhi Pass, Sengottah Pass, Cumbam Pass, and Palghat Pass. As a result, these regions have a high concentration of windmills. The strongest winds occur between April and September, during which the state generates approximately 80 percent of its annual wind energy.

Among these, the Aralvaimozhi Pass—particularly the Muppandal area—hosts the largest windmill installation in Asia (Figure 4). All four passes exhibit excellent wind conditions, with Aralvaimozhi standing out. It records a mean wind speed of about 6.563 m/s, a wind power density of 226 W/m², a most probable wind speed of 6.403 m/s, and a maximum wind speed of 8.699 m/s (Balaguru et al., 2021).

A study comparing the wind energy potential between Chennai and Kanyakumari concluded that Kanyakumari is more suitable for wind farms. The region offers installation potential with minimal impact on UNESCO World Heritage sites and has demonstrated environmental benefits, such as reduced land surface temperatures (Vachaparambil, 2013).

Figure 5: The major Wind Pass region in Tamil Nadu

Source: Department of Environment, Government of Tamil Nadu, 2020.

4. The case of Aralvaimozhi

Aralvaimozhi, located in the Kanyakumari district in the southern region of Tamil Nadu, is home to the largest wind farm site in India. Windmill installations began here in the 1980s, and by the early 2000s, the area had developed into a fully operational wind farm. Muppandal, in particular, is recognized as the largest functioning wind farm in the country. The district has been generating wind energy for over 30 years, making it the site of the oldest wind farm in the state.

Over the years, the wind energy sector in Tamil Nadu has undergone significant evolution, driven by technological advancements and increased deployment of wind turbines. These turbines convert the kinetic energy of wind into electrical power. For optimal performance, they are installed in areas with consistent and strong wind flows, allowing for efficient operation and substantial electricity generation.

Figure 6: Wind site Aralvaimozhi, Kanyakumari district, Tamil Nadu.

Aralvaimozhi is a prominent region for wind energy projects due to its strategic geographical location. The mountain pass through the Western Ghats, which opens to the west, allows for consistent wind flow for approximately 10 months each year, making it an ideal site for wind energy generation. As a result, a large wind farm has been developed in this region.

The site features a high concentration of smaller wind turbines, typically ranging from 50 to 65 meters in height. This configuration is well-suited to the area, as the higher wind density supports the efficient operation of lower-height turbines. Consequently, a larger number of smaller turbines have been installed to capitalize on the favourable wind conditions (Figure 4).

A field supervisor from an Operations and Maintenance (O&M) company emphasized that the Aralvaimozhi region is well-suited for smaller wind turbines. In contrast, larger turbines—typically around 120 meters in height—have been installed in low-wind areas such as Kayathar, Manoor, Ottapidaram, Kadambur, and Kovilpatti. Notably, the largest turbine in India, with a capacity of 4.2 MW, was installed at the Vadalivilai site in Valliyur, which is located nearby.

Before installing wind turbines, wind masts are set up to measure wind conditions over a period of one to two years. At the Muppandal site, the annual average wind speed ranges from 19 to 25 km/h. Ideal wind speeds in this region generally fall between 15 and 16 meters per second, reaching up to 25 meters per second during peak periods—conditions highly suitable for efficient energy production. I recorded a real-time overview of the energy monitoring system inside a wind turbine located in Aralvaimozhi (see Figure 1 in the Appendix).

4.1 Prior to the installation of the wind turbine

The installation of windmills, or wind turbines, involves several critical steps to ensure optimal performance and efficiency. The process typically begins with the installation of wind masts, which measure wind speeds over a period of one to two years to assess the suitability of a location. This data helps identify areas with consistent and strong wind flows—an essential factor for maximizing energy production.

The next step is site selection, which involves evaluating both wind conditions and environmental factors. Ideal sites are usually located on wasteland or dry land to prevent the displacement of fertile agricultural areas. Once a suitable site is identified, negotiations with landowners are conducted, and the necessary land is acquired.

Following land procurement, the wind turbines are installed. Turbines are spaced adequately in all four directions to ensure a safe distance between them, minimizing the risk of one turbine damaging another in the event of structural failure. Finally, regular maintenance is carried out to ensure the turbines operate efficiently and safely over time.

Typically, a windmill installation team consists of around five core members. However, during the installation process, specialized teams are deployed for specific tasks such as civil works, structural assembly, electrical line setup, and overall project coordination. Once the main project team completes its responsibilities, a separate communication team takes over. This team handles tasks such as configuring the internal support systems, managing the control systems, and arranging the electrical control boards.

After the turbines are installed and operational, a dedicated maintenance team is assigned to handle all labour-intensive tasks related to ongoing operations and upkeep. The installation of a single windmill requires a minimum of 20 workers. The process begins with civil, electrical line, and project-specific training, followed by the assembly and installation phase. On average, it takes approximately 25 days to fully install one wind turbine.

