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*EXPANSION OF WIND ENERGY IN RIO GRANDE DO NORTE: AN
INTERPRETATION FOR DEVELOPMENT¹*

**EXPANSÃO DA ENERGIA EÓLICA NO RIO GRANDE DO NORTE: UM
INTERPRETAÇÃO PARA O DESENVOLVIMENTO**

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ABSTRACT

This article aims to analyze the expansion of wind energy production in the Brazilian Northeast, especially in Rio Grande Norte, the largest producer of energy by wind power source in Brazil. The state has the natural conditions favorable and intrinsic to the sector. The central question of the work is to verify the correlation of this new economic activity and its expansion in the energy production as one of the vectors of the economic development of the state. The methodology consisted of a secondary and field analysis. First, a bibliographic review was carried out, which investigates the expansion of the wind sector in the Northeast, with an emphasis on Rio Grande do Norte. Secondly, a field research was carried out, collecting primary data from the economic agents involved in the wind activity in order to characterize and understand the development and challenges of the wind sector in the state. The results indicate that wind energy is a development vector for RN, but it presents important constraints on infrastructure and public policies, which need to be addressed, which may constitute opportunities for actions, partnerships and promotion policies to internalize the Activity in local development.

Key words: development, wind energy in Brazil, Northeast, Rio Grande do Norte.

RESUMO

O presente artigo objetiva analisar a expansão da produção de energia eólica no Nordeste brasileiro, sobretudo, no Rio Grande Norte, maior produtor de energia por fonte eólica no Brasil. O estado possui as condições naturais favoráveis e intrínsecas ao setor. A questão central do trabalho é verificar a correlação desta nova atividade econômica e sua expansão na produção de energia como sendo um dos vetores do desenvolvimento econômico do estado. A metodologia consistiu em uma análise secundária e de campo. Primeiramente foi feita uma

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revisão bibliográfica, que investiga a expansão do setor eólico no Nordeste, dando ênfase ao Rio Grande do Norte. Num segundo momento realizou-se uma pesquisa de campo coletando dados primários junto aos agentes econômicos envolvidos com a atividade eólica a fim de caracterizar e compreender o desenvolvimento e desafios do setor eólico no estado. Os resultados apontam que a energia eólica é um vetor de desenvolvimento para o RN, porém, apresenta importantes restrições em infraestrutura e políticas públicas, que precisam ser enfrentadas, o que pode se constituir em oportunidades de ações, parcerias e políticas de fomento para internalizar a atividade eólica no desenvolvimento local.

Palavras-chave: desenvolvimento, energia eólica no Brasil, Nordeste. Rio Grande do Norte.

INTRODUCTION

Energy and other natural resources have always been fundamental to the maintenance of human life, especially in modern society. From an economic perspective, energy is even more important, as it is essential for socioeconomic growth and development. Thus, as humanity evolved into a modern society, people became increasingly dependent on energy supply to sustain the capitalist productive system and domestic and social well-being (OLIVEIRA NETO, 2016; GOLDEMBERG, 2010).

In this sense, growth in energy consumption became exponential after the Industrial Revolution, in which the main sources of energy supply were primarily coal, oil, and gas, all of which have high extraction and transportation costs to consumer centers (GOLDEMBERG, 2010).

Therefore, this growing demand for energy required greater diversification of primary sources to guarantee energy supply. Consequently, other sources needed to be developed, and wind energy stands out as one of the most promising sources of electricity generation, being renewable, environmentally friendly, and increasingly economically competitive. Furthermore, this source can become an alternative for regional development in



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Brazil, as the country has favorable natural conditions, especially in the Brazilian Northeast, where winds are abundant (OLIVEIRA NETO, 2016).

When observing Brazil's wind map, the Northeast Region has the greatest technical feasibility for wind resources in the country, as more than half of the potential is located in this region, with Rio Grande do Norte (RN) standing out among the northeastern states.

Therefore, RN has experienced significant expansion in the installation of wind farms within its territory, particularly following the adoption of public policies to encourage production in 2009, especially through the establishment of energy auctions. However, as a hypothesis, it is believed that the impact of this activity on regional development can be enhanced through the internalization, as much as possible, of the wind energy production chain within the region and, consequently, within RN. This presupposes incentive policies aimed at overcoming productive, logistical, science, technology and innovation (ST&I), and professional qualification bottlenecks. Nevertheless, such policies are still insufficient in the region, especially in RN.

The central question is to identify the main challenges and opportunities for the wind sector to consolidate itself as a driver of development for the Northeast and Rio Grande do Norte.

