

India's Remarkable Rise as a Global Leader in Wind Energy: Achievements, Progress, and Future Potential

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Abstract

India has emerged as a global leader in embracing renewable energy, with a remarkable expansion in installed capacity, reaching an estimated 163 gigawatts by August 2022, including a significant contribution from wind energy. This growth has been accelerated by India's ambitious renewable energy initiatives and well-crafted policies. Notably, this transition has led to a decline in coal power capacity, with numerous coal projects either canceled or postponed, and 15.6 gigawatts of coal-fired capacity decommissioned between 2010 and 2022. This paper provides a comprehensive analysis of the current state of renewable energy in India, with a specific focus on the progress of the wind energy sector. It underscores India's significant achievements in wind energy and the vast potential for further growth. The study emphasizes the importance of sustained dedication, innovation, and strategic reforms, positioning India to meet its rising energy demands while solidifying its global leadership in wind energy. This journey towards renewable energy promises a sustainable and environmentally responsible future for the nation.

Keywords: renewable energy, sustainability, policies, energy security, regulatory framework

Introduction

India has unequivocally established itself as a prominent global vanguard in the embrace of renewable energy, positioning it as a pivotal element within its ongoing energy revolution. As of August 2022, the installed capacity of renewable energy, including a significant portion of wind energy, has experienced a remarkable expansion, progressing from a mere few megawatts (MW) in 2010 to an estimated 163 gigawatts (GW) (Singh et al., 2022). The advancement of the industry has been significantly expedited by India's ambitious pursuits in the realm of renewable energy, coupled with a well-crafted framework of policies and reforms. Moreover, it is worth noting that the aforementioned transition has led to the cessation of coal power capacity, as evidenced by the conspicuous decrease in augmentations observed throughout the fiscal year 2021/22. During the temporal span from 2010 to 2022, a considerable multitude of coal-fired power initiatives in the nation of India, amounting to an aggregate capacity surpassing 606 gigawatts, were either negated or deferred (Apeh et al., 2022). Furthermore, it is worth noting that a substantial 15.6 gigawatts of coal-fired power capacity underwent decommissioning throughout this specified time frame. The ensuing discourse presents a meticulous examination of the prevailing condition of renewable energy in the nation of India.

India has made remarkable strides in augmenting its renewable energy capacity. As per the latest update from the Ministry of New and Renewable Energy (MNRE) in September 2022, India has achieved a noteworthy milestone in its pursuit of sustainable energy sources (Mukherjee, 2022). The cumulative installed capacity for renewable energy in the country has surpassed an impressive 162 GW. This amalgamation encompasses a confluence of solar, wind, biomass, and small hydropower endeavours. The proliferation of solar energy has exhibited noteworthy growth within the Indian milieu. The nation boasts a substantial solar photovoltaic (PV) installation capacity that is of considerable magnitude on a global scale. The primary aim of the "Jawaharlal Nehru National Solar Mission" is to effectively accomplish the ambitious target of installing 100 gigawatts of solar power by the year 2022 (Suman & Ahamad, 2018). This mission places significant emphasis on the development of expansive solar projects and the widespread implementation of solar panels on rooftops. India stands as one of the foremost nations in the global arena when it comes to its impressive wind power capacity. Wind farms are strategically dispersed across numerous states, exhibiting a discernible concentration in the regions of Tamil Nadu, Maharashtra, Gujarat, Karnataka, and Rajasthan. The governmental body has commendably accomplished its objective of attaining a wind power capacity of 60 gigawatts by the year 2022.

Hydropower has traditionally functioned as a conventional form of sustainable energy within the Indian context. Both expansive hydropower endeavours and diminutive hydroelectric installations make substantial contributions to the nation's renewable energy repertoire. There exists a contemporary undertaking to promote the progress of diminutive hydropower initiatives and run-of-the-river installations as a strategy for ameliorating ecological repercussions. In the Indian subcontinent, there is a burgeoning trend towards the establishment and operation of biomass power plants and biogas initiatives. These innovative endeavours harness a diverse array of resources, including residual agricultural matter, forestry detritus, and organic refuse, to effectively generate electrical energy and support culinary endeavours. The government has implemented numerous initiatives to facilitate support for the progression of biomass-derived power generation and the expansion of bioenergy technology.

