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Barriers and perspectives for the expansion of wind farms in BRAZIL

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Abstract. The use of renewable sources for electricity generation has as main benefits the preservation of natural resources, security in the distribution of electricity and the reduction of greenhouse gas emissions. Research has shown that the participation of wind in the Brazilian electrical matrix has increased considerably in recent years, despite the existence of multiple barriers to the implementation of wind farms in the country. This study aims to identify and evaluate the current barriers to the expansion of wind farms in Brazil, suggesting ways to overcome them. Based on a systematic review of the literature, the evaluation of the complexity level and associated risk, the barriers were categorized into seven groups. The results indicated that four barriers are more relevant in relation to the expansion of wind farms in Brazil: unstable macroeconomic environment, government policy uncertainty, system constraints, and lack of infrastructure. On this basis, apart from the recent growth of wind energy in Brazil, actions must be taken to mitigate the identified barriers, as the most complex barriers need government intervention to be removed or mitigated, since the electricity market is highly regulated and complex in Brazil. Further research is needed to rank and analyze more deeply the barriers that were identified here, through interviews with stakeholders and visits to wind farms.

1 Introduction

After the Energy Crisis of 2001, Brazil has been developing public policies to increase the share of renewable energy in the national electricity matrix. The energy produced by wind is renewable, does not pollute, has low environmental impact, and has contributed for Brazil to meet the goals assumed in the Paris Agreement. This agreement aimed to reduce greenhouse gas emissions in the context of sustainable development. In the last two years, however, due to an apparent lack of commitment by the federal government, these goals have been left aside, at least in part [1,2]. Martins and Pereira [3] emphasized the need for political commitment related to sustainability.

As explained by Letcher [4], wind energy has the advantages of providing electricity without producing carbon dioxide or particles in the atmosphere; of providing national security, as it reduces dependence on foreign sources of fuel that are subject to price variation or import embargoes; and of allowing diversification of the domestic electrical matrix.

Silva, Alves and Ramalho [5] pointed out that the "zero" cost of its fuel (wind), low maintenance cost, and reduced time required for installation and operation have been solidifying the space of wind energy among other energy sources. Letcher [4] highlighted that in the last decade the cost of wind turbines has decreased significantly as a result of design improvements and mass production, making wind energy production competitive if compared to other energy sources. Kaygusuz [6] reported that the costs of onshore and offshore wind energy have decreased sharply in recent years through mass deployment and due to the use of larger components and more sophisticated control systems for wind turbines.

According to Energy Research Institute [7], the share of renewable energy in the Brazilian electrical matrix increased from 41.3% in 2015 to 46.2% in 2019. According to the Brazilian Association of Wind Energy [8], the installed wind capacity increased almost twice between 2015 and 2019, from 8,723 MW to 15,449 MW, which represents an average growth rate of 15.36% per year.

At present, all wind energy in Brazil comes from onshore farms. According to Pereira [9], the national onshore wind potential, revalidated for 100-meter towers, is 880 GW. Offshore wind potential studies by Energy Research Institute [10] indicated that for 100-meter towers, Brazil's offshore potential is 697 GW at sites up to 50 meters deep. Brazil's wind potential (onshore and offshore) is much higher than the installed capacity in the country by December 2019 (15.5 GW). Thus, one can infer that wind power generation has great potential for growth in Brazil in the coming years.

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Table 1. List of keywords used in the search platforms.

#	Keywords
1	Renewable energy
2	(renewable energy) and (wind energy)
3	(renewable energy) and (wind energy) and (onshore or offshore)
4	(renewable energy) and (wind energy) and (onshore or offshore) and (expansion or increase or growth)
5	(renewable energy) and (wind energy) and (onshore or offshore) and (expansion or increase or growth) and (challenge or barrier or obstacle or limitation)
6	(renewable energy) and (wind energy) and (onshore or offshore) and (expansion or increase or growth) and (challenge or barrier or obstacle or limitation) and Brazil

Table 2. Criteria for article selection.

#	Criteria
1	Relevance of the contents in relation to the theme addressed in this work
2	English and Portuguese language papers
3	Research or literature review articles
4	Theses and dissertations excluded
5	Ordering of the 100 most relevant articles, using the relevance criterion