In addition to this introductory section, the article is composed of four sections. The second section addresses the potential and production of wind energy in Brazil and the Northeast. The third analyzes the location of the production chain and technological mastery of wind energy in Brazil. The fourth deals with the methodology. The fifth section presents the evolution and recent performance of the wind energy sector in Rio Grande do Norte. Finally, the concluding remarks are presented.



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WIND ENERGY POTENTIAL AND PRODUCTION IN BRAZIL AND THE NORTHEAST

The Northeast Region has the greatest technical feasibility for wind resources in Brazil. Of the 143 GW of electricity generation potential that Brazil possesses, equivalent to 10 hydroelectric plants the size of Itaipu, more than half of this potential is located in the Northeast. There are 75 GW of energy supply potential using wind turbines (wind towers) at a height of 50 meters, with the coastal areas of Rio Grande do Norte and Ceará presenting the most favorable natural conditions. However, this potential can more than double with the use of 100-meter-high wind towers (CRESESB, 2001). Moreover, as innovation and technology have advanced considerably in this industry, as a result of Research and Development (R&D) in the sector, productivity in energy generation can be even greater.

All this natural potential refers only to onshore production because, if offshore production potential is taken into account, Brazil has more than 170 GW of potential to be explored, which is equivalent to practically the entire Brazilian electricity matrix. According to the report by the Global Wind Energy Council (GWEC), the country has already received project proposals for wind energy production in Brazilian waters (GLOBAL WIND ENERGY COUNCIL – GWEC, 2023).

Thus, the existing potential in Brazil can consolidate the Brazilian electricity matrix as one of the most renewable, environmentally sustainable, and competitive in the world in terms of production cost per Mega Watt (MW), given the productive scale. Therefore, the complementarity between hydropower and wind power places Brazil in a privileged position compared to the rest of the world, not to mention its solar energy production potential. In any case, the country will be characterized by the use of renewable sources with low carbon emissions and low environmental impact in electricity generation.



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Therefore, the exploitation of the Northeastern territory for wind energy production can stimulate the development of an industrial hub with innovation, technological development, and research through a production chain that manufactures machinery, equipment, and services for the sector. In this context, the symbiosis between the State and the private sector can enable the region to develop a sophisticated productive structure based on complex chains or networks interconnected with other industries and advanced services. The practical consequence of this type of industrial policy focused on competitive advantages, such as the almost infinitely elastic supply of wind, is the generation of knowledge, quality jobs, income, and wealth for the Northeast.

All these peculiar and intrinsic attributes of the Northeast led the region to receive the first wind energy projects in Brazil as a pioneer in electricity production. Consequently, the region is transforming itself into a strategic hub for major initiatives involving wind farm installation projects, attracting substantial investments from both national and foreign companies, not only for energy production but also for the development of the industrial sector.

Thus, when observing the installed capacity curve of wind power in Brazil, a virtuous growth of this source over the years can be verified. In 2005, wind power generation capacity was only 27 MW. By the end of 2022, Brazil had reached 25.6 GW of installed wind capacity, accounting for 13.4% of national electricity production, second only to hydropower with 54.1% and thermoelectric generation with 24.1%. The sector is responsible for supplying electricity to approximately 17 million homes and reducing CO₂ emissions by around 16 million tons per year (ABEEÓLICA, 2020; GWEC, 2023).

When analyzing the data by region, the Northeast concentrates 90.3% of the wind farms installed in the country, generating 70.48 TWh of energy out of the national total of 78.08 TWh, which is expected given the direct correlation between the region's enormous potential and the attraction of investments aimed



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at harnessing wind speed. Since the beginning of wind farm implementation in the region, there has always been, and continues to be, a concentration of wind farms in Rio Grande do Norte (RN), Bahia (BA), and Ceará (CE). However, as new areas are incorporated into wind farm expansion, other states are also being included in energy auctions due to their potential to host wind projects, such as Piauí (PI), Maranhão (MA), and Pernambuco (PE).

The 109 new wind farms installed in Brazil in 2022 represented an 18.8% increase in installed capacity, rising from 21.5 GW in 2021 to 25.6 GW in 2022. This investment was entirely directed to the Northeast, with Bahia benefiting the most, receiving 52 wind farms, followed by Rio Grande do Norte with 26, then Piauí with 24, followed by Pernambuco with 4 and Paraíba with 2 wind farms.