Wind energy scenario in India

The utilisation of wind power is progressively being perceived as a financially viable remedy to ameliorate the prevailing deficit within the nation. The utilisation of wind power possesses the inherent capacity to render a substantial contribution towards the preservation and fortification of national energy security, primarily owing to its enduring and sustainable cost-efficiency, as well as its minimal ecological footprint. Driven by the meticulous formulation of strategic blueprints, the adept implementation of the programme, and the provision of enticing remuneration packages, private entrepreneurs have enthusiastically immersed themselves in the realm of wind power industry. During the culminating stage of the Sixth Plan in the fiscal year 1983-84, the National Energy Planning Commission (NEPC) assumed a pioneering role in spearheading an endeavour by implementing 55 kW and 110 kW Wind Energy Generators (WEGs) within the geographical boundaries of the state of Gujarat (Awasthi, 2018). This endeavour initiated the process of commodifying wind energy in the Indian context. Owing to the convenient availability of Wind Energy Generators (WEGs) and the enticing incentive packages, investors have displayed noteworthy interest in the wind power sector for both self-utilization and supplying energy to State energy Boards (SEBs) (Kapila, 2015). The notable upswing in investor

activity can be ascribed to the support extended by State Governments and their corresponding electricity boards. The Ministry of New and Renewable Energy (MNRE) has devised an all-encompassing array of incentives to foster greater participation from the private sector. These incentives encompassed not only fiscal advantages but also financial aid with more advantageous conditions. The Ministry of New and Renewable Energy (MNRE) has demonstrated a praiseworthy focus on the pursuit of research and development. The establishment of the Indian Renewable Energy Development Agency (IREDA) by the Ministry of New and Renewable Energy (MNRE) has played a pivotal role in fostering the expansion and progression of wind energy within the country. IREDA assists in project finance, equipment financing, market development, and support to private entrepreneurs in the successful implementation of wind power projects (Ghosh et al., 2015). It has devised loan packages featuring favourable interest rates to expedite the execution of said projects.

State governments have formulated diverse policies to bolster the advancement of wind energy within their respective jurisdictions, as they stand to directly reap the advantages stemming from its successful integration. The governance and regulation of these policies are entrusted to the State Electricity Boards (SEBs). The System Expansion Boards (SEBs) assume the crucial role of furnishing the requisite infrastructure and grid amenities to proficiently convey and disseminate the electrical power generated by wind turbines (Pachauri & Mehrotra, 2020). Furthermore, wind power providers offer wheeling and banking services to proprietors of windmills, thereby facilitating the utilisation of generated wind power for internal consumption.

Table 1 State-wise wind energy potential

States / UTs	Estimated Potential	States / UTs	Estimated Potential
Andaman & Nicobar	365	Lakshadweep	16
Andhra Pradesh	14497	Madhya Pradesh	2931
Arunachal Pradesh	236	Maharashtra	5961
Assam	112	Manipur	56
Bihar	144	Meghalaya	82
Chhattisgarh	314	Nagaland	16
Dieu Damn	4	Orissa	1384
Gujarat	35071	Pondicherry	120
Haryana	93	Rajasthan	5050
Himachal Pradesh	64	Sikkim	98
Jharkhand	91	Tamil Nadu	14152
Jammu & Kashmir	5685	Uttarakhand	534
Karnataka	13593	Uttar Pradesh	1260
Kerala	837	West Bengal	22
Total			102788

Source: Ministry of New & Renewable Energy, Government of India

The utilisation of wind energy has emerged as a prominent constituent within India's renewable energy sector, owing to its considerable potential, advantageous environmental attributes, and its noteworthy contribution to the nation's energy security. India's unwavering commitment to the utilisation of wind power has yielded commendable advancements in this domain, propelled by propitious regulatory frameworks, groundbreaking technological breakthroughs, and an escalating demand for ecologically sound sources of energy. The utilisation of wind power assumes a pivotal role in India's pursuit of attaining sustainable energy generation and effectively tackling the multifaceted challenges presented by climate change. The nation's reliance on fossil fuels for power generation has precipitated a decline in environmental quality and has raised apprehensions regarding the stability of energy supply. India has made remarkable strides in the domain of wind energy, solidifying its position as a prominent global vanguard in the generation of wind power. The notable focal points of interest encompass: As of September 2021, India has achieved a remarkable milestone in the realm of renewable energy, with its total installed wind generating capacity surpassing an impressive 39 GW (Singh et al., 2022). The proliferation of onshore wind farms in states endowed with ample wind resources, such as Tamil Nadu, Maharashtra, Gujarat, Karnataka, and Rajasthan, can plausibly be ascribed to this particular phenomenon. The primary aim of this study is to comprehensively analyse the progression of the wind energy landscape in India.