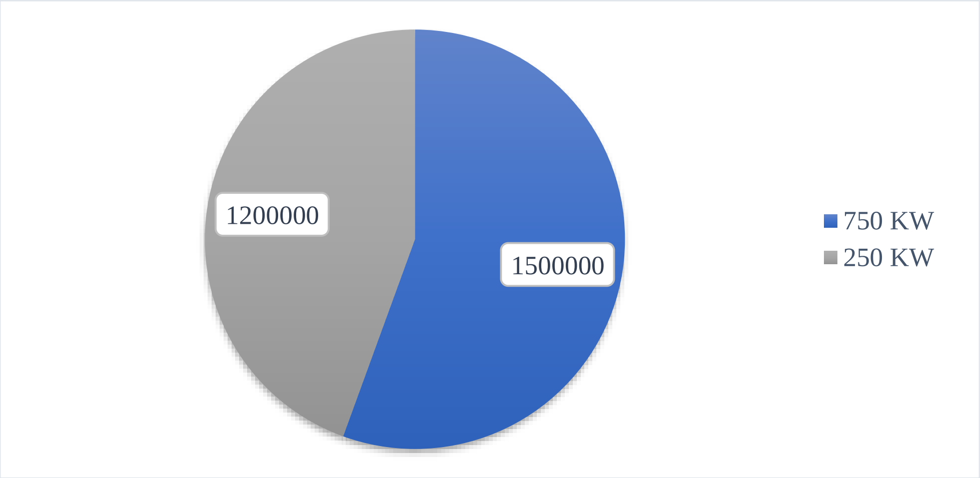
4.2 Prospects for Wind Energy in Aralvaimozhi

For a wind turbine with a capacity of 250 kW, the annual electricity generation is approximately 1.2 million (12 lakh) units. In comparison, a 750 kW turbine generates around 1.5 million (15 lakh) units per year (see Figure 7). Variations in production may depend on the wind potential of the installation area.

The wind energy sector offers significant opportunities for career growth and professional development. As the industry continues to expand, there is an increasing demand for skilled professionals to manage and maintain wind farms. The emergence of larger and more technologically advanced wind turbines has created new job roles and areas of specialization.

To make the sector more appealing to young professionals, it is essential to address challenges by implementing stronger safety protocols, offering competitive salaries, and providing targeted training programs. Furthermore, raising awareness about career prospects in wind energy can attract a new generation of skilled workers to this promising field.

Figure 7: Electricity supply by wind turbine capacity (Unit per year)



Source: Authors’ estimation from the field Aaralvaimozhi

4.3 Sustain electricity and green jobs

A wind turbine with a capacity of 250 kW generates approximately 1.2 million (12 lakh) units of electricity per year, while a 750 kW turbine produces about 1.5 million (15 lakh) units annually (Figure 7). Variations in production may be influenced by the wind potential of the area.

The wind energy sector offers significant opportunities for career growth and development. As the industry expands, the demand for skilled professionals to manage and maintain wind farms continues to increase. The introduction of larger and more advanced wind turbines has created new job opportunities and areas for specialization.

Addressing challenges through improved safety protocols, competitive salaries, and targeted training programs can make the sector more attractive to young professionals. Additionally, raising awareness about career opportunities in wind energy can help draw a new generation of skilled workers to the field.

4.4 The emergence of O&M companies and contractual jobs

We observed at this site that Operation and Maintenance (O&M) companies play a vital role in the wind energy sector. They function as third-party service providers, contracted by turbine owners to deliver operation and maintenance services for a specified period. Working in the wind energy sector, especially in O&M roles, comes with both benefits and responsibilities. Employees typically receive perks such as Employees' State Insurance (ESI) and Provident Fund (PF), which enhance job satisfaction and financial security. Additionally, companies ensure that replacement personnel are available in case of illness, and technicians operate in shifts to maintain continuous coverage.

Maintenance is a critical aspect of wind energy operations. It includes tasks such as changing gear oil, inspecting towers, and resolving mechanical, electronic, and electrical issues. The costs involved—such as for specialized grease and annual maintenance—can be substantial. However, regular maintenance is essential to ensure the longevity and efficiency of wind turbines.

Fault detection and monitoring are also crucial components of wind turbine operation. Wind turbines are equipped with sensors that track various parameters, including oil levels, voltage, and the status of mechanical components. These sensors play a key role in identifying and diagnosing issues promptly. O&M companies deploy trained personnel from the region to carry out this maintenance and monitoring activities, thereby ensuring the smooth and efficient production of wind energy.

Operators are responsible for supervising the turbines and conducting regular inspections. This includes working in shifts to monitor the equipment and carry out necessary maintenance tasks. Effective fault detection and supervision help minimize downtime and maximize energy production.

O&M companies provide monthly salaries to all teams involved in turbine installation. In the past, company-employed staff were present on-site; however, currently, only contract staff are engaged in most roles. The company staff typically includes four individuals: two in civil roles, two project managers, and one electrical technician. The remaining contract work is handled by another agency.