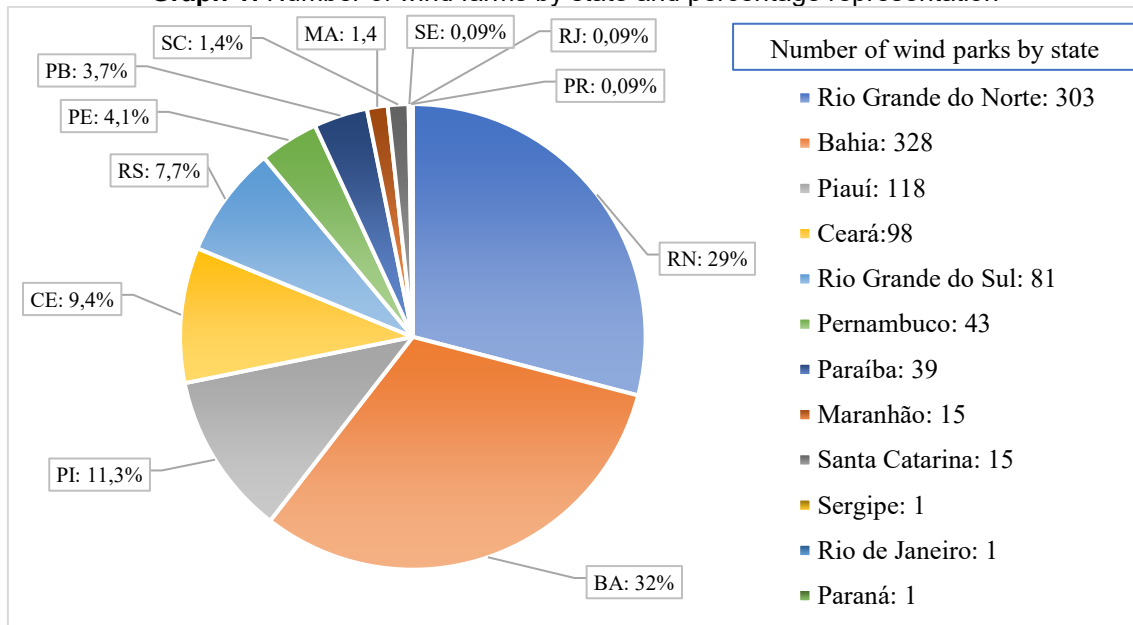
In terms of the number of wind farms and energy generation, Rio Grande do Norte also stands out. The state has the second-largest number of wind farms in Brazil, with 303 wind farms and 3,413 wind turbines. However, in terms of energy generation, the state ranks first, with a production capacity of 10 GW.

RN has always stood out in the wind energy sector, both in installed capacity and in the addition of new capacity. Graph 1 below shows the number of wind farms distributed among the Brazilian states, in which the Northeast leads the country in the number of wind energy projects and, consequently, in energy production, with Rio Grande do Norte and Bahia standing out. Together, these two states account for more than 60% of the 1,043 wind farms already installed. The first state, despite having fewer wind farms, has a greater installed capacity of 9,963 MW. Bahia, on the other hand, has more wind farms but slightly less energy generation capacity, totaling 9,715 MW (ABEEÓLICA, 2023).



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Graph 1: Number of wind farms by state and percentage representation



Source: Elaborated by the author from data of Abeeólica, 2023

However, despite all this prominence in terms of energy production, Rio Grande do Norte (RN) does not exhibit the same dynamism regarding the production chain. For comparison purposes, the states of Pernambuco (PE), Ceará (CE), and Bahia (BA) stand out not only in energy production but also in the industrialization of the production chain, contributing to the development of other areas related to wind energy, such as research and development, innovation, human capital qualification, infrastructure, among others. Likewise, these states increase competitiveness through cost reductions resulting from the growth in national demand for machinery and equipment, that is, through the expansion of their production capacities. In addition, by advancing the complexity of the production chain, they achieve economies of scale, which means greater efficiency in the production of wind turbines, blades, and towers (OLIVEIRA NETO, 2016).

In this context, the Brazilian Development Bank (BNDES), with the objective of developing the wind energy production chain in regions where wind



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resources are abundant, has implemented an industrial promotion policy known as the Local Content Policy (LCP). This policy requires companies to source part of their purchases of machinery, equipment, inputs, and services involved in the complexity of the wind industry from the local market, since market forces alone would not be sufficient to guarantee the participation of local producers in the development of the wind energy sector.