The Indian government has implemented regulatory measures and established incentives that foster an environment conducive to the advancement of wind energy. The realisation of investment facilitation and the advancement of market stability have been effectively accomplished through the utilisation of various mechanisms, such as the implementation of feed-in tariffs, the adoption of competitive bidding via auctions, and the establishment of renewable purchase obligations (RPOs) for energy distribution enterprises (Bose & Sarkar, 2019).

Table 2: State-wise wind energy installation

States / UTs	Installed Capacity	Percentage of Total Installation
Andhra Pradesh	753	3.5%
Gujarat	3414	16.1%
Karnataka	2409	11.3%
Kerala	55	0.3%
Madhya Pradesh	439	2.1%
Maharashtra	4098	19.3%
Rajasthan	2820	13.3%
Tamil Nadu	7276	34.2%
West Bengal	1.1	0.1%
Others	3.2	0.02%
Total	21268.3	100%

Source: Ministry of New & Renewable Energy, Government of India

The ascendancy of wind energy in India has been profoundly shaped by the pivotal role assumed by technological progress. The utilisation of turbines boasting enhanced capacity, refined turbine

design, and cutting-edge manufacturing techniques has yielded heightened energy generation efficiency and diminished expenditures. India has unequivocally expressed its dedication to the Paris Agreement, vowing to reduce the intensity of its carbon emissions and augment the share of renewable energy within its comprehensive energy portfolio. The nation has established an ambitious objective of achieving a comprehensive renewable energy capacity of 450 gigawatts by the year 2030 (Chirambo, 2018).

Discussion

Development of Wind energy

The exponential surge in energy consumption within India after the year 1991 can be attributed to the accelerated pace of economic advancement. The aforementioned assertion posits that the aforementioned demand shall persistently expand in tandem with the rapid advancement of the economy, concomitant with the augmentation of the populace. As per the esteemed International Energy Agency (IEA), it has been determined that India shall require a substantial power generation capacity of 327 GW by the year 2020 (Aditi & Bharti, 2021). This necessitates the creation of an incremental capacity of 13 GW on an annual basis. The imperative for energy has been duly acknowledged in the context of the national grid, wherein it was proposed that a modest 5% allocation be established in the fiscal year of 2009/10. It was further stipulated that this allocation be incrementally augmented by 1% annually, with the ultimate objective of attaining a commendable 15% allocation by the fiscal year of 2019/20 (Singh et al., 2023).

According to estimations provided by the Ministry of New and Renewable Energy (MNRE), it is postulated that a substantial capacity of 90 gigawatts can be potentially harnessed through the utilisation of diverse renewable energy sources (P et al., 2021). The aforementioned figures encompass a total of 48.6 gigawatts of wind power at a hub height of 50 metres, 14.3 gigawatts derived from small hydro power, and 26.4 gigawatts harnessed from biomass sources. Nevertheless, it is worth noting that the Indian government has yet to provide official assessments regarding the potential of solar energy within the nation. However, numerous private entities assert that India possesses a substantial capacity for harnessing solar energy. Table 2a illustrates the data at hand. The objective is to attain a total capacity of 100 gigawatts, encompassing the incorporation of 28 gigawatts from the previous 11th five-year programme. Following the 12th five-year plan (2012-17), there are intentions to augment the existing renewable capacity by a substantial 30 gigawatts. This ambitious endeavour is projected to necessitate a considerable investment of USD 53.1 billion. This comprises a total capacity of 15 gigawatts of wind energy, 10 gigawatts of solar energy, 2.7 gigawatts of biomass energy, and 2.1 gigawatts of small hydro energy. The Indian government's establishment of the National Action Plan for Climate Change (NAPCC) has put forth a recommendation stipulating the necessity of a minimum allocation for renewable energy within the energy sector (Chandel et al., 2016). The states of Gujarat, Karnataka, Andhra Pradesh, Maharashtra, and Tamil Nadu exhibit a substantial capacity for harnessing wind energy. These states possess regions characterised by favourable and unwavering wind patterns, rendering them amenable to the commercial exploitation of wind power. Therefore, India's wind energy capacity, amounting to 21,264 MW, is primarily concentrated in the states of Tamil Nadu (7276 MW), Maharashtra (4098 MW), Gujarat (3414 MW), Rajasthan (2820 MW), and Karnataka (2409 MW), as illustrated in Table 2b. Table 3 exhibits the comprehensive data about the yearly augmentation of wind energy capacity across various states, spanning from April 2005 to May 2014. On the other hand, Table 4 presents the