4.5 Manufacturing the spare parts of the windmill in the local market

The wind energy sector benefits significantly from a strong domestic manufacturing industry, which enables the local production of nearly 75% of the required components. Several prominent multinational corporations have established operations in the country, with around 14 companies manufacturing a diverse range of 35 wind turbine models (GOI, 2023).

Field observations reveal that the tower components of windmills are manufactured in Trichy, while the blades are supplied from Bangalore. However, the control systems are imported from countries like Denmark. The primary reason for manufacturing towers locally is their considerable height, length, and weight, which make transportation difficult and expensive. Importing these towers from abroad would be both costly and time-consuming due to the long shipping durations. As a result, a local production unit was established in Trichy specifically for tower manufacturing. Additionally, transformers are procured from Chennai, and other components such as generators and gearboxes are produced by the local market.

4.6 Repowering boosts wind energy

Repowering typically means replacing 2–5 existing smaller wind turbines with a larger one, which necessitates discussions with multiple owners and addressing valuation issues. Repowering, as a policy action, can increase the potential growth in the region's electricity generation without requiring additional land. Furthermore, replacing smaller wind turbines with larger ones will reduce their presence. For example, we noticed a repowered machine with 750 KW capacity in the field after replacing two smaller machines (250 KW) from the same owner (see Appendix Figure 2). Repowering results in effective electricity generation at lower costs, as well as reduced operational and maintenance costs. This repowering leads to the new installation of technologically upgraded machines, and as a result, there is a demand for local manufacturing in this sector. As a result, the number of green job opportunities in this sector has increased significantly.

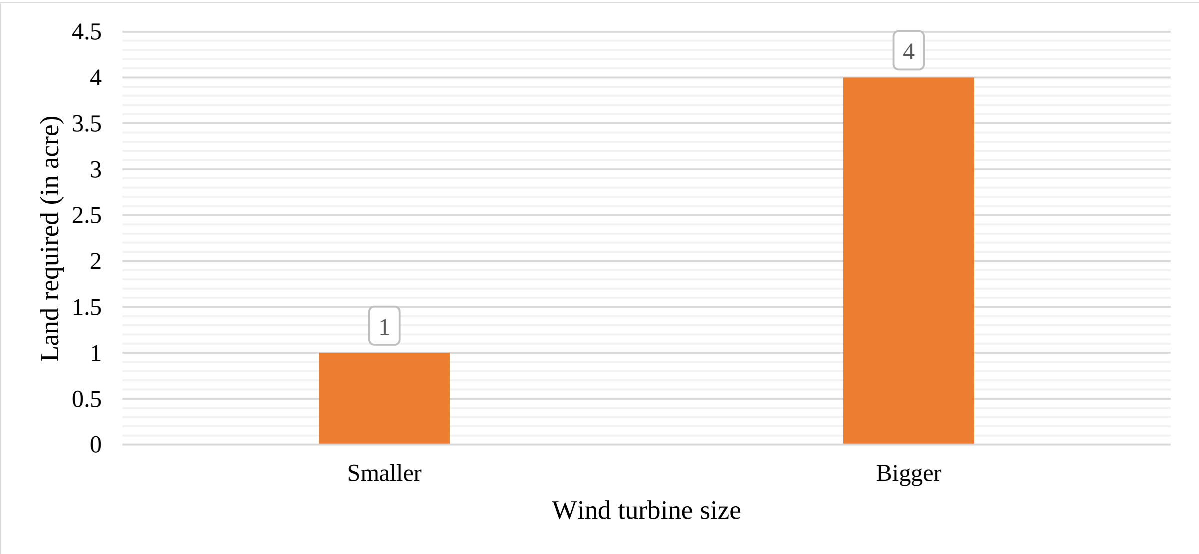
The wind turbines in Tamil Nadu prior to 1996, which have a total capacity of over 500 MW, are well-suited for repowering due to their advantageous wind energy sites in India. By increasing its capacity through repowering by a factor of 3–4, the state may add an extra 2000 MW. Vestas and Suzlon, equipment makers, emphasise that the Muppandal and Aralvaimozhi wind belts in Tamil Nadu have the capacity to generate about 1500–2000 MW through repowering (Goyal, 2010).

5. Challenges to Sustainable Wind Energy at the Site

5.1 Land Acquisition

One of the major challenges in this sector is land acquisition. Generally, OEM companies have at least two brokers, primarily for land procurement for windmill installation. The bigger machine with a 750-kw capacity requires approximately 3–4 acres of land, while the smaller machine (225 KW) requires 1 acre of land (Figure 8), excluding the nearby residential area. If the land ownership is a one-person name, then land registration and documentation will not be complicated. The turbine's three-bladed circle will guide the acquisition of land, and if it falls, it will require four directions, necessitating ample space.

Figure 8: Land requirements (in acre)



Source: Same as in Figure 7.

5.2 Logistical issues

The average size of wind turbines increased with technological upgrades, but transporting these heavy machines is difficult. Particularly from the road to the windmill site. This logistical reason also prompted the majority of owners in the onshore wind energy sector in the region to purchase smaller machines.