However, Macedo (2015) shows that the production chain for wind equipment, composed of wind turbines, blades, and towers, is almost entirely installed in the states of Bahia, Pernambuco, and Ceará, unlike Rio Grande do Norte, which has only two tower manufacturing plants installed within its territory. According to the author, in terms of productive capacity, factories are located in neighboring states because PE, CE, and BA offer better infrastructure conditions to attract productive investments. For example, these states provide favorable port infrastructure, economies of scale and scope, tax and financial incentives, as well as well-defined production and innovation strategies. As a result, these states are ahead of RN in wind energy industrial development (MACEDO, 2015).

According to data from the Federation of Industries of Rio Grande do Norte (FIERN), the state imported US\$ 435.374 million in international purchases in 2022. Of this total, considering intermediate goods (raw materials and inputs) and capital goods, the renewable energy sector accounted for 55% of foreign acquisitions. These imports included products destined for renewable energy generation, such as photovoltaic cells; parts for engines, generators, and generating sets; wind-powered generating units; solar cells in modules or panels; electrical converters; and geodesy and topography instruments and equipment (FIERN, 2022). Therefore, although RN presents excellent indicators in renewable energy production, particularly wind energy, the state still has a limited capacity to induce employment generation and economic activity within the sector and in its linkages with other sectors of the economy. This is largely due to its

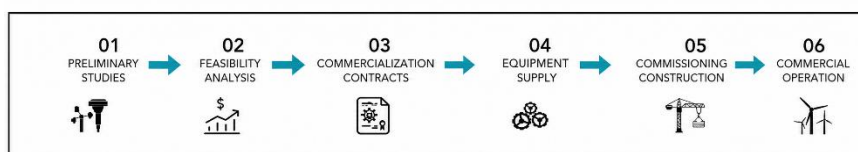


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dependence on imported machinery, equipment, and inputs, among other factors. Figure 1 below illustrates how the links in the wind energy production chain are interconnected and highlights the opportunities that RN loses by not internalizing part or all of the wind energy value chain.

Figure 1: Value chain of wind energy



Source: Sebrae, 2017.

Thus, the figure shows that the state of Rio Grande do Norte (RN) has, to some extent, been losing its capacity to generate employment, knowledge derived from the exploitation of local characteristics, as well as innovation and endogenous development.

LOCATION OF THE PRODUCTION CHAIN AND TECHNOLOGICAL MASTERY OF WIND ENERGY IN BRAZIL

According to a 2014 study by the Brazilian Agency for Industrial Development (ABDI, 2014), the location of wind equipment manufacturing plants follows different motivations.

In the case of nacelle and rotor hub assembly (see Chart 1), the companies Gamesa, Alstom, Acciona, and IMPSA have production units in the Northeast and in Rio Grande do Sul, close to the areas with the greatest potential for wind farm installation (ABDI, 2014). In the case of WEG and GE Energy, these companies preferred to use their existing manufacturing facilities in the cities of Jaraguá do Sul and Campinas, respectively. Wobben, which was the first assembler to establish operations in South America, chose the strategy of locating near its supplier network in São Paulo, as did GE.



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Chart 1: Wind Turbine Manufacturers with Factories in Brazil, by Location and Capacity

| Wind Turbine Manufacturers | Location | UF | Annual Capacity (Projected) |
|-----------------------------------|-----------------|-----------|--------------------------------------|
| IMPESA | Suape | PE | 400 wind turbines, expandable to 500 |
| IMPESA | Guaíba | RS | 100 wind turbines, expandable to 200 |
| WEG | Jaraguá do Sul | SC | 100 MW, amounting to 200 MW by 2014 |
| Wobben | Sorocaba | SP | 500 MW |
| GE | Campinas | SP | 500 MW |
| Alstom | Camaçari | BA | 400 MW |
| Gamesa | Camaçari | BA | 400 MW |
| Acciona | Simões Filho | BA | 135 hubs and 100 nacelles" |
| Vestas | Aquiraz | CE | 400 MW |

Source: Elaborated by the author based on data from ABDI, 2014.

Regarding the spatial location of tower manufacturers, there is a better distribution due to the need to be closer to the areas receiving wind farms (see Chart 2). This is even more evident in the case of concrete towers, as observed in Rio Grande do Norte (RN), Ceará (CE), and Bahia (BA). All of these states have factories located near wind energy projects. Steel tower manufacturers, on the other hand, may choose to locate either close to or farther from the projects, since steel plates can be transported.

In general, the choice of the type of tower to be used in a wind farm depends on several factors, such as the project design, turbine height, cost, assembly and maintenance requirements, as well as ease of transportation.