installed capacity of wind energy, categorised by state, commencing from the year 2005 and concluding in May 2013.

Tamil Nadu

Tamil Nadu stands as a vanguard in the realm of wind energy within the Indian subcontinent. Owing to its favourable policies about wind energy, this particular state has consistently garnered preference from the wind energy industry for the installation of projects ever since the inception of the Indian wind energy programme. The inception of the wind farm established by M/s. Pandian Chemicals in Kanyakumari on the auspicious day of March 28, 1990, featuring a formidable 250 KW wind turbine, marked a pioneering milestone as the foremost wind farm to be developed by a private enterprise within the Indian subcontinent. In addition to the establishment of wind farm development, the state has also witnessed the initiation of wind turbine manufacturing through a collaborative effort between NEPC of India and Micon of Denmark. Subsequently, a multitude of esteemed manufacturers, including Vestas, Gamesa, Suzlon, and RRB, have established their production facilities within the region. As a result, Tamil Nadu has emerged as a prominent epicentre for the manufacturing of wind turbines within the nation. Due to the absence of intricate topography in the wind farm sites of Tamil Nadu, the transportation of wind turbine equipment to these locations is facilitated, thereby rendering the process of project development relatively straightforward. The Muppandal wind farm, situated on the esteemed Aralvaimozhi mountain pass, stands as a testament to the state's commitment to renewable energy. Boasting an impressive generation capacity of 1500 MW, this wind farm proudly holds the title of being the largest of its kind in all of Asia. The site boasts an extensive array of wind turbines, encompassing a diverse range of sizes spanning from 200 KW to 1650 KW.

Tamil Nadu stands as the preeminent purveyor of wind energy, boasting an impressive aggregate installed capacity of 7,276 MW. This remarkable figure constitutes a substantial 34% of India's overall wind capacity. Except for the year 2007, it is noteworthy to observe that Tamil Nadu has consistently demonstrated the highest annual capacity addition among all the states starting from the year 2002. In the year 2011, Tamil Nadu accomplished yet another remarkable feat by successfully implementing a wind energy capacity of 1,083 MW within twelve months. This notable achievement stands as the most substantial annual installation of wind energy by any state within the nation of India during a single calendar year. In recent times, it has come to light that the districts of Coimbatore, Tirruppur, and Theni have emerged as the primary sites for the installation of a substantial number of wind turbines. The remarkable expansion of wind energy in Tamil Nadu can be ascribed to the unwavering commitment of the government in evaluating the potential of wind resources and implementing conducive policies to entice private investments.

Maharashtra

The investor-friendly policies implemented by the Government of the state of Maharashtra have garnered significant investment in the wind sector due to its favourable conditions and the commendable technical feasibility of the demonstration projects. The state of Maharashtra boasts the most substantial installed capacity of wind energy in India, second only to Tamil Nadu. With an impressive 4098 MW, Maharashtra accounts for approximately 19% of the nation's total wind capacity. When the Indian government initiated its wind energy programme in the 1980s, the state of Maharashtra also decided to establish an agency dedicated to energy development, aligning with the aforementioned programme. Henceforth, the establishment of the Maharashtra

Energy Development Agency (MEDA) was orchestrated to spearhead the advancement of renewable energy as a prominent state-level entity, operate under the auspices of the Ministry of New and Renewable Energy (MNRE). As a result of the enduring assurance offered by the regulatory framework and various policy initiatives, there has been notable progress in the establishment of installed capacity centred around renewable energy sources, with particular emphasis on wind energy. Maharashtra has garnered considerable acclaim as a preeminent state for wind energy investment, primarily owing to its judiciously crafted policies that foster an environment conducive to attracting and accommodating investors. Satara, Sangli, Dhule, and Panchgani are renowned locales within the state of Maharashtra that boast a substantial array of wind power generation installations.