When these wind machines were installed in the 1990s, there were fewer households on the nearby road. As a result, it was easy to move heavy machines and spare parts from the roadside to the windmill site. However, the construction of numerous houses over time has narrowed and complicated the path for carrying spare parts to the windmill site.

5.3 Overwind speed

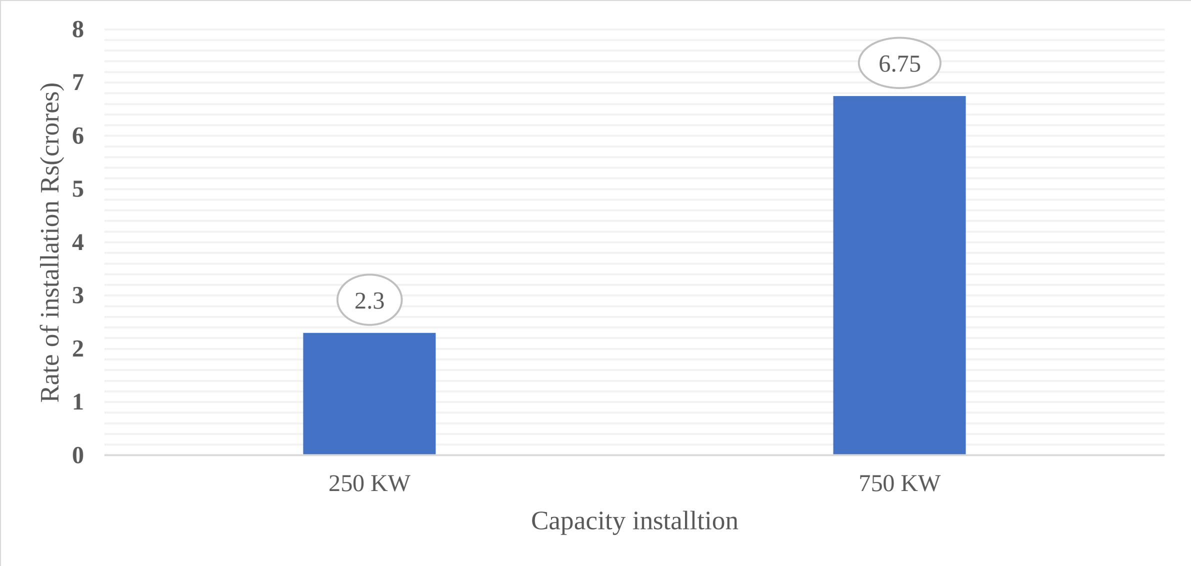
Sometimes, over-wind speed causes an error in the machine. Generally, when the speed exceeds 25 meters, the machine encounters an error. We don’t experience a constant 25-metre wind speed in this region, but usually 15–16 metres. Within this limit, we have constant production. If a cyclone occurs, the windmill will automatically stop when it exceeds the wind's speed.

Occasionally, the system stalls, causing its sensor to malfunction, leading to a loss of control. Blades break due to overwind speed in the region, which incurs a higher cost because of this fibre material. This material is expensive and requires ordering from Chennai, while all these parts are now produced locally.

5.4 Higher Initial cost

The initial capital cost of installing a 750 KW wind turbine is approximately Rs. 6.75 crore, while a 250 KW turbine costs around Rs. 2.3 crore. High initial investments can be a barrier for many potential investors (Figure 9).

Figure 9: Cost of installation of Wind turbines



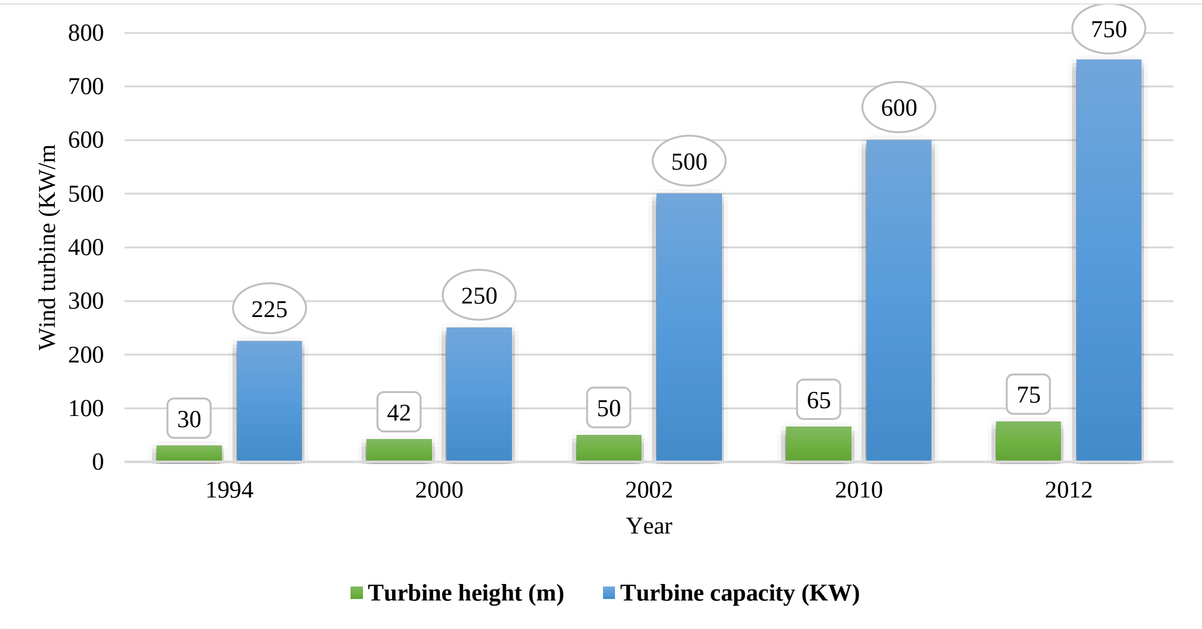
Source: Same as in Figure 7.