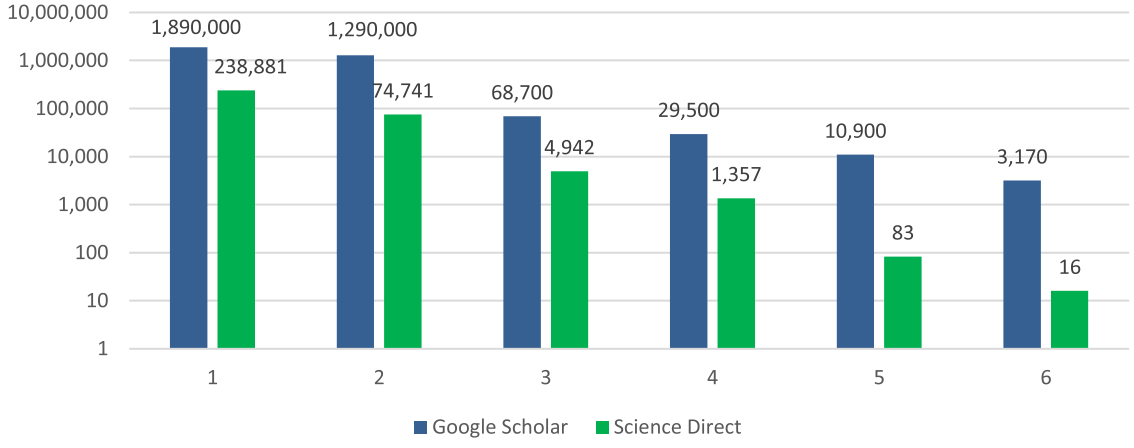

Fig. 1. Number of publications for each keyword combination. Source: Google Scholar and Science Direct. Data collected on 01/23/2021.

The expansion of wind energy in the world has encountered some obstacles. Painuly (2001) [11] categorized the barriers to the growth of renewable energy into seven categories: market failure/imperfection; market distortions; economic and financial; institutional; technical; social, cultural and behavioral; other barriers.

The objective of this paper is to evaluate the barriers to the desired expansion of wind farms, specifically in Brazil, and to point out ways to overcome them. First, a systematic literature review was conducted retrieving studies from two different databases: Science Direct and Google Scholar. Then, the identified barriers were classified according to the associated risk: "country risk" or wind sector risk. After that, the complexity level of the barrier was evaluated. Finally, measures were suggested to mitigate the identified barriers.

This paper is organized into five sections: besides this Introduction, Section 2 discusses the Method; Section 3 presents the Systematic Literature Review, Section 4 presents the Discussion and Section 5, the Conclusion.

2 Method

The study was conducted through a systematic literature review to identify the most important barriers affecting the expansion of wind energy in Brazil. These barriers were then classified into two parts: Brazil when referring to the Brazilian economic context (Brazil risk), and sector when referring to the wind industry. Additionally, the level of complexity of the barrier was evaluated: low when it can be removed or decreased in the short term (1–3 years),

Table 3. Barriers to renewable energy expansion.

Barrier Category	Barriers
1. Market Failure / Imperfection	Highly controlled energy sector
	Lack of information and knowledge
	Restricted access to technology
	Lack of competition
	High transaction costs
	Lack of market infrastructure
	High investment requirements
2. Market Distortions	Favoring conventional energy (subsidies) or lack of subsidies for renewable energy.
	Taxes on renewable energy
	Non-accountability of externalities
	Barriers to Trade
3. Economic and Financial	Not economically feasible
	High discount rates
	High payback period
	Small market size
	High cost of capital
	Lack of access to capital
	Lack of access to consumer credit
	High initial capital cost for investors
4. Institutional	Lack of financial institutions to finance renewable energy
	Lack of institutions / mechanisms to disseminate information
	Lack of legal/regulatory framework
	Problems in the realization of financial incentives
	Unstable macroeconomic environment
	Lack of stakeholder involvement in decision making
	Clash of interests
	Lack of Research and Development culture
	Lack of private sector participation
	Lack of professional institutions
	Lack of political desire by the elected government
5. Technical	Lack of standards, codes and certifications
	Lack of qualified personnel / training facilities
	Lack of Operation & Maintenance facilities
	Lack of entrepreneurs
	System restrictions
	Unreliable product
6. Social, Cultural, and Behavioral	Lack of consumer acceptance of the product
	Lack of social acceptance for some renewable energies
	Uncertainty of government policies, such as incentives
7. Other Barriers	Environment
	High-risk perception of renewable energies
	Lack of infrastructure

Source: Painuly [11].

medium (5–10 years) and long (over 10 years). The analysis also allowed the suggestion of measures to mitigate these barriers.

The criteria used in the systematic literature review, aiming at the identification and selection of studies to compose the analysis, were:

- Elaboration of the guiding question: What are the most important barriers to the expansion of wind farms in Brazil?
- Selection of electronic search platforms for academic journals: The databases used were Science Direct and Google Scholar.
- Definition of descriptors and combinations, as shown in Table 1.
- Primary selection of the articles found according to the criteria presented in Table 2;
- Secondary selection of papers after reading the full article;
- Quantitative analysis of the collected data;
- Qualitative analysis with identification of the papers that answered the guiding question.

Figure 1 displays a comparative graph, in logarithmic scale, of the search for scientific publications using the Science Direct and Google Scholar databases, as well as the result of the combinations shown in Table 2.