Gujarat

The region of Gujarat is endowed with an extensive coastline spanning a distance of 1600 kilometers, wherein the prevailing wind velocities exhibit sufficient potential for harnessing and transforming into electrical energy. Similar to the establishment of MEDA, the Government of Gujarat took the initiative to establish the Gujarat Energy Development Agency (GEDA) in 1979, to address the oil crisis that plagued the 1970s. This entity represents a state-level nodal agency that has been established to cultivate the advancement of sustainable energy systems that are well-suited for a nation such as India, which heavily depends on imported petroleum resources to fulfil its energy requirements. As a result of the diligent endeavours undertaken by the government, India witnessed the establishment of its inaugural joint sector wind farm, boasting a commendable capacity of 1.10 MW, in the year 1985. This pioneering development took place in the region of Mandvi, situated in the state of Gujarat. The government of this particular state demonstrates a consistent commitment to fostering investment in wind energy, as evidenced by the implementation of various incentives such as an elevated feed-in tariff, as well as the facilitation of energy wheeling and banking. As a consequence of this phenomenon, prominent energy conglomerates such as China Light and Power (CLP), Tata Power, and ONGC have established wind energy generation facilities within the confines of this particular region. The Oil and Natural Gas Corporation (ONGC) has successfully implemented a wind power project with a capacity of 51 megawatts in the Kutch district of a certain state. This endeavour has been undertaken primarily to cater to the energy requirements of ONGC's own facilities located in Vadodara, Ahmedabad, and Mehsana. The generated energy is skilfully transmitted to these manufacturing plants, ensuring a sustainable and self-sufficient power supply. The government of Gujarat, in response to the exigencies of the present moment, has undertaken a revision of its wind energy policy intending to augment the production of wind-generated power within the nation. In recent times, specifically on the 25th of July in the year 2013, the governing body of the state made a significant announcement regarding a novel policy about the utilisation of wind energy, aptly titled Wind Power Policy - 2013. Following the recently implemented policy, there has been a notable augmentation in the wind energy tariff, coupled with a more streamlined facilitation of the captive utilisation of wind energy. The Gujarat government has bestowed a significant respite upon developers by offering land on a lease basis for the establishment of wind power projects.

Karnataka

Karnataka stands as a prominent state within India, boasting a commendable capacity for harnessing renewable energy sources. Currently, the predominant sources of energy in this state are thermal and hydroelectric power. Notwithstanding, it is worth noting that renewable energy sources currently account for approximately 24% of the overall installed capacity within the

state. The state's renewable energy capacity is projected to reach a substantial 28 gigawatts, primarily harnessed from wind power, small-scale hydroelectricity, co-generation, and biomass sectors. According to C- WET, Wind energy potential of the state at 80 meter hub height is 13.6 GW. The state of Karnataka, in its pursuit of sustainable energy solutions, devised the Karnataka Renewable Energy Policy in 2009, under the astute guidance of the Karnataka Renewable Energy Development Limited (KREDL). This visionary policy aimed to harness the potential of renewable energy sources and set a commendable target of establishing a robust capacity of 4,300 MW by the year 2014. Utilizing this policy, the state government has implemented provisions to facilitate the financing of renewable energy projects, the establishment of specialised economic zones dedicated to renewable energy, and the expeditious granting of clearances from diverse departments, thereby ensuring prompt execution of said projects. Of the aggregate capacity of 2409 MW originating from external regions, a noteworthy 1089 MW of projects have been successfully established after the implementation of the aforementioned policy. Due to the intricate topography of Karnataka, the region boasts a multitude of diminutive wind farms strategically situated upon elevated hillocks. This state currently holds the distinction of possessing the most substantial quantity of wind farms. Chirtadurga, Dharwad, Gadag, and Belgaum are regions of notable prominence within the state, specifically in the realm of wind energy. Chitradurga, boasting an impressive assemblage of over 20,000 wind turbines, stands as a prominent locale renowned for its exceptional Plant Load Factor (PLF), thus securing its position as the Indian region with the most noteworthy PLF. The observed average Plant Load Factor (PLF) in Chitradurga is documented at an impressive 34%, surpassing the performance of comparable installations in other regions of the country. Owing to its advantageous energy policies, Karnataka has emerged as a prominent hub for major Independent Power Producers (IPPs). In the present state, independent power producers (IPPs) have made substantial investments across diverse energy sources. Among the aggregate energy infrastructure installations amounting to 13.94 gigawatts, it is noteworthy that a significant proportion of 32% is attributed to energy projects that have been established through private investments. Indeed, it is worth noting that Acciona Energy, a prominent global frontrunner in the realm of renewable energy, has successfully implemented three wind farms within the aforementioned state, collectively boasting an impressive capacity of 85.8 MW. All three projects have been duly registered with the United Nations under the auspices of the Clean Development Mechanism (CDM) as prescribed by the Kyoto Protocol.