5.5 The age-old standing turbines

The introduction of two-leaf windmills in the late 1980s marked the beginning of wind energy development in the area. Over time, advancements in technology have led to the deployment of more advanced and efficient wind turbines. According to the Tamil Nadu Electricity Regulatory Commission (TERC) notice of 2019, wind power generation in Tamil Nadu commenced in 1986 using turbines with capacities ranging from 200 KW to 600 KW. These machines have exceeded their anticipated lifespans but are still functioning. The majority of these machines are subject to either EPA or EWA agreements, with tariffs set at Rs. 2.75 and Rs. 2.90 per unit. Due to technological improvements, the present machines have experienced a growth in their capacity, reaching values such as 750 KW, 850 KW, 1500 KW, 2000 KW, 2100 KW, and so on (TERC, 2019).

The Aralvaimozhi site primarily features lower-height turbines, which range in height from 30 m to 75 m, due to the higher wind speed. According to the O&M company information from our field visit, the company manages a total of 80 machines. However, it has maintained 34 turbines in the Aralvaimozhi region. Some of the machines were installed in the 1990s with a 30 m height and 225 KW capacity. Later, the installation underwent a gradual update, increasing its capacity to a maximum of 750 KW. Similarly, many of the wind turbines in and around this site are quite old, having been in operation for over 25 years.

Figure 10: Turbine height with its capacity in Aaralvaimozhi



Source: Same as in Figure 7.

The owners of these old machines request that the state government and local authorities extend the operational life span of the wind turbines in this area. Consequently, many wind turbines are still running, even if they have already crossed their operational lifespan. The longer life span leads to higher operational costs, more frequent faults and errors, and lower production. It also blocks new employment opportunities by postponing the replacement of the new wind turbines on the site.

These aged machines led to an increasing annual maintenance cost, including grease changes and other servicing, which can amount to Rs. 80,000 per machine. This includes costs for specific types of grease, gearbox oil, and transformer filtration.

The windmill at this location extensively depends on AC induction motors, which are a cost-efficient choice for numerous industrial applications where durability and reliability are crucial. However, the technologically enhanced and high-capacity turbines, when combined with Permanent Magnet Synchronous Motors (PMSMs), provide increased efficiency, superior performance, and accurate control. This makes them the preferred option for advanced applications that require exceptional performance and energy economy. The price of this particular motor is higher than that of the AC induction motor. As a result, the owners of smaller wind turbines are largely more reliant on conventional technology than the most advanced wind turbines.

5.6 Evacuating infrastructure

The infrastructure for transmission of wind energy has to be improved. This will help to transmit the energy to the local substation in the region. The Tamil Nadu Electricity Board (TNEB), responsible for establishing substations and transmission lines. It has to maintain the lines effectively which ease the transmission of energy from windmill to the substation and subsequently to the grid and distribute to the consumers.