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Chart 2: Tower Manufacturers with Factories in Brazil, by Type, Location, and Capacity

| Tower manufacturers | Type | Location | UF | Annual Capacity (Projected) |
|----------------------------|-------------|-------------------------|-----------|------------------------------------|
| Gestamp | Steel | Cabo de Santo Agostinho | PE | 450 |
| Engelbasa | Steel | Cubatão | SP | 168 |
| Engelbasa | Steel | Guaíba | RS | -300 |
| Torrebras (Windar) | Steel | Camaçari | BA | 220 |
| Intecnia | Steel | Erechim | RS | 100 |
| Tecnomaq | Steel | Aquiraz | CE | -100 |
| Brasilsat | Steel | Curitiba | PR | 50 |
| ICEC-SCS | Steel | Mirassol | SP | 100 |
| Alstom | Steel | Canoas | RS | 120 |
| Alstom | Steel | Jacobina | BA | -150 |
| Ernesto Wobbecke | Concrete | Gravataí | RS | * |
| Wobben | Concrete | Parazinho | RN | 500 |
| CTZ Eolic Tower | Concrete | Fortaleza | CE | 120 |
| Inneo | Concrete | Trairi Casa Nova | CE/BA | 250 |
| Eolicabrás/(sede) | Concrete | São Paulo | SP | 40 a 50 |

Source: Elaborated by the author base on data from ABDI, 2014.

Finally, the spatial location of blade manufacturers is distributed between the state of São Paulo and the Northeast, particularly Ceará and Pernambuco (see Chart 3). This provides a comparative advantage for these two states over the others in the Northeast, as they specialize in the production of wind energy equipment and machinery, resulting in productive efficiency and, consequently, serving as export platforms for the other states in the region. This leads to greater employment opportunities for the workforce in those states with higher industrial capacity.



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Chart 3: Wind Blade Manufacturers with Factories in Brazil, by Location and Capacity

| Wind blade manufacturer | Location | UF | Annual capacity |
|--------------------------------|-----------------|-----------|------------------------|
| Tecsis | Sorocaba | SP | 6000 |
| Wobben | Sorocaba | SP | 1500 (total) |
| Wobben | Pecém | CE | CE/SP |
| Aeris | Pecém | CE | 600 |
| LM Wind Power | Suape | PE | 1000 |

Source: Elaborated based on data from ABDI, 2014.

As can be observed, Brazil already has a well-developed production structure in the wind energy sector, including wind turbine assembly units and the manufacturing of components and subcomponents for blades, towers, nacelles, and hubs.

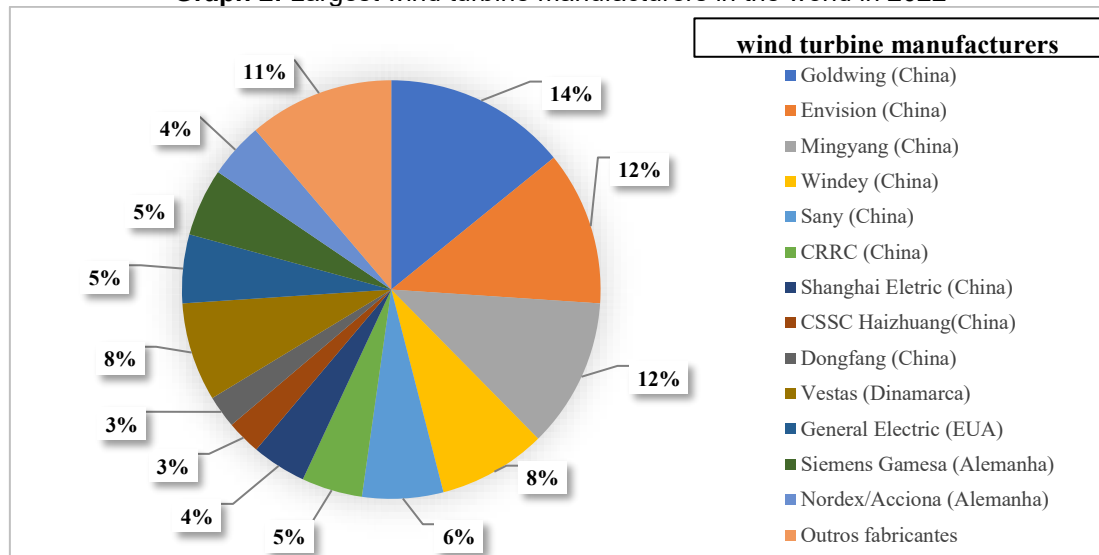
On the other hand, it can be seen that the leading wind turbine manufacturers are European, American, and Asian (China and India), which are at the forefront of the wind industry development process.

