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Article

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Analysis of Competitiveness Factors of Wind Power: A Case study in the *Alto Sertão* Wind Complex in the State of Bahia, Brazil

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ABSTRACT

The increasing demand for electricity in Brazil has significant economic implications for the energy market. In this context, it is important to investigate alternative sources that can meet this demand, as well as understand the key factors that influence this process. The Wind power is considered one of the most promising sources, due to its exponential growth, cost-effectiveness, and continuous supply assurance. However, given the consolidation of fossil fuel sources in economic and technical terms, it is necessary to understand the factors of competitiveness that can be considered as potentials or constraints for the full development of wind energy. Thus, the overall objective of this research was to analyze the competitiveness factors of wind energy, using the Alto Sertão wind complex located in the state of Bahia as a case study. The methodology used in this research was based on an exploratory documentary approach, which sought regulated information from government agencies. The research predominantly used secondary data sources, combined with conducting interviews. The results indicate three factors that confer competitiveness to the sector. Unlike other states in the Northeast, which have a higher occurrence of winds along the coast, Bahia has its greatest wind potential concentrated in the interior, east of the São Francisco River, from the *Espinhaço* Range to municipality of Juazeiro-BA. This is due to low cloudiness and the process of high atmospheric pressure moving towards the Northeast, resulting in excellent quality winds for wind energy generation, which makes the region competitive.

Keywords: Wind Power, Competitiveness, Wind Complex, Brazil, Bahia
JEL Classifications: J48, L10, L11, L21

1. INTRODUCTION

In recent decades, interest in renewable energy has increased significantly due to emerging global issues such as climate change, overexploitation of the environment, and the pursuit of sustainable development. However, electricity generation from renewable energy sources still cannot compete economically with fossil fuel-generated electricity, as it faces uncertainty, variability, and performance issues (Gao et al., 2016; Houser and Wern, 2016; Jülch, 2016; Ntanos et al., 2018; Purkus et al., 2018).

Even in countries like Brazil, where the share of renewable sources in the domestic electricity supply exceeds 70% (EPE, 2022), mainly due to the use of hydropower (56.8%), other alternative sources such as solar (2.5%), wind (10.6%), and biomass (8.2%) face difficulties in consolidating, especially due to the competitiveness in terms of costs presented by electricity production from traditional fossil sources.

Despite these difficulties, renewable energy sources, due to their lower environmental impacts and CO_2 emissions (Dong et al., 2018; Soam et al., 2016; Xu et al., 2014), have gained a prominent place on the socio-environmental agenda, especially since December 2015, with the 21st Conference of the Parties (COP 21) of the United Nations (UN), being promoted as key measures to address climate change (Borges et al., 2016; Martins et al., 2019).

Sociopolitical factors are narrowing the gap between the conception of low-carbon energy policies and the implementation of renewable energy technologies to mitigate the effects of climate change. Among the available renewable sources, wind energy is currently considered one of the most promising, as it is an inexhaustible renewable resource that has demonstrated economic viability where it has been utilized, and the ability to ensure constant supply, especially when compared to other clean energy sources, such as solar and biomass (Das; Krishnan; Mccalley, 2015; Gonzalez-Salazer et al., 2017; Ding et al., 2019).

Thus, to further enable wind energy, driven by political, economic, and social reasons, encouraged by the current sustainable development agenda, greater integration between the wind energy generation process and power transmission lines will be necessary, as well as better energy planning by countries and greater research for offshore park installation. One of the major environmental and economic challenges of wind generation is the need for large areas to maintain its operation.

The Northeast region of Brazil, according to the Brazilian Wind Energy Association (ABEEÓLICA, 2022), accounts for 75% of the national production capacity (the remainder is concentrated in the South of the country) and 88.7% of the energy generated by this source in the country. Of the five largest producing states, four are from the region: Rio Grande do Norte, Ceará, Bahia, and Piauí.

Regarding the specific case study analyzed in this research, the potential for wind energy generation is significant. ABEEÓLICA (2022) data shows a generation of 21.75 TWh in the state of Bahia. Furthermore, logistical considerations were taken into account for the site visits and interviews across various regions of the state, which reflect a similar reality to that of the Northeast as a whole. Priority was given to municipalities with existing renewable energy plants that were selected as research sites according to the methodological procedures of the study, as detailed in the section outlining the scope of the research.

Therefore, the main objective of this research is to analyze the competitiveness factors of the Alto Sertão wind complex using information extracted from field research with key stakeholders involved in the wind energy generation process in the complex, along with data collected from relevant reports. The combination of qualitative and quantitative data allowed for a better understanding of the key competitiveness factors in the region where the complex is located, as well as in the state of Bahia.

In addition to this introduction, this article has four more sections. Section two provides a brief historical overview of the evolution of wind energy in the world, and in Brazil. Section three highlights the methodology used in the research. Section four analyzes the results obtained. Finally, section five presents the conclusions and recommendations for future research.

2. WIND POWER LANDSCAPE

In May 2018, the Global Wind Energy Council (GWEC) released its Annual Global Wind Energy Report, showing a mature industry successfully competing in the global market, even against highly subsidized traditional energy generation technologies in some countries. More than 52 GW of wind energy were added in 2017, bringing the total installations to 539 GW globally. The global wind energy market expanded 19% in 2019, with approximately 60 GW of new capacity added to global power grids (including over 54 GW onshore and over 6 GW offshore). This was the second-largest annual capacity increase, following three consecutive years of decline after the peak in 2015 (63.8 GW). Offshore wind energy is playing an increasingly important role in the global market. The newly installed wind energy capacity in 2019 increased the global total by 10%, to about 651 GW in total (621 GW onshore and nearly 30 GW offshore).

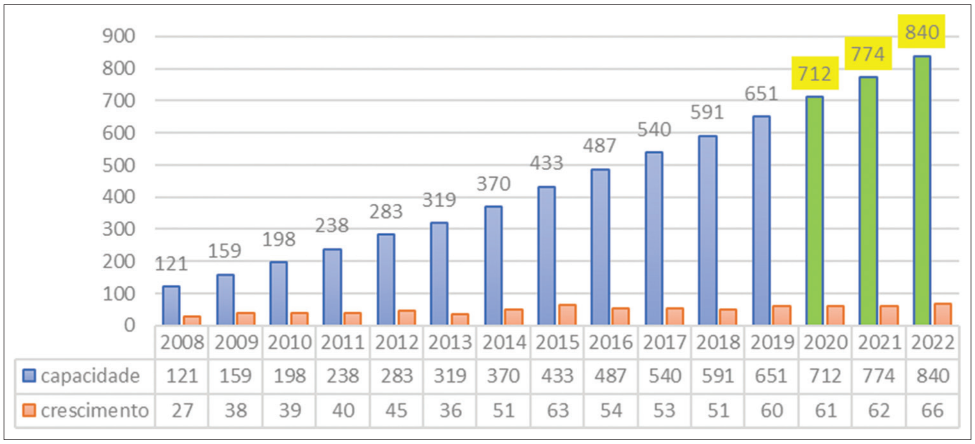
According to GWEC (2019), the rapid growth of wind energy was largely due to investments made by China, the United States, and Europe, despite the ongoing contraction of the market in Germany. Some emerging markets experienced slowdowns due to delays in public tenders and disruptive policies, which hindered greater investment. However, several markets in Africa, Latin America, the Middle East, and Southeast Asia showed notable growth compared to 2018. For 2022, GWEC's Market Forecast estimates that more than 840 GW of wind energy will be installed globally, maintaining a high growth rate, although lower than the period from 2008 to 2019, which was 16.7%. The comparison between capacity and growth is shown in Figure 1.

Based on the predictions of installed wind power capacity, it has been proven that its growth has exceeded the expected levels, having reached 845 GW of installed wind power in 2021 (REN 21, 2022). At the end of 2016, the world saw an increase of 54,600 MW in installed capacity, which represented a 13% growth compared to the total accumulated in 2015. This was a low percentage compared to the growth in 2015 (17%), but significant when compared to the slow pace of global economic growth during the same period (2.3%) (GWEC, 2016).

The future data presented in Figure 1 refer to contracts made viable in auctions already held and in the free market, as well as new auctions that will add more installed capacity in the coming years. The vast majority of the new capacity installed is onshore wind power. According to the GWEC (2019), by the year 2010, offshore installations accounted for around 1% of the total installations, and after 2014, offshore wind power installations represented between 5% and 8% of the total installations (GWEC, 2019).

The wind power economy has become the main motivator for new installations. Outside of China (which has a feed-in tariff, or FIT, for wind power) and the United States (which offers tax credits and state renewable portfolio standards, or RPS), the global demand for wind power in 2019 was largely driven by other

Figure 1: Global capacity, additions and forecast of wind energy in GW in the world



Source: REN21 (2020)

policy mechanisms, including auctions (or tenders), which exerted downward pressure on prices (Bayer et al., 2018; GWEC, 2018).

China installed the largest wind power capacity in 2019, accounting for 23,760 MW of the total installed capacity. The United States installed 9143 MW and Germany installed 1078 MW of new capacity, while India and Spain increased their installed capacity by 2377 MW and 2319 MW, respectively. The top 10 countries accounted for 80.2% of the total installed capacity. In terms of cumulative wind power capacity, China leads with 35.26% of the world's total capacity. The United States and Germany represent 16.20% and 8.28% of the world's capacity, respectively.