5.7 Payment delays

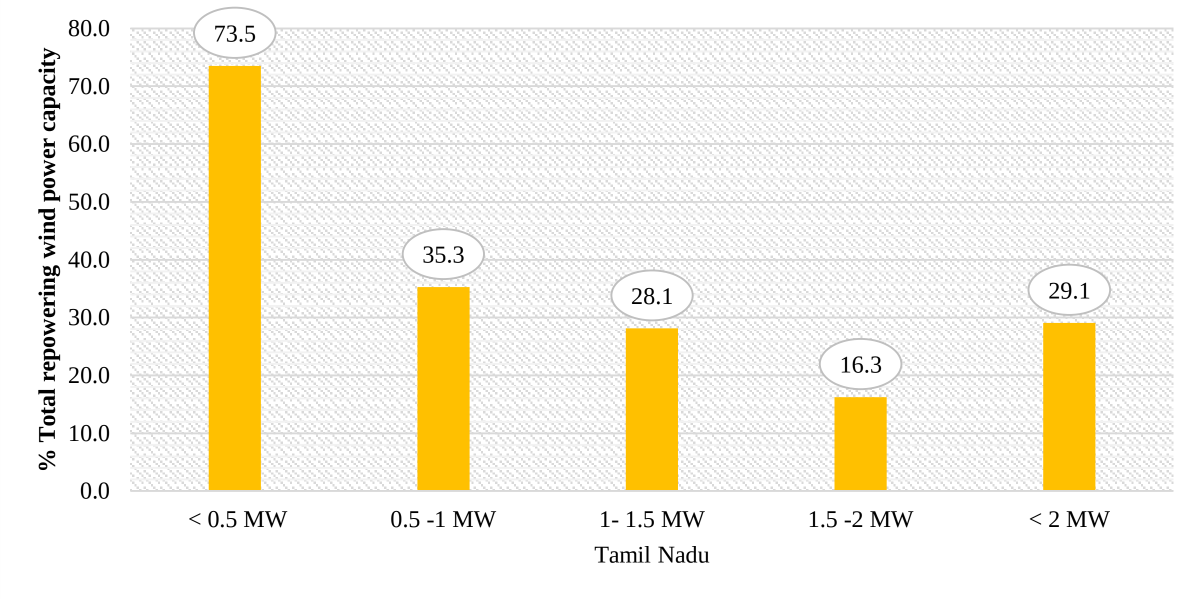
The irregular payments from the Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) are causing financial strain for the owners of this site. This is a complex issue because, if the payment is due, the machine owner will struggle to cover the O&M company's annual servicing charge. These days, the energy producer receives the payment in instalments.

5.8 Repowering is a challenge

The repowering solution necessitates negotiations with several wind site owners, given that the wind machines are owned by multiple individuals and are located in close proximity. A single individual cannot own many wind turbines in the region, largely due to their initial capital expenditure and maintenance. When repowering the wind mills, government-level initiation is more critical to reaching a consensus among the owners. Repowering may be challenging in this region due to its higher wind speed.

Figure 11 depicts the total repowering capacity in Tamil Nadu. It consists of 73.5 percent of the total wind farms with a capacity of less than 0.5 MW. This is the highest share of low-capacity wind machines in India. It is clearly evident that as MW capacity increases, their repowering percentage share decreases with each additional increase in wind machine size. Thus, it is evident that these are the lower-height wind machines, ranging from 30 to 60. These wind turbines, with their inefficient technology, are typically lower in height than the recently installed 120–140 m range in India (MNRE, 2023). The Muppandal and Panakudi sites in Kanyakumari district are examples of wind farms in India with a lower-height hub.

Figure 11: Percentage distribution of total repowering wind power capacity in India



Source: Authors' estimation from Table 2.

While repowering the higher-height upgraded machine will be installed in general, but this higher wind speed in this region allows for the installation of medium-height turbines only. The height of this tower typically ranges from 30 to 50 metres, allowing for effective energy harvesting. This may be one of the reasons Tamil Nadu doesn't have the higher potential wind energy range of 120 m hub height and 150 m hub height in the recent estimation (Table 1).

The evidence suggests that repowering will yield an additional 3000 to 4000 MW in the state (The Hindu, 2024). Our observations in the specific field of Aaralvaimozhi-Panakudi, however, indicate that the owners of smaller wind turbines will incur additional costs if they choose to install advanced turbines during repowering. Therefore, they are not inclined to pursue repowering, particularly when it involves higher-capacity machines with advanced technology.

5.9 Clean Energy Waste

If repowering takes place at this oldest wind farm, it will result in a significant increase in waste materials from the turbines. The state lacks experience with large-scale repowering and its implications, particularly regarding energy waste and environmental impact. The notion of wind power as a clean-energy alternative will be challenged if turbine waste is not properly managed.

5.10 National Repowering & Life Extension for Wind Power Projects 2023[1]

Table 2: National Repowering & Life Extension for Wind Power Projects

States	Total capacity (MW)				
	< 0.5 MW	0.5-1 MW	1-1.5 MW	1.5-2 MW	< 2 MW
Tamil Nadu	1181	2919	1813	1473.5	7386.5
Maharashtra	243	1068	1389	731.35	3431.35
Karnataka	0.3	954	652	1417.05	3023.35
Gujarat	51	1457	1352	1805.35	4665.35
Rajasthan	39	1192	788	914.9	2933.9
Madhya Pradesh	0	290	260	1012	1562
Kerala	0	18	0	10	28
Andhra Pradesh	92	378	195	1701.2	2366.2
Total	1606.3	8276	6449	9065.35	25396.65

Source: MNRE, 2023.

Table 2 displays India's estimated total repowering wind capacity. This clearly shows that these eight major states need to repower their age-old wind turbines. But, according to the MNRE 2023 estimation, Tamil Nadu needs to repower a significant portion of its wind machines across almost all categories, which is more than any other state in India. As per the national repowering policy for 2023, the allowed repowering size of wind machines is less than 2 MW. In this category, the state also has a significant portion of repowering capacity. As discussed in the previous section on challenges, repowering this large segment of wind machines, especially lower-height hubs, may result in both opportunities and challenges for the state.