Rajasthan

Rajasthan is increasingly being regarded as the preeminent location for the establishment of wind power initiatives. The aforementioned state has witnessed a remarkable surge in its installed capacity, escalating from a mere 16.1 MW in 2002 to an impressive 2,820 MW by March 2014. The primary rationale behind this growth pertains to the conscientious allocation of resources by governmental entities to foster the advancement of sustainable energy alternatives. The inception of the wind energy development programme in Rajasthan dates back to the year 1999, when the Ministry of New and Renewable Energy (MNRE) initiated a scheme aimed at the installation of 2 MW demonstration projects. Following the resounding triumph of these demonstration projects, the commencement of commercial endeavours in the realm of wind energy ensued. The inception of the 25 MW Wind energy project undertaken by the esteemed Rajasthan Renewable Energy Corporation Limited (RRECL) in the year 2004 marked a significant milestone as the pioneering commercial endeavour of the state. Subsequently, a multitude of Independent Power

Producers (IPPs) such as CLP, IL&FS, NALCO, and others have made substantial investments in the state's wind energy initiative. The esteemed organisation known as IL&FS has successfully executed a project of significant magnitude, boasting a capacity of 38.4 megawatts. This remarkable feat was accomplished through the installation of 63 Enercon E-53 wind turbines, each with a commendable power output of 800 kilowatts, situated in the region of Jaisalmer. Based on the comprehensive analysis of meteorological data provided by the esteemed meteorological department, it can be confidently asserted that this particular location holds immense potential for the successful implementation of wind energy projects. CLP India has put forth a proposition to establish a wind energy project of substantial magnitude, amounting to 100.8 MW, at the esteemed location of Tejuva. This ambitious endeavour entails the installation of 48 units of Suzlon S-97 – 2.1 MW wind turbines, which are renowned for their commendable efficiency and performance in harnessing the power of wind. In pursuit of augmenting the proportion of wind energy within the energy amalgamation, the state government, on June 17, 2014, sanctioned an amendment to the Wind Energy Act of 2012. The primary objective of this amendment is to entice substantial investments for a wind energy project with a capacity of 400 MW. Rajasthan has demonstrated unwavering dedication to the advancement and proliferation of various renewable energy technologies. Consequently, it has emerged as a prominent frontrunner in the realm of solar energy, boasting an impressive cumulative solar installation capacity of 500 MW.

Andhra Pradesh

Based on the comprehensive research undertaken by the esteemed institution known as C-WET, it has been determined that the state of Andhra Pradesh possesses the second most substantial capacity for harnessing wind energy. Specifically, it has been ascertained that this region has the potential to generate a remarkable 14.5 gigawatts of wind energy, assuming an optimal hub height of 80 metres. Throughout the past biennium, this particular state has borne witness to a substantial upsurge in the installation of wind energy infrastructure. In the year 2012, Andhra Pradesh experienced a notable surge in its installation efforts, as it successfully implemented over 200 MW of wind energy projects. This marked a significant departure from the previous trend, wherein the annual installation capacity had never surpassed the threshold of 60 MW. Furthermore, it is worth noting that in the year 2013, a significant milestone was achieved in the realm of renewable energy with the establishment of a substantial 305.35 MW wind energy capacity, as documented in reference [23]. The proliferation of wind energy in the region has been attributed to the keen engagement exhibited by independent power producers (IPPs), notably Mytrah Energy and Greenko Group. Mytrah Energy Limited serves as a subsidiary with a primary focus on India within the esteemed Mytrah Group originating from the United Kingdom. The aforementioned wind power generation company is headquartered in Hyderabad, a prominent city, and is duly enlisted on the Alternative Investment Market (AIM) of the esteemed London Stock Exchange. This establishment has established