Between 2008 and 2019, global cumulative wind capacity increased more than five-fold as shown in Figure 1, going from a capacity of 121 GW to 651 GW. Although the potential for future growth in wind capacity is highly favorable, there are several important barriers that need to be overcome, such as high initial investment costs, the need for transmission line infrastructure, and the need for large spaces for installation (Diógenes et al., 2020; Sadorsky, 2020; Zwarteveen et al., 2021).

In 2021, there was also a significant increase in global installed wind energy capacity, surpassing growth predictions. The highlight during this period was that countries adopted a policy of energy diversification and investment in renewable energy, especially wind energy. As a result, still leading in installed capacity growth, China installed the largest wind energy capacity in 2021, representing 30.7 MW of total installed capacity. The United States installed 12.7 MW, and Brazil with 3.8 MW of new capacity, highlighting it as the third country with the highest installed capacity in 2021 and also jumping to the sixth position as a country with the highest installed wind energy capacity, while Vietnam grew by 2.7 MW of installed capacity and Turkey with 1.4 MW, showing that several countries are seeking to incorporate renewable energy into their energy matrices. Therefore, the top 10 countries accounted for 76.7% of the total installed capacity, decreasing their capacity hegemony compared to 2019, demonstrating the concern of all countries to generate clean and renewable energy as shown in Table 1, showing the Total Installed Capacity Ranking in GW.

Table 1: Ranking capacidade total instalada (GW)

Position	Countries	Total installed capacity
1	China	310.6
2	United States	134.6
3	Germany	56.8
4	India	40
5	Spain	28.3
6	Brazil	21.5
7	France	19.1
8	Canada	14.2
9	United Kingdom	14
10	Sweden	10
	Total countries	649.1
	Global total	845

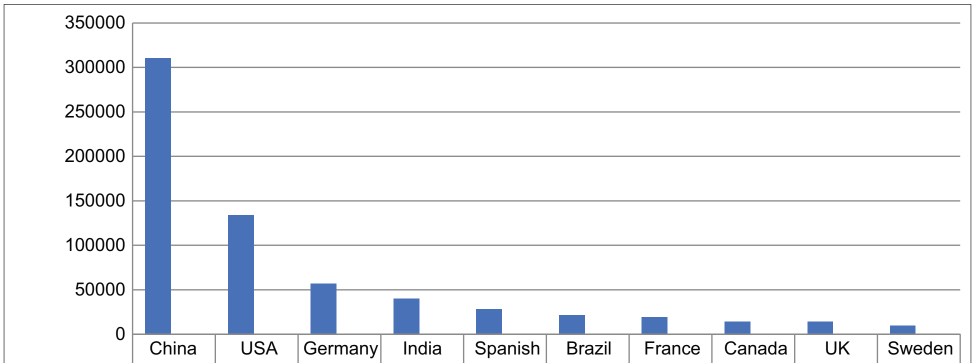
Fonte: Adapted from GWEC (2022)

A systematic literature review on wind energy implementation and growth conducted by Diógenes et al. (2020) was able to map some significant barriers to the development of onshore wind energy. These barriers include market failures, market distortions, economic and financial issues, organizational, technical, and social barriers. Market failures arise from a very restricted and highly regulated sector, limited information and access to technological innovations, lack of competition, high business costs, still deficient market structure, and the great need for large investments. Despite these inherent difficulties, the main countries in installed capacity continue to expand, as shown in Figure 2, which displays the ranking of the most productive countries in 2022.

Of all countries with wind power projects, only 10 exceed a capacity of 10,000 MW. Brazil joined this group in 2016, when it reached the level of 10,500 MW, now surpassing the United Kingdom, Canada, and Sweden, taking sixth place in the world ranking of installed capacity of 21,500 MW (GWEC, 2022). With this advance in energy production capacity, the effect of globalization on the wind energy market is evident, emphasizing partnerships and technological advances, and also involving enormous benefits for humanity, from improvements in health to the diffusion of culture and economic growth.

Based on the Global Wind Energy Council (GWEC) report in 2019, wind energy has gained prominence in the last 20 years,

Figure 2: Ranking of the main countries in installed wind energy capacity (MW) in 2022



	China	USA	Germany	India	Spanish	Brazil	France	Canada	UK	Sweden
Capacidade	310600	134300	56800	40000	28300	21500	19100	14200	14000	10000
Percentual	35.26	16.2	8.28	5.76	3.96	2.37	2.37	2.06	2.06	1.61

Source: GWEC (2022)

despite numerous successes and failures, providing clean energy at a competitive cost worldwide. However, the trend towards environmental sustainability intensifies the transformation of traditional manufacturing (Chang et al., 2021).

Recent studies demonstrate that three main factors affect the development of sustainable manufacturing: government regulations, customer expectations, and cost savings. As an essential part of sustainable manufacturing, the wind energy industry has grown rapidly in the last decades, mainly due to substantial technological improvements (Fangani et al., 2018).

2.1. Wind Power in Brazil

Brazil was the first Latin American country to install a wind turbine in the 1990s. However, wind power did not receive much attention during that period, mainly due to its uncompetitive price and lack of incentives through public policies (Simas and Pacca, 2013). This context changed in the 2000s, motivated by the energy crisis of 2001, which led to the creation of the Emergency Wind Energy Program (PROEÓLICA), proposing the installation of approximately 1000 MW of wind power capacity to complement hydroelectric generation. The adoption of incentives for wind power, mainly, increased its share in many countries. According to Simas and Pacca (2013), Brazil was no different: in 2002, the PROINFA was created, which proved to be an effective public policy focused on the electric sector, providing safer investments where a technology was still little known in Brazil. It aimed to increase the share of electricity from wind, biomass, and small hydroelectric power plants (PCH) in the National Interconnected System (SIN).

Among the main socioeconomic benefits brought by renewable energies are: technological innovation and industrial development; distributed generation and universal access to energy; regional and local development, especially in rural areas; and job creation (Simas and Pacca, 2013). In this context, after the 2001 energy crisis, the Brazilian electric sector went through an important growth cycle that encouraged investments in new sources for the Brazilian electric system. In particular, wind power was one of the most developed sources, accounting for more than one-fifth of the expansion of the Brazilian electric matrix capacity between 2012 and 2016 (Martins et al., 2018).

It can be considered that in the history of Brazilian wind power, the year 2019 was a turning point. Ten years were celebrated since the first exclusive auction for wind power, assuming the second place in the electric matrix and increasing from about 600 MW to 15.45 GW of installed wind power capacity in the last decade (ABEEÓLICA, 2019a). The evolution of installed capacity in this period is illustrated in the following graph 5. In 2019, 38 new wind farms were installed, with a total of 744.95 MW of new capacity. The states covered by the new projects were Bahia, Rio Grande do Norte, and Maranhão.

It is important to clarify that this new capacity was below the results of previous years. This is explained by the absence of auctions between the end of 2015 and 2017, as shown in Table 2.

With the addition of the 38 new wind farms, the year 2019 ended with a total of 620 wind farms and 15.45 GW of installed wind power, which represented a 5.07% growth in power compared to December 2018, when the installed capacity was 14.70 GW (ABEEOLICA, 2019b). The installed capacity of 15.45 GW is composed of 15.37 GW of parks in commercial operation (99.54%) and 0.07 GW of testing operation (0.46%).

The year 2020 also represented progress for the sector, where wind power continued to grow and reached the mark of 18 GW of installed capacity, in 695 wind farms and more than 8,300 wind turbines. The data were released on February 18, 2021, by ABEEÓLICA (2021).

Thus, considering all sources of electricity generation that make up the Brazilian energy matrix, in 2020, 2.61 GW of power were installed, with growth led mainly by hydro and wind sources. The new wind capacity installed in 2021 made the source reach a 10.60% share of the Brazilian electric matrix, as illustrated in Figure 3, which presents the participation of all generation sources in the Brazilian electric matrix at the end of 2021.

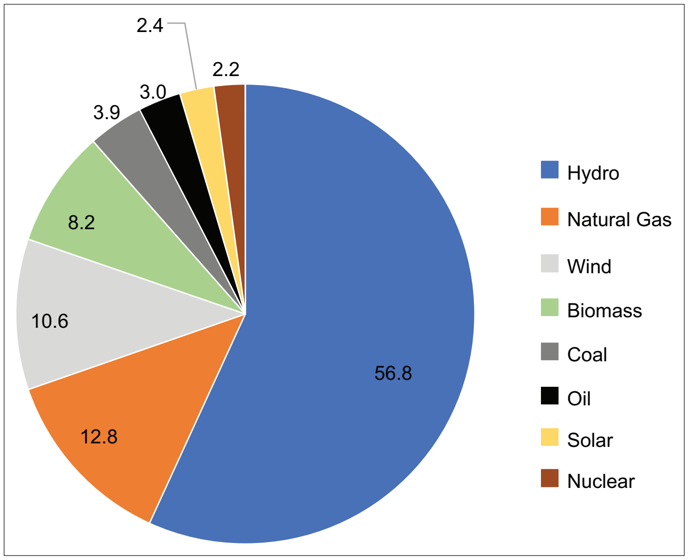
The development of wind power in Brazil can be seen as a reference case for a combination of energy and industrial policies. While policies for other economic uses of the sea, such as the oil and gas industry, are well established in Brazil, regulation

Table 2: Installed capacity in Brazil in 2019 (MW)

State	Power (MW)	Number of Complex
Bahia	501.9	30
Rio Grande do Norte	145.8	5
Maranhão	97.2	3
Total	744.9	38

Source: ANEEL (2022)

Figure 3: Brazilian electrical matrix in 2021 (GW)



Source: ANEEL, (2022)

of the offshore wind sector is still under development (Orestes et al., 2020).