6. Central and State Government Policies and Initiatives

6.1 Incentives available for Wind sector

The Government has implemented various measures to promote renewable energy, including wind energy, in the country. These initiatives include

- *The government is allowing up to 100 percent foreign direct investment (FDI) under the automatic approval route.*

[1]https://cdnbbsr.s3waas.gov.in/s3716e1b8c6cd17b771da77391355749f3/uploads/2023/12/202312131874296229.pdf

- *Exemption from Inter-State Transmission System (ISTS) charges for interstate solar and wind energy sales for projects commissioned by June 30, 2025.*
- *Establishment of a clear trajectory for renewable purchase obligations (RPO) extending to the year 2030.*
- *The development of ultra-mega renewable energy parks offers land and transmission infrastructure to renewable energy developers on a plug-and-play basis.*
- *Construction of new transmission lines and the creation of additional sub-station capacity to facilitate the evacuation of renewable energy.*
- *The establishment of a Project Development Cell aims to draw and streamline investments in the renewable energy industry.*
- *The introduction of standard bidding guidelines for a tariff-based competitive bidding process for procuring power from grid-connected solar PV and wind projects is underway.*
- *Government orders stipulate that power dispatch will require a Letter of Credit (LC) or advance payment to ensure timely payments from distribution licensees to renewable energy generators.*
- *The Green Energy Open Access Rules 2022 have been issued to encourage the adoption of renewable energy.*
- *The Late Payment Surcharge and Related Matters Rules for 2022 have been introduced.*
- *The following are specific initiatives for wind energy promotion:*
- *Establishing a clear trajectory for wind renewable purchase obligations (Wind RPO) up to the year 2030.*
- *Providing concessional customs duty exemptions on specific components needed for manufacturing wind electric generators.*
- *The government is offering a generation-based incentive (GBI) for wind projects commissioned on or before March 31, 2017.*
- *Providing technical assistance, including wind resource assessment and site identification, through the National Institute of Wind Energy, Chennai.*

6.2 The Government of Tamil Nadu is offering incentives and facilities

- *(i) TNEB purchases surplus energy at a rate of Rs. 2.75 per unit from wind mills commissioned before May 15, 2006, starting from the date of renegotiation of the existing agreement, and at Rs. 2.90 per unit from wind mills commissioned after May 15, 2006, according to the new tariff order by the Tamil Nadu Electricity Regulatory Commission.*
- *(ii) A concessional wheeling charge of 5% is applied for captive use of power, allowing industries to draw power produced anywhere in the state at the point of consumption.*
- *(iii) A 5% charge applies to banking facilities used within the same financial year.*
- *(iv) Wind data and power potential at prospective sites are provided based on studies conducted by TEDA.*

6.3 Tamil Nadu Repowering & Life Extension Policy for Wind Power Projects – 2024[2]

- *The policy aims to optimise the utilisation of wind energy by establishing a supportive structure for the revitalisation or renovation of outdated wind turbines.*
- *Additionally, it provides a thorough compilation of incentives to enhance the commercial viability of repowering for current wind energy generators.*
- *Under this policy, all wind energy generators (WEGs) in Tamil Nadu with State Transmission Utility (STU) connectivity that have been in operation for over 15 years since installation will be eligible for repowering or refurbishment.*
- *From the date of issuance until March 31, 2030, or until the introduction of a new Repowering Policy, whichever comes first, the policy will be in effect.*

- *A refurbishment project refers to any initiative that involves a wind energy generator (WEG). a) Implements modifications to turbine components, including the gearbox,*

[2] https://www.indiaspend.com/h-library/draft-repowering-and-life-extension-policy-for-wegs-2024.pdf
https://prsindia.org/files/parliamentry-announcement/2022-11-01/Draft%20National%20Repowering%20Policy%20for%20Wind%20Power%20Projects.pdf

blades, generator, and controller, among others. b) Increases the hub height without altering the rotor blade diameter.

- *Repowering or refurbishment projects can be categorised into two types:*

Standalone Project: A WEG consisting of one or more wind turbines owned by a single entity.

Aggregation Project: A wind power project comprising a group of wind turbines owned by multiple stakeholders, utilising shared common infrastructure.

7. Policy suggestions

- The policy should facilitate a seamless transition to repowering in the state, particularly by offering incentives to owners of low-height wind turbines. This would help alleviate the financial burden and encourage these owners to initiate the repowering process independently.
- The repowering policy should support the adoption of upgraded technology suitable for low- to medium-height hub turbines in high-wind regions such as Aralvaimozhi in southern Tamil Nadu.
- The issue of delayed payments by TANGEDCO in Tamil Nadu remains unresolved. Addressing this issue would enable turbine owners to repay O&M companies for their services in a timely manner.
- Private participation continues to dominate the wind energy sector, both nationally and within Tamil Nadu. Increased government involvement should be encouraged to promote employment generation and strengthen the sector’s overall development.
- The Tamil Nadu government should prioritize the use of lower-height hub turbines, as many existing machines are outdated, have exceeded their operational lifespan, and rely on inefficient, conventional technology.
- The state’s repowering policy—which includes dismantling and decommissioning, land acquisition, evacuation system upgrades, and the renewal of leases and consents, all at the owner's expense—places a significant financial burden on turbine owners. This could deter them from initiating repowering projects. The state should consider covering these costs, particularly for owners of smaller turbines.
- Both the state and central governments should work together to identify potential sites suitable for 120- and 150-meter hub turbines across various regions. They should also ensure the availability of advanced technological equipment by promoting local

manufacturing, which would reduce reliance on imports and support job creation in the sector.