As shown in Graph 2, the industrial wind energy market is organized as an oligopoly. The five largest manufacturers in the sector (Vestas, Siemens, General Electric, GoldWind, and Enercon) account for nearly 50% of the global market for wind energy equipment. Thus, these firms possess market power due to the existence of entry barriers related to production scale and the industry's continuous technological innovation requirements. The result is absolute cost advantages and product differentiation advantages for firms already established in the market.



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Graph 2: Largest wind turbine manufacturers in the world in 2022



Source: Enerdata, 2024

Therefore, in terms of technological mastery in wind energy, Brazil does not have a specific R&D policy for the sector aimed at developing its own knowledge according to the characteristics of its territory, strategic needs, and actual production conditions. Under this productive configuration, the country has expanded its wind energy market through technologies developed in countries that lead innovation, generate knowledge, and drive the technological evolution of the sector. To develop an endogenous wind energy development strategy for the Brazilian Northeast, it is necessary to examine what has been done in the countries leading this technology and adapt it to the Brazilian reality, since the wind turbine models installed in Brazil follow standards developed through research conducted abroad.

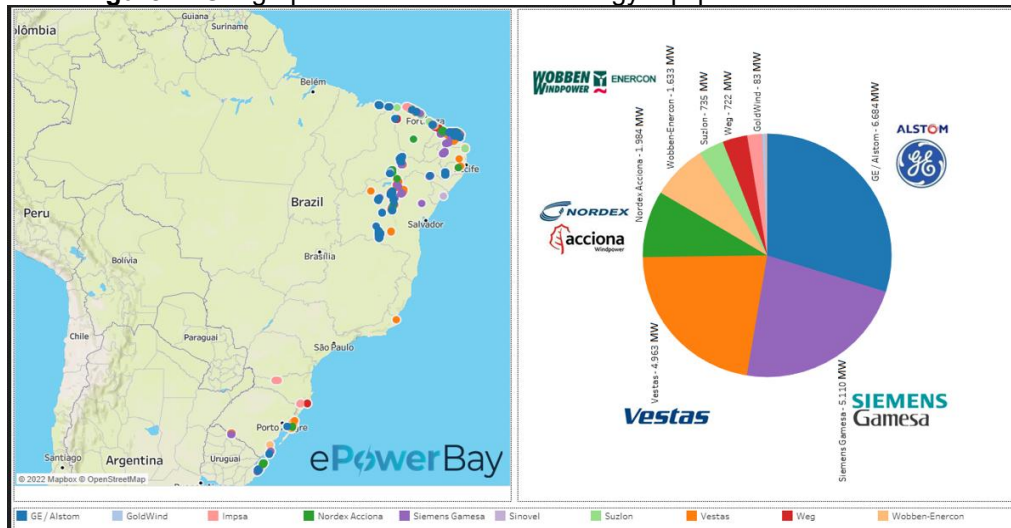
Data from ePowerBay (2022) show that foreign manufacturers such as Vestas, Siemens Gamesa, General Electric Alstom, Nordex Acciona, and Suzlon dominate nearly 90% of the market for supplying equipment for wind farm installations in Brazil. In other words, this is a market characterized by an oligopoly capable of influencing prices. As expected, most wind turbine manufacturing facilities are located in the Northeast Region, as shown in Figure



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2 below, which indicates the locations of wind complexes operating with equipment supplied by each manufacturer.

Figure 2: Geographical location of wind energy equipment manufacturers



Source: Epowerbay, 2023.

However, in the absence of, or with little willingness to develop, a strong and competitive domestic industry, the country becomes dependent on the development of the wind energy industry in Brazil through foreign capital, since it will be these actors that generate positive externalities through technological development, innovation, and knowledge generated across various sectors of their home economies.

METHODOLOGY

The methodology applied in this article includes both secondary and field research. The literature review investigates the expansion of the wind energy sector in the Northeast, as it is the region with the greatest potential in the country, giving particular emphasis to Rio Grande do Norte, since it is one of the states that has experienced significant growth in the number of wind farms installed within its territory. By emphasizing Rio Grande do Norte, the research seeks to



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correlate this new economic activity as one of the drivers of the state's economic development.

In this regard, this research uses the historical method with bibliographic and documentary procedures concerning the formation and expansion of the wind energy sector in Brazil, the Northeast, and RN.