Electricity generation in Brazil from public service and self-producers reached 656.1 TWh in 2021, a 4% increase from 2020. Public service power plants contributed 82.6% to the total generation. Hydroelectric power, the main source of electricity production in Brazil, decreased by −8.6% compared to the previous year.

Electricity generation from non-renewables accounted for 22.6% of the national total, compared to 16.8% in 2020. However, it is important to highlight the evolution of natural gas, which over the last 10 years, by displacing fuel oil and diesel, has contributed to minimizing emissions from electricity generation from non-renewable sources. Net imports of 23.1 TWh, added to national generation, ensured a domestic electricity supply of 679.2 TWh, a 0.3% increase from 2020. Final consumption was 570.8 TWh, representing a 5.7% expansion compared to the previous year (EPE, 2022).

Furthermore, according to EPE (2022), Brazil has a predominantly renewable energy matrix, with hydroelectric power accounting for 53.4% of the domestic supply. Considering that almost all imports come from the *Itaipu* plant, the share of hydroelectric power reaches around 57%. Renewable sources represent 78.1% of Brazil's domestic electricity supply, which is the result of the sum of the amounts related to national production plus imports, which are essentially of renewable origin.

3. METHODOLOGY

An exploratory documentary research was carried out, seeking information from government agencies, such as the Ministry of Mines and Energy (MME), EPE, regulated sources, as well as consulting documents made available by some national and international institutions related to the object of study, such as ABEEOLICA, IEA and GWEC, and specialized journals.

The aim of this research is to complement and subsequently triangulate the data collected with key actors through interviews. The joint analysis of qualitative information and quantitative data allowed for a broader view of competitiveness aspects, as well as the potential and limitations of wind energy in the Northeast region, specifically in Bahia, compared to Brazil and the world.

To understand the factors that influence the competitiveness of renewable wind energy in the Northeast, specifically in the state of Bahia, the methodological approach followed the classification of research, which takes into consideration its nature, problem approach format, objectives, and technical procedures adopted.

The study is oriented towards an interpretive perspective of perceptions, based on the viewpoint that events in social reality do not exist in any effective sense, but rather consist of the effect of subjective experiences and the understanding of the interviewed individuals.

The individuals' perception was complemented by quantitative analysis of the collected data, resulting in a broader perspective of competitiveness aspects of wind energy in the state of Bahia, specifically the Alto Sertão wind complex.

3.1. The Information Collection

The primary data collected refer to interviews carried out with 38 individuals, representatives of several key sectors of the wind energy sector in Bahia. The choice of these key agents took into account the degree of knowledge they have about the renewable energy program and its socioeconomic context in which it is inserted, defined by the direct and indirect action in renewable energy plants, in the energy sector, whether in government agencies, research institutions, among others in the energy productive sectors.

The criteria adopted to identify the specialists and their institutions and participating companies, was due to demonstrating a direct relationship with the area of renewable energies, direct and indirect participating bodies of the sector and research institutions inserted in the process. For Triviños (1987), the in-depth interview is more appropriate for qualitative methods as it highlights the researcher's presence and, together, provides all possible perspectives for the respondent to reach the necessary freedom and spontaneity, enhancing the investigation.

The list of key agents interviewed or sent the questionnaires is shown in Chart 1, respecting the exception regarding freedom of expression on their part, in which they were guaranteed complete secrecy regarding their identification at the time of showing the study.

Chart 1: Key research agents interviewed

Categories	Institution-Municipality-Representative interviewed	Number of participants
Government Institution	SEINFRA - Secretariat of Infrastructure - Salvador - BA	1
	SEI - Superintendence of Economic and Social Studies - BA	1
	SDE - Secretariat for Economic Development - BA	1
	CODEVASF-São Francisco Valley Development Company – Guanambi/ Bom Jesus da Lapa	1
Entities/Federation/Organizations	SEBRAE - Brazilian Micro and Small Business Support Service Vitória da Conquista/Guanambi - Mrs. José Viana	1
	Commercial and Industrial Association of Caetité	1
Power plants	Alto Sertão Wind Complex-Renova Energia-Caetite-Bahia	20
	Enel Green Power-Tacaratu-Pernambuco	1
Supplier of equipment and parts	Manufacturers of parts for wind power plants	1
	Ex. Alstom-Wind Tower Factory-Jacobina-BA (TEN-Wind Towers in the Northeast. (31) 3195-4330	
	Gamesa Wind Generator Factory-Simões Filho-Bahia	
	Wobben-Wind turbine factory-Juazeiro -Bahia	1
	(015) 2101-1860	1
Technical assistance	Specialized companies in the sector (SIEMENS; GAMESA; ENERGISA)	1
	UFBA – Federal University of Bahia	3
Research/teaching		
Financial	Northeast Bank	1
Entrepreneurs	Entrepreneur/Microentrepreneur	2
Consultoria e outros	EOLUS Consulting-Salvador-BA	1
Total		38

Source: Research data

The questionnaires were sent electronically to the key agents in the wind renewable energy production chain, who were classified in the survey as Specialist Agents in renewable energies, specifically wind energy. In addition, on-site visits were also carried out to observe the process and conduct some interviews.

3.2. Data Treatment and Analysis

According to Gil (2008), there are no specific methods and techniques for the treatment and analysis of data obtained in a case study. However, the author suggests triangulation of the information obtained as an alternative to enable maximum breadth in the description, explanation, and understanding of the studied phenomenon.

To identify and verify the focal points of wind energy competitiveness, evaluations were assigned ranging from very unfavorable to very favorable for the questions developed according to selected determinant factors for the study. The Likert scale, a type of psychometric response scale used in questionnaires, was used to measure the level of agreement, frequency of certain activities, importance level assigned to a specific activity, evaluation of a service, product, or company, and probability of future actions.

The questionnaire also provided a space for respondents to make comments on each question, if necessary. The data obtained from the questionnaires aimed to collect the perceptions of expert agents regarding factors that affect wind energy competitiveness. A simple statistical treatment was performed using Microsoft Excel software to represent the percentages of each question.

Thus, a general appreciation of each focal point and determinant factor was obtained. By combining the structured questionnaire responses with the evaluation of interviews, bibliographic and documentary material, a triangulation analysis was carried out to make the research results more robust.

4. RESULTS AND DISCUSSION

In this section, the results of the study are presented. These results were based on both primary data collected from selected key authors and secondary data. The joint analysis of these qualitative and quantitative information enabled a deep diagnosis of the competitiveness factors of wind energy associated with the Alto de Sertão wind complex in Bahia.

Thus, the section is divided into two parts. The first part deals with the competitiveness aspects associated with the focal points identified in the literature analysis. All nine points were discussed and compared with the findings obtained from the interviews. The second subsection deals with quantitative aspects and data collected from relevant agencies and organizations. This information supports the findings from the interviews and reinforces the strategic and competitive importance of wind energy produced in the Northeast region of Brazil, especially in the Alto Sertão wind complex in Bahia.

4.1. Competitiveness of Wind Power: Evaluation of Systemic Factors and Associated Focal Points

Regarding renewable energies, especially wind energy, the participation and action of both the Federal and State Government are of substantial importance in establishing laws, regulations, and guidelines that dictate the market's overall direction.

Before any considerations are made regarding the legal framework and its association with sector policies, it is pertinent to argue about the reasons why government intervention is so important for the economic development of a specific region, product, or service.

Government participation and interventions have been positive for creating and introducing new businesses, considering that historical economic instabilities can occur at any time, turning the wind energy business into a high-risk venture.

This aspect justifies discussion because both regulations and public policies are mechanisms that the government possesses to establish incentive structures that guide the decisions of private agents. Rules, norms, laws, and regulations exert pressure on a branch or sector by setting economic conditions, a scenario that imposes greater responsibility on public managers to manage their contracts, as well as the programs and incentives for the renewable wind energy production and generation chain defined by the government, directing the decisions of chain members.

In this context, promoting research and development related to renewable energy has assumed the status of a principle/objective in the National Energy Policy agenda through the (Law 9.478/97 and Law 12.490/11, which identifies in its Art. 1 the national policies for the rational use of energy sources aimed at the following objectives listed in some of the articles presented in Law No. 9.478 of August 6, 1997 (BRAZIL, 1997):

i. Preserve national interest;
ii. Promote development, expand the job market, and enhance energy resources;
iii. Identify the most suitable solutions for the supply of electricity in different regions of the country;
iv. Use alternative sources of energy, by economically harnessing available inputs and applicable technologies;
v. Promote free competition;
vi. Attract investments in energy production;
vii. Expand the country's competitiveness in the international market
viii. Fomentar a pesquisa e o desenvolvimento relacionados à energia renovável.