A notable wind energy endeavour with a total capacity of 100.4 megawatts is being undertaken in two distinct geographical regions, specifically Burgula and Vajrakarur. In January in the year 2014, Mytrah Energy, a notable entity in the realm of renewable energy, entered into a Memorandum of Understanding (MoU) with the esteemed government of Andhra Pradesh. The purpose of this agreement was to establish a wind energy project of substantial magnitude, boasting a capacity of 2850 megawatts. In July in the year 2014, this esteemed organisation has ascended to the position of being the foremost independent power producer in the realm of wind energy in the nation of India. This notable achievement was accomplished through the

possession and operation of an impressive portfolio of wind assets, totalling a substantial capacity of 524.85 megawatts. Greenko group, a prominent entity in the realm of Independent Power Producers (IPPs), has successfully established a substantial wind farm with a capacity of 100.2 MW at the esteemed Rayala site, situated in the Anantapur district of Andhra Pradesh [33]. The implementation of this project has been executed in two distinct phases, with the initial phase reaching its culmination in November of the year 2013, followed by the subsequent phase which concluded in February of the year 2014. Andhra Pradesh is poised to emerge as a prominent state in India's wind energy sector, bolstered by the support of these prominent Independent Power Producers (IPPs). In the present year of 2014, Andhra Pradesh is diligently endeavouring to implement a wind energy initiative of substantial magnitude, aiming to install a formidable 500 MW capacity. Notably, the state has already entered into legally binding power purchase agreements (PPAs) with esteemed investors, thereby solidifying its commitment to this sustainable energy endeavour.

Madhya Pradesh

The government of Madhya Pradesh has exhibited commendable leadership in championing diverse renewable energy sources, notably wind energy, through its astute policy initiatives and attractive incentives tailored towards attracting and encouraging investments in the realm of renewable energy. Despite its relatively modest wind energy potential, Madhya Pradesh does not rank among the frontrunning states in this domain. The state's capacity to generate a mere 2931 MW of wind energy is indicative of its current standing in the field. However, it is evident that the state government consistently demonstrates a strong inclination towards augmenting the allocation of wind energy as a means to foster sustainable development. During October in the year 1994, a state entity took the initiative to establish a collaborative enterprise known as M.P Windfarms Ltd. This endeavour was brought into existence through a Memorandum of Understanding (MoU) between Madhya Pradesh Urja Vikas Nigam, IREDA, and Consolidated Energy Consultants Limited (CECL). The primary objective of this joint sector company was to undertake the development of wind energy projects within the geographical boundaries of the aforementioned state. During the period spanning from 1995 to 1999, the aforementioned corporation successfully executed a wind power initiative, amounting to a total capacity of 13 megawatts, in the region of Dewas. This endeavour served as a pivotal foundation for subsequent ventures in the realm of commercial wind energy projects. After that, a total of 439 megawatts of wind energy projects have been successfully implemented within the state, strategically situated across various locations such as Dewas, Ratlam, and others. Dewas, in isolation, boasts a commendable installed capacity of 139 MW [34]. In July in the year 2014, General Electric (GE) made public its intentions to establish two distinct wind energy initiatives, each boasting a capacity of 50 megawatts, within the confines of Betul district. Both of these projects are anticipated to commence commercial operation by December in the year 2014. The government of Madhya Pradesh has implemented significant amendments to its wind energy policy to pursue the ambitious goal of establishing an installed capacity of 1800 MW in the foreseeable future, with support from the private sector. To date, a total of 46 projects, with an estimated capacity of 1500 MW, have been duly allocated to the private sector.