Subsequently, acknowledging the importance of wind energy activity for the Northeast and, specifically, for the state of RN, this study conducted field research, collecting primary data from economic agents involved in wind energy activities, such as companies and/or their representatives, as well as institutional agents (governments, regulatory entities, representative organizations, and support/promotion institutions).

EVOLUTION AND RECENT PERFORMANCE OF THE WIND ENERGY SECTOR IN RIO GRANDE DO NORTE: CHALLENGES AND PROSPECTS

Rio Grande do Norte has a privileged geographical position, as it presents significant wind potential both along the coast and inland. The strongest winds are located in regions along the coastline, especially in the northern and northeastern parts of the state, as well as in elevated areas in the northeast and mountainous regions (COSERN, 2003). According to data on wind speeds found in the Wind Energy Atlas of Rio Grande do Norte, annual averages ranged between 6 m/s and 9 m/s, considering wind towers of 50 m, 75 m, and 100 m. The final results indicated an installable potential of 9.6 GW with 50 m wind turbines; 19.4 GW with 75 m turbines; and 27.1 GW with 100 m turbines, considering regions with wind speeds equal to or greater than 7.0 m/s (COSERN, 2003).

Due to all this potential, Rio Grande do Norte offers the basic natural conditions for the installation of wind turbines within its territory, namely strong



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and abundant winds. This is why the state stands out nationally in energy production from wind sources, as demonstrated in previous sections.

However, in recent years RN has lost some ground to other Northeastern states such as CE, PI, MA, PE, and especially BA. Nevertheless, the advance of wind energy production creates a tendency for wind farms to seek, in other states, greater wind incidence and higher generation productivity, given that geographical areas in RN are becoming less productive.

Even so, the state of RN added 2.2 GW of installed capacity from the 58 wind farms installed in 2023, followed by BA with 1.6 GW from 44 inaugurated wind farms. For the third consecutive year, Brazil achieved new wind energy records, reaching 4.8 GW of new installed capacity, more than 1,000 wind farms in operation, and surpassing 30 GW of total installed capacity. The electricity matrix reached nearly 84% renewable sources, consolidating the country as an international reference in clean energy transitions (GWEC, 2024; ABEEÓLICA, 2023).

Although it is not possible to affirm that the wind energy sector has altered the distribution of formal employment among the sectors of the economy involved in the development of this industry, it is impossible to disregard the presence of jobs related to this activity in the Northeast and RN, given the wind potential that the state possesses, which is reflected in its annual energy production capacity. Nevertheless, limiting factors are also observed, one example being the incipient production chain.

Thus, wind energy is a major opportunity to drive the development of the state, but, on the other hand, the challenges are enormous. First, the wind sector can be viewed as an important driver of development for the state. From this perspective, there are possibilities for adopting public development policies, such as tax incentives, affordable credit, and low interest rates. On the other hand, the abundance of wind resources, that is, an infinitely elastic supply, guarantees



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energy demand, in other words, investment in the sector, and this may determine business strategies regarding the location of the production chain.

Regarding the challenges and bottlenecks for advancing the development of the sector, the state should seek improvements in infrastructure, offer, through public institutions, training courses to develop a qualified workforce, and promote technological development based on geographical and natural characteristics. In this sense, the search for new energy sources drives the country's energy sector, and Rio Grande do Norte, due to its geographical characteristics, can be considered a privileged state.

Furthermore, in addition to onshore wind energy, there is also offshore wind potential available in RN, as well as other renewable energy sources, such as solar energy, which, when "associated," can generate employment and income even in the interior of the state.

Another important factor for advancing the sector lies at the federal level, such as Federal Government tariff regulations, economic instability, and the lack of energy transmission infrastructure, which would positively impact ANEEL auctions.

From the perspective of science, technology, and innovation, some institutions in the state have been making efforts to generate knowledge and research on the wind energy sector. The Federal Institute of Education, Science and Technology of Rio Grande do Norte (IFRN) has been active in teaching, research, and extension activities, in addition to establishing partnerships for doctoral programs and research projects with important public and private entities (OLIVEIRA NETO, 2016).

The Federal University of Rio Grande do Norte (UFRN) has also been making efforts in research and knowledge generation regarding the sector. Several researchers from different departments of the institution are dedicated to studying this topic. Another important point is the implementation of appropriate



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strategies concerning Science, Technology, and Innovation, highlighting the role of the state, the Private Sector, and the University. Professor Marciano Furukava, from the Department of Materials Engineering, draws attention to the government's need to offer advantages to attract investments: tax incentives; infrastructure improvements; logistics; public financing; among others. In the case of the private sector, entrepreneurs must recognize and be prepared to seize the new opportunities presented by the wind energy sector. Universities, in turn, need to promote and support study and research, in addition to training personnel and developing new products.