Public policies aimed at increasing the use of new renewable energy sources in Brazil, particularly in relation to wind power, had their initial milestone in the first program explicitly focused on the development of wind power in Brazil, which was the Emergency Program for Wind Energy - PROEÓLICA (GCE Resolution No. 24/01) (BRASIL, 2001). Created with the objective of contracting 1050 MW of projects by December 2003, the program was not even regulated by ANEEL due to numerous operational and bureaucratic obstacles.

Thus, in its place, a new program was created regarding the promotion of alternative sources of electric power, which is included in article 3 of Law No. 10,438 of April 26, 2002 (BRASIL, 2002), which institutes the Program for Incentive to Alternative Sources of Electric Power-PROINFA, with the objective of increasing the participation of electric power produced by Independent Autonomous Producers projects, based on wind power, small hydroelectric plants, and biomass, in the National Interconnected Electrical System, and in the modifications introduced by Law No. 10,762, of November 11, 2003, and Law No. 11,075, of 2004 (Do Valle Costa et al., 2008). The Program shapes the material scope of renewable energy development only up to 3300 MW in a first stage, of which a contingent of 1429 MW for the installation of wind-powered electricity production facilities was awarded.

The uncertainty regarding the Program's long-term continuity, compromised by the profound regulatory changes implemented by Law 10,848, of 2004, which established that the entirety of the regulated market must acquire energy through auctions promoted by ANEEL, and protectionist measures inherent in the designed model, as well as the precarious political definition, which demonstrated a clear lack of ambition in its energy objectives, particularly in relation to wind power, seriously hindered the Program's development. The regulation of the wind renewable energy sector is evolving in a structured way with other public policies and with the demands themselves, as legislation is not static, it matures and evolves over time.

In this research, Determining Factors and Focal Points were taken into consideration in order to understand the level of competitiveness of the sector. The thematic Focal Points Legal Framework and Public Policies were taken into account, with the main elements being portrayed: Law 9478/1997 and other legislations; Bill 2505/2007 and other legislations; Wind Energy Auctions; Specific policies and programs and Renewable energy expansion policies.

4.1.1. Diagnosis of determining factors and focal points associated with a focus on the legal framework

The results of the questionnaires applied to the specialist agents present in the wind energy chain regarding the thematic elements of the Systemic Determining Factor and Focal Points associated with a focus on the Legal Framework are presented in Figure 4, followed by a discussion of the perceptions of the interviewees and a review bibliography.

According to the presented data, the implementation of Law 9.478/1997 and its various amendments and complementarity in the legal framework for national energy policy, as a set of guidelines to be followed for the rational use of national energy sources to improve the competitiveness of the renewable energy market, was considered very favorable, representing 85% in total (Favorable/Very Favorable).

This finding is consistent with the interviewees' statements associated with the fact that energy is a strategic business for economic development and performance, and that the low production and increasing disposal of oil prices in the global market have highlighted the need to seek other energy sources, particularly renewable ones. In other words, the need to incorporate clean energy, especially wind energy, into the energy matrix is seen as a viable alternative and denotes an advancement in the competitiveness aspect of the renewable energy market. In this sense, there was agreement among the interviewees regarding wind energy as an energy alternative capable of reducing dependence on oil (Braga and Braga, 2012).

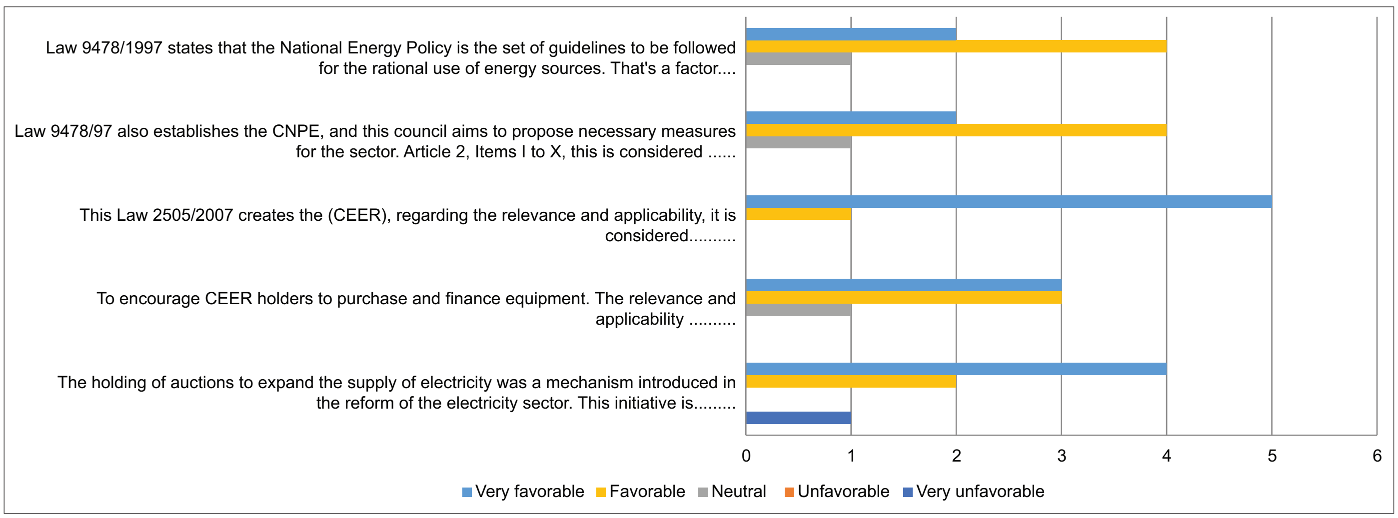
4.1.2. Diagnosis of determining factors and focal points associated with a focus on public policies

Os resultados dos questionários aplicados aos agentes especialistas presentes na cadeia da energia eólica com relação aos elementos temáticos do Fator Determinante Sistêmico e Pontos Focais associados com foco nas Políticas Públicas são apresentados na Figura 5, seguida por uma discussão das percepções dos entrevistados e de uma revisão bibliográfica.

The results of the selection of investigated data regarding public policies aimed at promoting the production and generation of wind renewable energy in the Northeast, specifically in Bahia, formulated by the Federal and State Governments, were evaluated by the interviewees and considered highly satisfactory, characterizing an overall evaluation of 68% as favorable/very favorable. It was also exposed that a significant part of the responses was neutral, as many of the respondents reported that the governments could act in a more harmonious and transparent way for the progress of the public policies being developed, improved, or formulated.

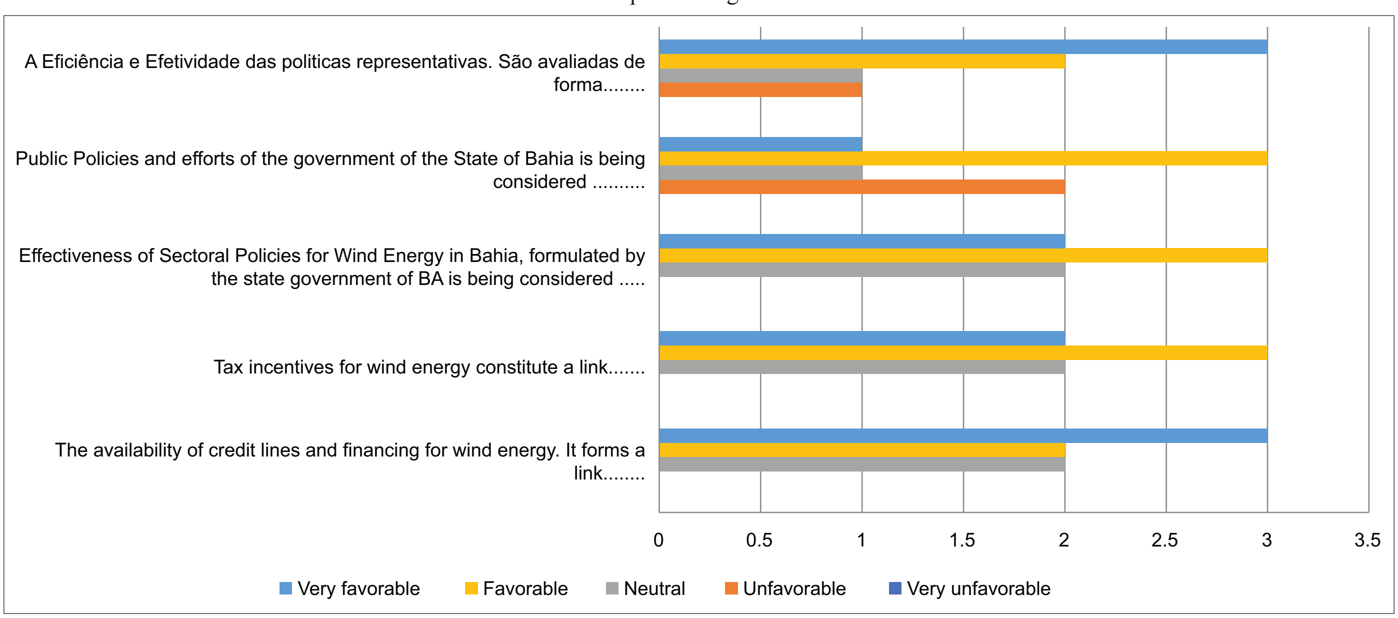
Contributing to the data regarding public policies, a point raised by the interviewees is that despite the advances and boosting in the sector, experts affirm that the lack of integration of these policies among the federated entities and the central government creates inefficiency in the possibilities of expanding the generation and utilization of these energy sources in their respective territories. The direct and indirect support mechanisms applied and those that are imminent to be applied by Brazil are developed and put into practice by different actors, such as BNDES, FINEP, ANEEL, the Ministry of Science and Technology (MCT), the Ministry of Mines and Energy (MME), States, Municipalities, and Research Institutions. In fact, in addition to making the sector's knowledge more complex, it hinders the completion of policies over the years, since the agents may have different objectives, and there is no responsible entity for organizing the Brazilian wind sector.