Kerala

The Kerala government established The Agency for Non-Conventional Energy and Rural Technology (ANERT) in the year 1986, to serve as an autonomous entity responsible for conducting comprehensive surveys aimed at procuring projects about renewable energy sources. ANERT, in collaboration with the Ministry of New and Renewable Energy (MNRE), has

undertaken comprehensive research endeavours to assess the wind energy potential of a given region. The aforementioned analysis pertained to the current condition of the state's power supply, with a calculated estimation of approximately 605 megawatts. The aforementioned agency is currently engaged in the implementation of a 2 megawatt demonstration project at the esteemed Rammakalmedu site, situated within the Idukki district. The Rammakalmedu site has been duly recognised as the most promising location within the state for the establishment of wind power infrastructure, boasting an estimated capacity of 80 megawatts. In the region of Kerala, a total of 16 prospective locations have been discerned to investigate the potential of harnessing wind energy. The aforementioned sites encompass a total of ten distinct locations within the Idukki district, five within the Palakkad district, and a solitary location within the Thiruvananthapuram district. This particular state has exhibited a notable sluggishness in the implementation of its wind energy initiative, as evidenced by its current installed capacity of a mere 55 MW. From the year 2002 onwards, a notable observation emerges wherein seven years transpired without witnessing the implementation of any wind energy initiatives within the confines of the state. In the year 2013, Kerala's installation of a mere 19.8 megawatts is worth noting. However, the government of Kerala is diligently endeavouring to overcome this prevailing misfortune, employing the assistance of prominent energy corporations within the nation. In a recent development, the state of Kerala has entered into a formal agreement with the esteemed National Hydroelectric Power Corporation (NHPC) to establish a wind power project within the confines of the Palakkad district. During the initial stage, the proposed strategy entails the establishment of a wind farm with a capacity of 82 MW in the regions of Kottathara and Nallasingam within the Palakkad district. The projected expenditure for this undertaking is approximately USD 80.3 million. The National Thermal Power Corporation (NTPC), a prominent energy enterprise in India, has entered into a Memorandum of Understanding (MoU) with the state government to establish a 200 MW wind power project within the region. This endeavour shall be implemented within the geographical confines of the Idukki and Palakkad districts, both of which are situated within the larger administrative entity known as the state with the numerical designation of 36.

West Bengal

The establishment of the West Bengal Renewable Energy Development Agency (WNREDA) in 1993 marked the inception of a state nodal agency dedicated to the effective execution of non-conventional energy initiatives within the region. The aforementioned agency has been bestowed with the responsibility of fostering the advancement of renewable energy initiatives within the region, whilst simultaneously cultivating a favourable milieu for the successful commercialisation of said projects. This esteemed agency has successfully executed a multitude of initiatives encompassing diverse renewable energy technologies such as Wind Turbines, Wind Diesel Hybrid, Small Hydro, Solar Thermal, Solar Photovoltaic, Biogas Plants, Biomass Gasifier, Tidal Power, and more. However, it is worth noting that the installed capacity of wind energy in the state is a mere 1.1 MW. To enhance the proportion of wind energy in the overall energy composition, the West Bengal Green Energy Development Corporation (WBGEDC) put forth a proposition in 2009. The proposal entailed the establishment of a substantial facility spanning 1,400 acres in the serene backwaters of the Bay of Bengal, specifically at Dadanpatra, situated approximately 150 km away from Kolkata in the Purba Medinipur district. This facility aimed to generate an impressive 40-50 MW of wind power. Suzlon expeditiously demonstrated a keen inclination towards this project, albeit its execution was impeded by complications about land execution. Currently, the state of Frazerganj is host to a quartet of wind energy units, each

boasting a commendable power output of 250 kilowatts. A composite, in the context of materials science, refers to a substance that is composed of two or more distinct components, each with

Conclusion

India has made remarkable strides in the field of renewable energy, with a specific focus on wind energy. Its commitment to sustainable energy sources, coupled with strategic policies and incentives, has led to a significant increase in renewable energy capacity, including wind power. The nation's progress in wind energy, as evidenced by its substantial installed capacity, highlights its dedication to addressing environmental concerns and energy security. Through technological advancements, regulatory measures, and a commitment to international agreements, India is solidifying its position as a global leader in the renewable energy transition, promising a more sustainable and environmentally responsible future.

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