Furthermore, the role of research and knowledge-generation centers is highlighted, such as that of UFRN, in articulating and integrating with other entities, such as the Federation of Industries of Rio Grande do Norte (FIERN), SENAI, SEBRAE, the Ministry of Science, Technology and Innovation (MCTI), and the Center for Gas Technologies and Renewable Energies (CTGAS), seeking to develop a productive arrangement more favorable to Innovation and Entrepreneurship. For example, the creation by the University of a Technology Park, particularly in the city of Macaíba/RN, at the Jundiá Agricultural School, focused on renewable energies, sustainability, fisheries resources, mineral resources, and information technology.

Thus, when observing investment data in the wind energy sector in Brazil, the prospects are extremely positive for the coming years. In 2022 alone, investment in the sector amounted to approximately US\$ 5.8 billion, contributing to the expansion of planned industrial production capacity by 5 GW per year. In other words, every year the wind industry can add 5 GW in the production of machinery, equipment, and wind turbines for wind farms. The Brazilian Energy Research Company (EPE) estimates investments of around US\$ 59 billion in centralized energy generation and another US\$ 20.2 billion in transmission and substations between 2020 and 2029 (GWEC, 2023).



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Therefore, the sector is in full expansion; however, there are still major challenges for the Northeast and, especially, RN to take advantage of the positive externalities of wind energy as a driver of economic development.

On the other hand, there are structural factors that prevent the full flourishing of wind energy in the country, especially in the Northeast and RN. First, the decline in energy demand, a practical consequence of the COVID-19 economic crisis. However, with the resumption of economic growth, as is already occurring (GDP grew by 3.4% in 2024), demand is expected to increase again. Second, the lack of transmission lines, which has become a serious problem in Brazil, particularly in areas with the greatest wind energy potential. This is an infrastructure bottleneck that must be overcome to strengthen the energy distribution system. Finally, financing is fundamental to maintaining the wind sector in full expansion. The Brazilian Development Bank (BNDES) is the main financier of wind energy in Brazil and recently announced new financing rules for the energy sector, supporting low-impact renewable energies such as wind power.

FINAL CONSIDERATIONS

Wind energy has been expanding both in electricity generation and in the consolidation of its production chain in Brazil. Rio Grande do Norte has enormous wind resource potential (high-quality and consistent winds) and, therefore, has shown significant growth in the production of this energy source, standing out nationally in terms of the number of wind farms.

However, despite this prominence, the production chain remains incipient, as the state has not been presenting or developing sufficient competitive factors to attract manufacturers for the assembly of wind turbines and other components. An aggravating factor is that the State Government, through



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its representative, does not appear to be convinced that public policies could contribute to internalizing the wind energy production chain within the state.

The interviewees highlighted logistical and infrastructural issues as bottlenecks/demands, such as a larger and higher-quality port area; transmission lines (federal investment); poor roads; among others.

It is worth noting that Brazil has two more developed industrial hubs to meet the demand for wind energy equipment: one in the South/Southeast region (concentrated in São Paulo) and the other in the Northeast (concentrated in BA, CE, and PE), both of which offer favorable infrastructure conditions.

It was also observed that the evolution of the production chain follows a concentrated pattern, basically in the South/Southeast region, with the state of São Paulo standing out. In the Northeast, the states of Ceará, Bahia, and Pernambuco stand out because they already possess a structure capable of assembling all components and subcomponents of the wind energy sector. It was also possible to observe that both in Brazil and in the Northeast, the generation of knowledge through Science, Technology, and Innovation (ST&I) initiatives aimed at the wind energy sector remains incipient.

Thus, it is evident that RN faces challenges in overcoming the obstacles that currently prevent it from transforming wind energy into a genuine driver of development for the state, because wind alone does not generate development.

Finally, it should be made clear that this study does not intend to exhaust the discussion on wind energy, especially because the sector is still undergoing rapid development. Therefore, it is still premature to conduct a more precise and conclusive analysis of the impacts of the growth of this energy source on the economy and, above all, on the creation of opportunities for development in the Northeast and Rio Grande do Norte. Thus, the present study seeks to contribute to the debate and reflections on the future of wind energy in Brazil, but especially



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in the Northeastern and Potiguar territories, encouraging further research and studies on the sector.

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