Figure 4: Assessment of determining factors and focal points associated with a focus on the legal framework according to the perception of wind energy specialist agents



Source: Research data

Figure 5: Assessment of determining factors and focal points associated with a focus on public policies according to the perception of wind energy specialist agents



Source: Research data

Regarding public policies for alternative renewable sources and the efforts expended by the Bahia state government in promoting and incentivizing the increase of new renewable energy sources, especially wind energy, it was considered by the interviewees that 57.10% believe it to be favorable/very favorable, highlighting the commitment to the effectiveness of new renewable energy sources. A point reported and confirmed by the interviewees was the initiative of Bahia, which was a pioneer in enacting Resolution CEPRAM N° 4.180/2011, which deals with the Environmental Licensing Process for Electricity Generation Projects from Wind Energy Sources in the State of Bahia, through the approval of Technical Norm NT- (01/2011). On October 05, 2018, published in the Official Gazette, Resolution CEPRAM N° 4.636, DE 28 DE SETEMBRO DE 2018, was established, which sets criteria and procedures for the environmental licensing of electricity generation projects from wind energy sources in terrestrial environments in the state of Bahia.

4.1.3. Diagnóstico dos fatores determinantes e pontos focais associados com foco na macroeconomia

The results of the questionnaires applied to expert agents present in the wind energy chain regarding the thematic elements of the Structural Determinant Factor and Focal Points associated with a focus on Macroeconomics are presented in Figure 6, followed by a discussion of the perceptions of the interviewees and a literature review.

According to the data collected on the Systemic Determining Factor and Associated Focal Points (Competitiveness and Market) with a focus on Macroeconomics, a generally average evaluation was found, categorized as 54.3% (Favorable/Very Favorable), with 11.4% of neutrality and 34.3% (Unfavorable/Very Unfavorable). The detailed results are discussed below.

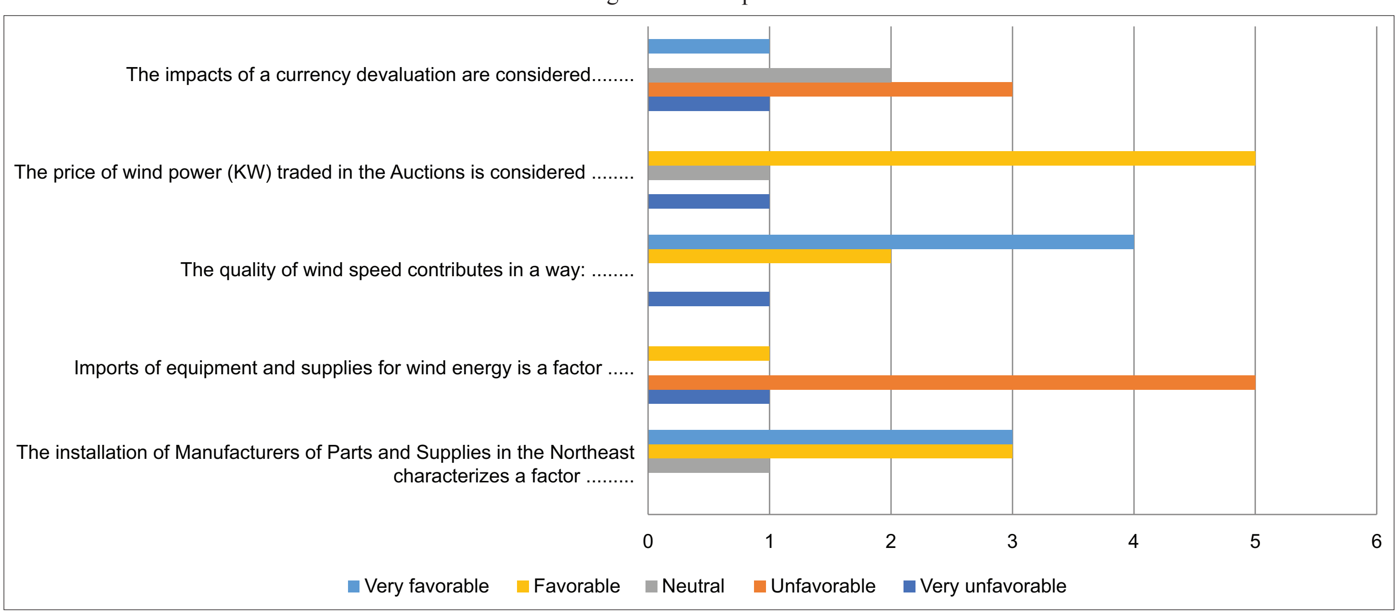
In the context of renewable energy production and generation, particularly wind energy in Bahia, macroeconomic conditions are of great importance. However, their impact on the sector's competitiveness depends on the economic and political conjuncture at any given moment.

The systemic determining factors and focal points analyzed, such as exchange rate, inflation rate, credit, and financing, are mechanisms to evaluate whether the conditions are favorable or not for improving the competitiveness of wind energy in Bahia. Moderate results were found, as unfavorable/very unfavorable perception and neutrality prevailed in these indicators, showing that the interviewees have uncertainties regarding changes in these variables in the domestic and international markets.

For some of the respondents (11.4%), who analyzed the topic neutrally, there is a question about whether the energy will be imported or exported, or consumed locally. If the policy for the sector is well-designed, it should lead to the complete realization of wind turbines, wind generators, blades, and other equipment related to wind energy generation within the state of Bahia, forming a complex similar to what happens in the automotive industry. Therefore, they believe that it is not fiscal incentives or exchange rate (which in this case is an exogenous variable to the business) that stimulates wind energy activity. Other respondents also support the idea that the industrial matrix becomes capable of producing the goods and equipment of the chain, or more complex technologies.

Regarding the respondents' perception of the impacts of a devaluation of the exchange rate, it is considered unfavorable for the competitiveness of renewable wind energy in Brazil since the devaluation of the exchange rate discourages the purchase of materials related to wind energy production, given that a significant portion of the equipment is imported. Another issue is related to the greater ease of selling inputs to the foreign market, given that the purchasing power of the Brazilian currency decreases compared to

Figure 6: Assessment of determining factors and focal points associated with a focus on macroeconomics according to the perception of specialist agents in wind power



Source: Research data

other currencies, especially the US dollar. This leads to an increase in project values, making it difficult to compete.

Thus, the actual analysis of the impacts of a devaluation of the exchange rate on the competitiveness of renewable wind energy in Brazil was considered quite concerning by more than half of the interviewees, with a percentage of 57.1% as (Unfavorable/Very Unfavorable) due to the devaluation of the national currency against the dollar and other currencies of countries that produce equipment and inputs, given that a significant portion of these is imported. Changes in the exchange rate directly affect the competitiveness of enterprises, meaning that a rise in the exchange rate means a devaluation of the real and has implications for increasing competitiveness, as part of the products that make up the wind energy industry are imported.

4.1.4. Diagnosis of determining factors and focus points associated with microeconomics

The results of the questionnaires applied to expert agents in the wind energy chain regarding the thematic elements of the Determining Systemic Factors and Focus Points associated with Market, with a focus on Microeconomics, are presented in Figure 7, followed by a discussion of the respondents' perceptions and a literature review. The results of the data selection related to the microeconomic issues for increasing wind energy in Brazil and Bahia were considered satisfactory, representing an overall evaluation of almost 75% as favorable/very favorable.

Regarding the points related to the need for expansion and improvement of the transmission infrastructure of electric energy generated for large consumer centers, they are seen as quite favorable for the competitiveness of wind energy, representing a general index (Favorable/Very Favorable) of 85.6%.

According to the interviewees, the issue of energy transmission is still a point that demands significant investments for the flow of electrical production from all potential wind energy producing sites, in which some potential wind complexes still depend on the approach of transmission lines to be designed. In addition, delays in expanding transmission networks were not the responsibility of project developers until 2013. Furthermore, energy purchase contracts included a clause that not only released project developers from their contractual responsibilities but also guaranteed compensation if the project developer could prove that their plant was ready to operate without the necessary transmission lines available.