- Additionally, the state government should consider financing local windmills where repowering is necessary. This can complement the central government's repowering support, including the 0.25% interest rate rebate offered by the Indian Renewable Energy Development Agency (IREDA) for new projects.

Appendix

Figure A 1: Wind turbine with 750 KW capacity in the Panakudi site

Note: This wind turbine is newly installed after repowering, replacing two older 250KW machines with a 750KW unit from the same owner at the Panakudi site.

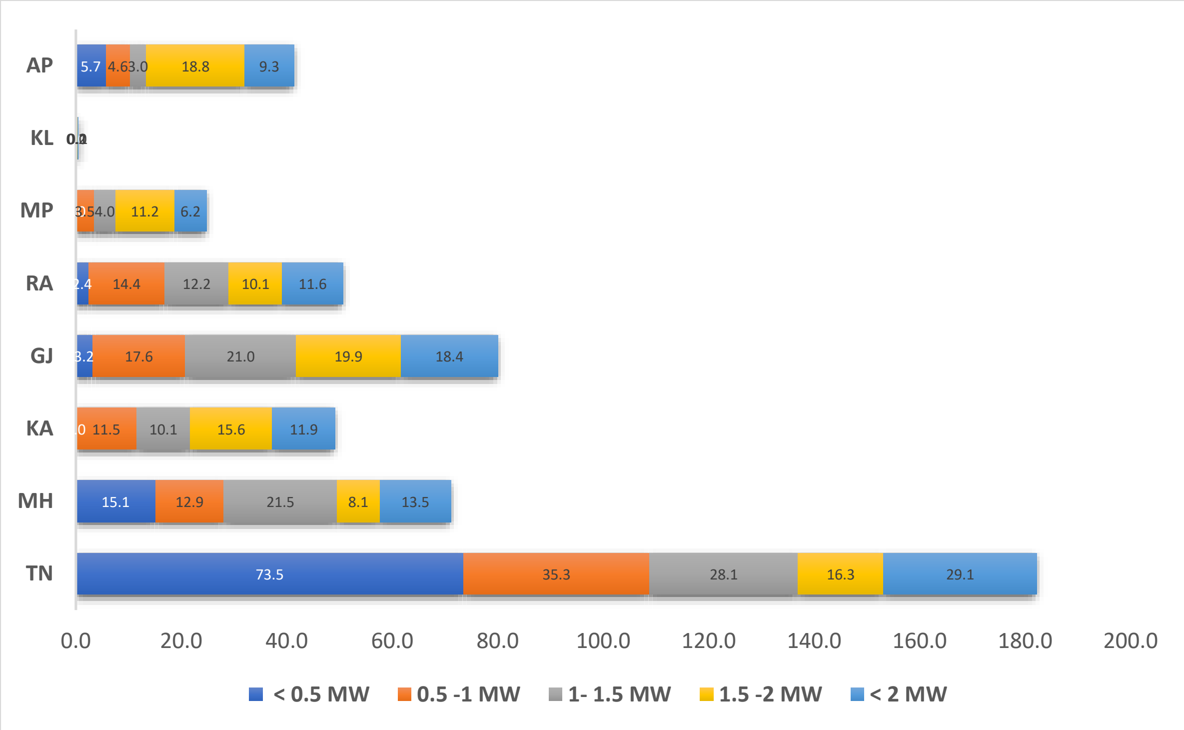
Figure A 2: Energy generation overview machine

Table A 1: Electricity generation from the Wind source

STATE	FY 2019-20 (in MUs)	FY 2020-21 (in MUs)	FY 2020-21 (in MUs)	April, 2022- January, 2023 (in MUs)
Andhra Pradesh	7626.63	6557.75	7134.58	6691.66
Gujarat	13748.53	13058.52	17854.77	17062.81
Karnataka	10148.66	9610.91	9491.62	8657.01
Kerala	119.76	130.42	136.41	165.18
Madhya Pradesh	4425.99	3913.45	4346.66	4000.28
Maharashtra	7984.27	6384.74	7085.98	6553.88
Rajasthan	6172.7	5708.27	6493.19	5467.08
Tamil Nadu	14126.93	14564.99	15821.18	15703.6
Telangana	238.25	220.91	275.69	244.61
Others	54.66	0	0	0
Total	**64646.38**	**60149.95**	**68640.07**	**64546.1**

Source: MNRE, 2023.

Figure A 3: Percentage distribution of total repowering wind capacity in India



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