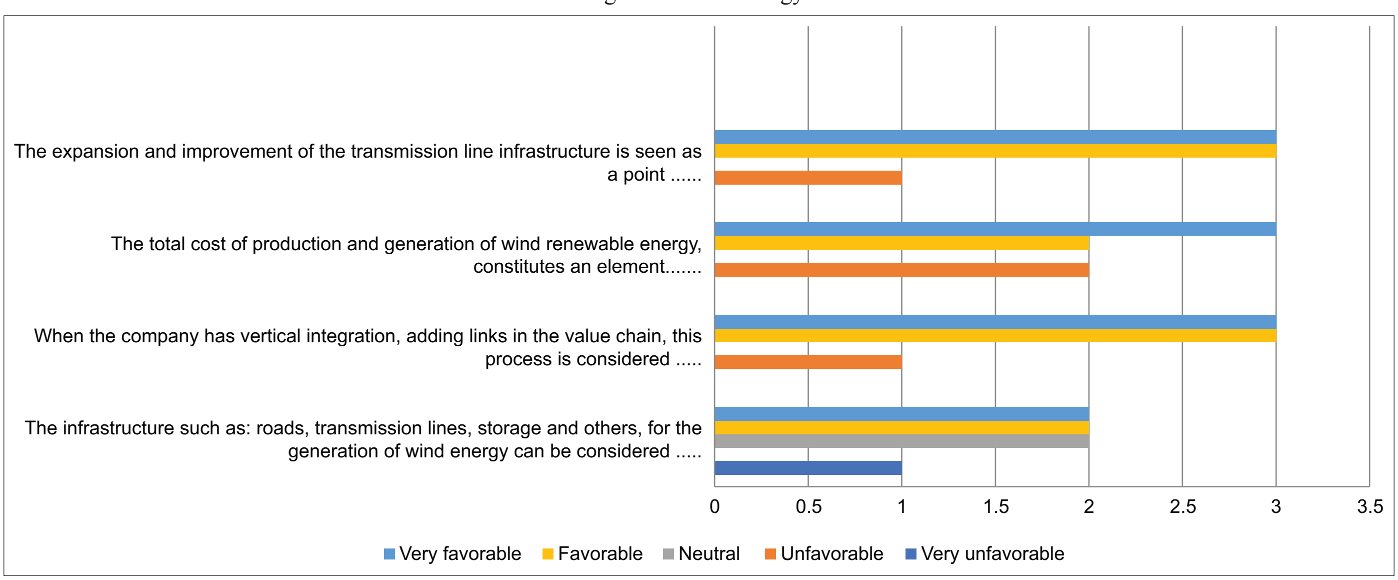
From the LEN 11/2013 auction, the risk of delays in extending the transmission network was transferred to the project developers. Therefore, even if the extension of the transmission network is delayed, the project developer is obliged to honor their contractual obligation to provide energy.

Thus, for Bayer et al. (2018), the higher costs of wind projects due to legislative changes transferred the financial risk of transmission delays to wind project developers. Nonetheless, Brazil has experienced significant advances in energy policy, promoting the expansion of wind capacity. This has been achieved through an auction-based mechanism that has also increased the number of investors (Herrera et al., 2019).

Ainda assim, o Brasil tem experimentado avanços significativos na política energética, que promovem a expansão da capacidade eólica. Isso vem sendo conseguido por meio de um mecanismo baseado em leilão que também vem aumentando o número de investidores (Herrera et al., 2019).

Regarding the total cost of production and generation of renewable wind energy, interviewees considered this to be an important element for the competitiveness of wind energy, with a general index (Favorable/Very Favorable) of 71.4%.

Figure 7: Assessment of determining factors and focal points associated with a focus on microeconomics according to the perception of specialist agents in wind energy



Source: Research data

The evaluation made by interviewees regarding microeconomics, in terms of distribution, is still not considered economically viable. However, considering wind power plants for commercial generation, costs are being reduced as the sector grows, thus increasing competitiveness, which cannot be considered favorable, reaching a percentage of 28.6% that analyzes the issue unfavorably with regard to the cost of production and generation being an element that demonstrates competitiveness. Reflecting on the issue, interviewees justify their perceptions when large-scale production finds channels for flow and integration with local industry and specialized services carried out internally. A new cost estimate will need to be made to effectively analyze production and distribution costs with greater efficiency.

The Alto Sertão I Wind Complex had all its energy contracted in the 2009 reserve energy auction (LER)[1]. However, the complex only began operating in 2014 due to the delay in the construction of transmission lines, which was the responsibility of Chesf, certifying what was provided for in the contract. With an installed capacity of 294 MW, the Complex was deployed in the municipalities of Caetité, Guanambi, and Igaporã, in the semi-arid region of Bahia. A total of 184 wind turbines were installed, mounted on 80-m towers, with blades 42 m in length. The energy produced is capable of supplying around 650,000 households, a significantly higher number than the number of households in the region, whose population is around 400,000 (RENOVA, 2011).

The Alto Sertão II Wind Complex had its energy contracted in the 2010 LER for 6 parks and in the 2010 New Energy Auction (LEN)[2] for 9 parks. The Complex includes 15 wind parks, with construction beginning in 2012, with the delivery of 6 parks in 2013 and the remainder in 2014, with the start of operation the following year after delivery. The Complex reached 386.1 MW of installed capacity, using 230 wind turbines. The municipalities involved in the Complex are Caetité, Guanambi, Igaporã and Pindaí, all located in the southwest of Bahia.

4.1.5. Diagnosis of determining factors and focal points associated with a focus on management

The results of questionnaires applied to expert agents present in the wind energy chain regarding the thematic elements of Determining Business Factors and Associated Focal Points (Economic Analysis; Competition and Operational Costs) with a focus on management are presented in Figure 8, followed by a discussion of interviewees' perceptions and a literature review.

According to the data collected in the Business Determinant Factor and Associated Focal Points (Economic Analysis; Competition; Operating Costs; Technology and Hybrid Generation) with a focus on management, with an approach to advance R&D together with partnerships with research institutions, constitute important vectors for the competitiveness of the entire production chain, and a general evaluation considered very satisfactory with a general index of 14.3% as favorable and 85.7% as very favorable, demonstrating advances in research and the need for improvement and qualification was found.

In recent years, manufacturing competitiveness has become an important point of research, and globalization and the highly competitive environment have led to an urgent need to create effective competitive strategies to survive. Therefore, companies need a better understanding of the interrelationships between the factors that determine competitiveness and indexes to measure it (Rita and Freitas, 2015).

The analysis of manufacturing competitiveness and its driving factors can not only effectively identify new problems and phenomena in the development of manufacturing but also promote the participation of major world economies in sustainable manufacturing development (Dou et al., 2021).

In the study by Irfan et al. (2020a) "Competitive assessment of the wind energy industry in South Asia: SWOT analysis and combined value chain model," the aim of this study was to develop a value chain model for the wind energy industry in South Asia, examine internal and external factors to analyze the feasibility of the current condition and future roadmap for promoting the wind energy sector, adopting Strengths, Weaknesses, Opportunities, and Threats (SWOT) model, showing how research can positively influence the competitiveness of wind energy (Irfan et al., 2020b).

It was observed by the interviewees with respect to the performance of the government of the state of Bahia in the development of research and extension aimed at minimizing bottlenecks in wind energy production for the increase in sector competitiveness, considered incipient, neutral, or unfavorable with percentages of 57.1% as neutral and 14.3% unfavorable for the sector.

According to the interviewees in their perceptions, there is no concrete policy to encourage research and development for the sector. Although research is funded by the Foundation for Research Support of the State of Bahia - FAPESB, these funded projects are covered by general regulations and not by having a mechanism of incentive or specific notice for the theme. The interviewees also reinforce the rhetoric that state government incentives are still timid. However, when combined with Federal Government incentives and private sector investments, Bahia has become a major state in wind generation, endorsing the 14.3% percentage as favorable to the government's research development for the wind renewable energy sector.

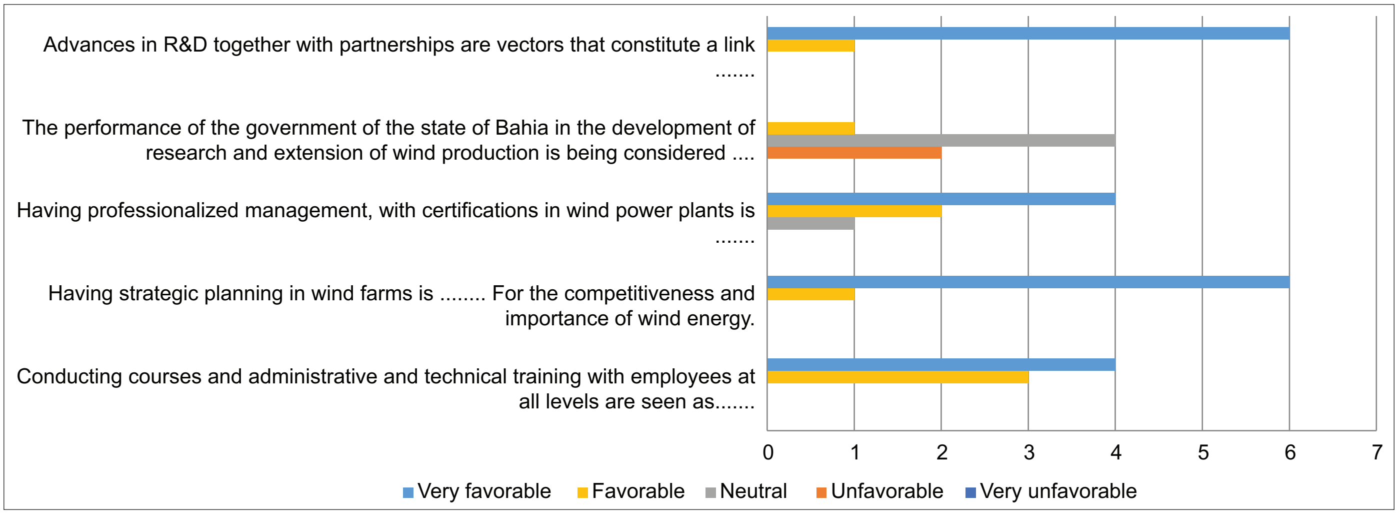
For some interviewees, there are many studies, including those done by the Infrastructure Secretariat - SEINFRA. But also at the state level, the policy for the development of the wind sector is still timid. And even in the Plurianual Plan - PPA 2021-2024, there is no detailed detachment of the state government's technological development policy intentions towards renewable energy.

In the study entitled "Brazilian wind energy market, social and environmental impacts," the authors Pinto et al. (2017) show that

1 Promoted by the Federal Government. The contracting of reserve energy was created to increase security in the supply of electricity in the National Interconnected System (SIN).

2 The purpose of the new energy auction is to meet the increased load of distributors. In this case, energy from plants yet to be built is sold and contracted.

Figure 8: Assessment of determining factors and focal points associated with a focus on management according to the perception of wind energy specialists



Source: Research data

from the experience acquired by PROEÓLICA served as a basis for government programs to encourage renewable sources at the national and state levels that were subsequently implemented in order to promote the diversification of the Brazilian energy matrix.

The PROINFA was a governmental program developed within the MME, and it was through political decisions that were fundamental to enable the wind energy market in Brazil. Through these incentives and a series of institutional actions adopted to facilitate the implementation of new projects, the participation of wind energy grew rapidly in Brazil's electric matrix (Pinto et al., 2017).

In the view of the interviewees, having a professionalized management, with certifications in renewable wind energy plants, for better competitiveness of wind energy is considered by 85.7% of the interviewees as (favorable/very favorable), and still a percentage of 14.3% see the issue of professionalized management with neutrality or apathy, thus demonstrating the importance of efficient management. Also, for the interviewees, the issue of having strategic planning in wind plants is of great importance for the competitiveness of wind energy, with the objective of seeking to achieve ambitious and increasingly challenging goals in the sense of evolving with the generation and production of renewable wind energy. This represented an index of 14.3% as favorable and 85.7% as very favorable in the interviewees' view, demonstrating the degree of commitment of the sector to grow and have increasing participation in the Brazilian energy matrix.

Given the numerous changes that society is undergoing, organizations are also seeking to change. The business world is seeking to define a new organizational posture as a result of the problems caused by the rapid modernization and globalization of companies. Thus, organizations are faced with an uncertain future, with rapid and unforeseen changes.

In this perspective, competitiveness among organizations has become accentuated and complex in an intense market, where small differentials can be of great relevance for the survival of companies.

Given this finding and the perceptions of the interviewees, the realization of administrative and technical updating courses and training with employees at all levels is seen as improvements in qualification with the purpose of advancing the competitiveness of the wind plant. Thus, for the interviewees, it was pointed out with an index of 42.8% as favorable and with an index of 57.2% as very favorable in investments in training, courses, and updates always with the aim of improving knowledge to apply for qualification.

4.2. Competitiveness in Quantitative Terms of the Northeast Region and the Alto Do Sertão Wind Complex – BA

As the research demonstrates, the wind energy sector has been gaining increasing importance in the Brazilian energy matrix. The Northeast region of the country, in particular, presents a great potential for wind energy production due to its privileged geographic location and constant winds for much of the year.

The Brazilian Northeast is one of the regions with the greatest potential for wind energy production in the world. According to data from the National Electric Energy Agency (ANEEL, 2022), the region has a potential for generating 528.6 GW of wind energy, which represents about 90% of the country's electricity generation capacity. Additionally, the region presents constant winds for much of the year, guaranteeing high efficiency in energy production from this source.

Despite the high potential and benefits of wind energy, the sector still faces some challenges in the Northeast region. One of the main obstacles is the lack of infrastructure for the transmission of energy produced by wind farms. This is because the region has a large number of wind farms but still has a limited power transmission network, which can generate bottlenecks in the distribution of electricity.

The lack of adequate transmission line infrastructure to transport electricity production from renewable sources, including wind energy, can negatively affect the competitiveness of the sector in the Northeast region of Brazil. This is because when there are limitations on transmission capacity, the connection costs of wind farms to the power grid may increase, reducing the attractiveness of investments in the sector.

Moreover, the lack of transmission lines can also lead to congestion problems in the power grid, limiting the amount of energy that can be delivered to consumers and causing losses for the entire electricity sector. Therefore, it is essential to invest in transmission infrastructure to ensure that energy produced from renewable sources can be transported to major consumer centers, thus allowing for the expansion of the wind sector in the region.

Despite still being a bottleneck, the transmission line infrastructure for transporting electricity production from wind energy in the Brazilian Northeast has been expanded in recent years to meet the increased installed wind generation capacity in the region.

In 2019, the first section of the transmission line that will transport energy production from wind farms in the *Caetité* region, in Bahia, to the Southeast of the country was inaugurated. The project, called "Green Line," has a total length of 1,517 km and will interconnect the states of Bahia, Minas Gerais, Espírito Santo, and Rio de Janeiro.

Moreover, other transmission line projects are underway in the Northeast region, such as the transmission line that will connect the Osório Wind Complex in Rio Grande do Sul with the Northeast, through a 2,375 km transmission line that will connect the states of Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Minas Gerais, and Bahia.

Another challenge is the need for investments in research and development of technologies for wind energy production. Despite the great potential, the technology used in wind farms is still relatively new and requires continuous investment in research to ensure greater efficiency in energy production.

An important competitive factor is the average cost per MWh. If the average cost of wind farms in the Brazilian Northeast region is compared with that of other countries, there is a considerable difference, especially compared to countries such as Spain, Germany, and Denmark. Table 3 shows the average cost (in US$/MWh) of electricity generation among wind farms in the Northeast and other countries with a history of wind energy production.

Table 3: Comparison between electricity production costs between wind farms in the Brazilian Northeast and other countries

Wind farms	Average generation cost (US$/MWh)
Northeast of Brazil	39.3
México	37.7
U.S	41.9
Spanish	54.2
Germany	57.3
Denmark	64.4

Source: GWEC (2021)

Table 3 presents a comparison of the average cost per MWh of electricity generated in wind farms in the Northeast region of Brazil with wind farms around the world. In the Brazilian Northeast, the average cost of electricity generation in wind farms is 39.3 US$/MWh, which is relatively low compared to other countries such as Spain, Germany, and Denmark, where the average cost is over 50 US$/MWh. However, it is important to note that the cost of electricity generation in wind farms can vary depending on various factors such as wind speed, equipment cost, and financing cost.

In Mexico and the United States, the average cost of electricity generation in wind farms is relatively low, around 37.7 and 41.9 US$/MWh, respectively. This is partly due to favorable wind conditions in these countries.

Overall, wind power is a renewable and clean source of energy that has become increasingly competitive with other sources of energy. The table above provides an overview of the costs of electricity generation in wind farms in different parts of the world, highlighting the competitiveness of wind energy as a source of energy compared to other sources.

Regarding the Sertão Wind Farm Complex - BA, this is one of the largest wind energy projects in operation in Brazil and presents important aspects of economic, social, and environmental competitiveness. The complex consists of 14 wind farms with a total installed capacity of 1.5 GW, making it the largest wind farm complex in Latin America.

In addition, the complex is responsible for providing clean and renewable energy to more than 600,000 households in the country, contributing to the diversification of Brazil's energy matrix and the reduction of greenhouse gas emissions.

According to the company responsible for the park, AES Brazil, the construction of the complex generated about 2,000 direct and indirect jobs in the region, and currently, the park employs around 150 people in its operation.

One of the main aspects of economic competitiveness of the complex is its ability to generate jobs and stimulate the local economy. The project involved hiring around 4000 workers during its construction, in addition to employing more than 250 people in its operation. Moreover, the project has a significant impact on the local economy, promoting commercial and service activities, and generating taxes and revenues for the State.

In terms of social competitiveness, the complex offers several benefits to local communities. One of the main benefits is the generation of clean and renewable electricity, which contributes to the country's energy security and the reduction of greenhouse gas emissions. Additionally, the project includes social responsibility actions such as the construction of schools, health posts, and water supply systems in nearby communities (Albuquerque et al., 2017).

Regarding environmental aspects, the Sertão Wind Farm Complex also presents significant advantages. The generation of electricity from wind power is a clean and renewable way to produce electricity, contributing to the reduction of greenhouse gas emissions and the mitigation of the effects of climate change. Additionally, the construction of wind farms was carried out with attention to environmental aspects, minimizing impacts on local fauna and flora and respecting environmental preservation regulations.

An important indicator of economic and financial competitiveness and sustainability is the Capital Expenditure (CAPEX). CAPEX can be defined as the total capital expenses or investments in capital goods that are made to create, maintain or expand a given business structure or to expand the scope of a company's operations. It is an important concept in the business world since it evaluates the cash flow being used in investments within companies (Ross et al., 2015).

Table 4 presents a comparison of the Sertão Wind Farm Complex with other projects. In addition to the cash generation capacity for investment, measured by CAPEX, other information is compared, such as the generation potential, wind speed, and energy yield.

Regarding this factor (wind speed), it is determinant for the performance of wind farms in the Northeast Region of Brazil. This is due to the fact that the energy produced by a wind turbine is proportional to the cube of the wind speed. In other words, small variations in wind speed can have a large impact on the amount of energy generated.

The capacity factor of a wind farm is a measure of the efficiency of wind energy utilization at a given location and is calculated as the ratio of the energy produced by the wind turbine to the energy that would be produced if the turbine were operating continuously at its maximum capacity. The capacity factor can be influenced by various factors, including wind speed and quality, turbine density, tower height, and other factors related to wind farm design and operation.

In general, wind farms installed in the Northeast Region of Brazil have relatively high-capacity factors due to favorable wind conditions in the region. However, it is important to conduct feasibility studies and detailed technical analyses to evaluate the potential of wind energy generation at a specific location, taking into account not only wind speed and quality but also other factors relevant to wind farm operation and maintenance.

Thus, the average wind speed is an important factor for the efficiency of wind farms because it determines the amount of energy that can be generated by the turbines. Wind speed standard deviation is also an important factor as it can affect the stability of wind energy generation.

In comparison, the average wind speed in other wind farms in Brazil can vary from about 6 m/s to 10 m/s, depending on the geographical location and climatic characteristics of the region. In other countries, values can be even higher, reaching around 12 m/s in some areas with strong and constant winds.

Wind speed standard deviation can also vary widely between different wind farms, depending on local conditions. In general, wind speed standard deviation in wind farms is higher in regions with more turbulent and irregular winds, which can affect energy generation efficiency.

It is important to note that average wind speed and wind speed standard deviation values can be influenced by various factors, including local topography, climatic conditions, altitude, and wind turbine density in the wind farm. Therefore, detailed feasibility studies and data analysis are necessary to evaluate the potential for energy generation at each specific location.

Regarding the cost of electricity generation, the Alto do Sertão Complex has a cost of R$ 150/MWh, which is lower than other projects, whose costs range from R$ 180/MWh to R$ 220/MWh. However, it is important to note that the cost of electricity generation can vary according to various factors, such as wind speed, equipment cost, and financing cost.

Finally, regarding the average CAPEX cost, which is the initial investment for the construction of the project, the Alto do Sertão Complex has a value of R$ 4.5 billion, which is higher than other projects whose costs range from R$ 500 million to R$ 1.5 billion. This value can be explained by the higher installed capacity of the complex and investments in infrastructure, such as transmission lines and substations, carried out in the region in recent years.

Lastly, a broader quantitative factor related to the average price of wind energy practiced in the last auctions held (2017 to 2021) is compared with other sources in Table 5, including hydro, solar, biomass, natural gas, coal, and petroleum.

According to Table 5, wind energy generation is the cheapest when compared to other sources in the Brazilian energy matrix. Therefore, in addition to the issues related to competitiveness analysis discussed in this thesis, under various aspects, the lower price of energy input may lead to more complex discussions, such as climate change caused by CO_2 emissions.

Table 4: Comparison between the Alto do Sertão Wind Complex and other wind farms in the Northeast region of Brazil

Complexo	Potencial de Geração	Velocidade média dos ventos	Custo de Geração	CAPEX
Alto do Sertão	1,5 GW	8.5 m/s	R$ 150/MWh	R$ 4,5 billion
Asa Branca	292 MW	8.0 m/s	R$ 180/MWh	R$ 1,2 billion
Santo Agostinho	283 MW	7.5 m/s	R$ 220/MWh	R$ 1,5 billion
Água Doce	93 MW	8.0 m/s	R$ 220/MWh	R$ 500 millions

Source: EPE (2022)

Table 5: Comparison between the average prices of different energy sources in the auctions from 2017 to 2021 in Brazil

Energy source	Average auction price (R$) (2017-2021)
Water	R$ 197.96-R$ 276.00
Wind	R$ 98.62-R$ 144.51
Solar	R$ 118.07-R$ 220.00
Biomass	R$ 204.00-R$ 299.00
Natural Gas	R$ 208.00-R$ 409.00
Coal	R$ 194.00-R$ 209.00
Oil	R$ 298.00

Source: ANEEL (2022)

In general, Brazilian wind farms have very low CO_2 emissions, as wind energy generation does not emit carbon dioxide during the production process of electricity. However, it is important to highlight that the construction and installation of wind farms involve greenhouse gas emissions, especially in the manufacture of wind equipment and the construction of roads and transmission lines. These emissions, however, are considerably lower than those generated by energy generation sources that use fossil fuels.

5. CONCLUSION

According to the results obtained in this work and its approaches regarding the subject, it is observed that it fits into a context of growing worldwide concern about climate change and the search for sustainable development. In Brazil, this concern has been observed through the government's purpose of diversifying the Brazilian energy matrix, with the essential guideline for expanding the generating park prioritizing the participation of renewable energy sources. In this circumstance, there has been a significant increase in wind energy contracting in the country in recent years, as wind energy, besides being a clean and renewable source, presents significant characteristics that stimulate its contracting in Brazil, such as its complementarity with hydropower and photovoltaic solar, great potentials still underexplored in the country in the form of hybrid plants and high competitiveness compared to other renewable and non-renewable sources in the national market.

Thus, the study on the expansion of wind energy and its consequences for development and competitiveness in the semi-arid region of Bahia is placed in an environment of broader analysis that contemplates the political-institutional, socioeconomic, and structural conditioning responsible for the insertion of this source in the Brazilian electrical matrix, the role of different public and private actors that participate in the process of production and management of spaces, as well as their knowledge from the articulation of different measures of the process, taking into account the capacity of this sector to develop possibilities for socio-economic growth and insertion in the spaces of the municipalities of Caetité, Guanambi, Igaporã, and Pindaí, where the Alto Sertão wind complex is located.

This source of energy has had significant expansion in the last 20 years and already demonstrates a relevant reality both for developed and developing countries. The total installed capacity on the planet reached 845,000 GW at the end of 2021, with an increasing estimate until the end of 2022. Currently, Asia leads as the driving region for wind development, and China stands out in production and installed capacity.

Its expansion on the international scene is due to significant investments in research and development of new technologies for the wind energy industry, as well as the need to invest in sources seeking to reduce greenhouse gas emissions. With regard to socio-political aspects, it is observed that PROINFA was very important and decisive for the expansion of wind energy in Brazil, mainly after the insertion of energy auctions. The development of the sector caused the demand for materials and equipment from the wind industry, in the absence or scarcity of national manufacturers of equipment of this type in the country. Thus, this led the Brazilian State, through financing and investment policies, to encourage the installation of productive units of materials and equipment of the wind industry, such as wind turbines, towers, and blades in the national territory, determining the nationalization of these equipments. Therefore, the Northeast region stands out as all wind components are being assembled in the industrial hubs of the States of Pernambuco (Suape), Ceará (Pecém), and Bahia (Camaçari). This certifies that wind activity provides possibilities for productive association and collaborates both to expand the supply of wind energy in the country, as well as to boost the economic development of the region in the sense of job creation, income, and industrial growth.

It is understood that wind energy plays a significant role in expanding the country's energy matrix, mainly because it is clean and does not emit greenhouse gases, its possibility of complementarity with existing hydro and photovoltaic solar sources, and, nevertheless, by the expectation that arises to enrich the level of socioeconomic development in the Northeast region, as it is where the highest potential for wind energy production and electricity generation is found. Therefore, it can be said that the expansion of wind energy sources in the Northeast is changing the reality of these spaces, as:

- Operational flexibility: Pumped hydroelectric storage can be quickly activated to meet energy demand during peak periods, providing a reliable and flexible source of energy.
- High efficiency: The conversion efficiency of electrical energy to hydraulic potential energy and vice versa is high, reaching up to 80-85%.
- Large-scale storage: The technology allows for the storage of large amounts of wind energy in a short period of time.
- Compatibility with wind energy characteristics: Pumped hydroelectric storage is particularly suitable for storing wind energy, as wind production tends to be intermittent and varies over time.
- Contribution to electric system stability: Pumped hydroelectric storage can help stabilize the electric system by providing energy when needed and absorbing excess energy when demand is low.

In Bahia, where there is great potential for wind power generation, pumped hydro storage can be an interesting solution to help address the challenges related to the variability of wind energy production and improve the reliability of the electrical system.

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