After searching the database and using the criteria listed in Table 2, 16 Science Direct articles and 50 Google Scholar articles were shortlisted. After reading the title and abstract, 8 Science Direct and 10 Google Scholar articles were selected. At the end of the full-text reading, 8 studies were excluded for not answering the guiding question and 10 papers were selected as pertinent to compose this systematic review. Such a small number of papers is justified by the very specific focus of the research, i.e., the objective of evaluating the barriers to the desired expansion of wind farms specifically in one country, Brazil, and to point out ways to overcome them.

This research is similar to the one by Diógenes, Claro, Rodrigues e Loureiro [12], however these authors published on the topic of barriers from an empirical perspective, while in this paper a systematic literature review was the main source of data and information for the analysis. We hope to add validity to the analysis presented here by using recent peer-reviewed papers.

Based on this systematic review, the barriers to wind energy were analyzed and identified. In the discussion section, solutions were sought in the literature, focusing on examples from other countries that could help mitigate the barriers that were found.

3 Systematic literature review

This section is organized into two subsections: Section 3.1 shows the main categories of barriers to the growth of renewable energy; Section 3.2 presents the results of the systematic literature review on barriers to wind energy, focusing on meeting the research objectives.

3.1 Categories of barriers to renewable energy expansion

Table 3 categorizes the main barriers to renewable energy expansion, according to the study of Painuly (2001) [11]. It is reasonable to assume that these categories apply specifically to wind energy. It becomes interesting, therefore, to verify which barriers are more significant and important for the expansion of this type of energy in Brazil.

3.2 Barriers to wind farm expansion in brazil

Table 4 shows an analytical summary of the barriers identified for the expansion of wind farms in Brazil, according to the systematic literature review, using the aforementioned classification by Painuly (2001) [11].

The authors identified a total of 13 most important barriers to the expansion of wind farms in Brazil. These barriers are listed on the Table 5. These will be discussed next.

3.2.1 Market failure/imperfection

Two topics related to market failure/imperfection were identified: lack of information and knowledge and high transaction costs.

Diógenes et al. [12] mentioned the absence of recent, detailed and accurate wind data as a barrier to the growth of wind energy in Brazil. Martins and Pereira [3] mentioned the Atlas of the Brazilian Wind Potential of 2001 [21] and indicated that the data should be revised according to the technological advances of wind turbines and also highlights the lack of knowledge regarding the Brazilian offshore wind potential. The authors emphasize that without reliable wind information, potential investors tend to avoid the risk related to the development of wind projects in Brazil. It can be noticed that there is a 15-year gap in the updating of the Brazilian onshore wind potential. This mapping should be updated in shorter periods of time, as this is the first step to attract the attention of investors to this type of enterprise.

As for high transaction costs, Diógenes et al. [12] mentioned the time to connect to the transmission grid as a limiting factor for the growth of wind energy in Brazil. Köberle et al. [18] revealed that due to interconnection problems, delays occur for wind projects in Brazil. Because of this, the sensitivity analysis of their study assumes a conservative fixed parameter of three years for delays in wind power plants, totaling an average of 6 years for the feasibility of building wind farms. The high transaction costs discourage investment in this type of enterprise in Brazil, as investors end up looking for other alternatives (other countries, for example) that allow them to anticipate the time of return on invested capital.

3.2.2 Market distortions

In relation to market distortions, two factors were identified: favoring conventional energy (subsidies) and not considering externalities.

Table 4. Summary of the systematic literature review barriers.

References	**Question;** What are the most important barriers to the expansion of wind farms in Brazil?	Barriers
[13]	Government subsidies and exclusion of environmental costs.	– Favoring Conventional Energy (Subsidies) – No Consideration of Externalities
[3]	Subsidies for fossil fuel consumption; technological difficulties; unreliable information; high initial capital costs; market volatility and institutional aspects (financing risks, little credibility and regulatory stability). Lack of political commitment by elected government.	– Favoring Conventional Energy (Subsidies) – System Restrictions – Lack of Infrastructure – Lack of Information and Knowledge – High Capital Costs – Unstable Macroeconomic Environment – Uncertainty of Government Policies
[14]	Local social conflicts.	– Lack of Social Acceptance
[15]	Exclusion of externalities.	– No Consideration of Externalities
[16]	High initial cost and transmission infrastructure.	– High Capital Cost – System Restrictions – Lack of Infrastructure
[17]	Opposition from local community.	– Lack of Social Acceptance
[18]	Interconnection problems with the national electrical system have caused delays to the start of operation of wind farms (cost)	– System Restrictions – Lack of Infrastructure – High Transaction Cost
[19]	Inadequate transmission infrastructure, lack of clear regulations to obtain licenses, unattractive financial loans and unstable macroeconomic environment.	– System Restrictions – Lack of Infrastructure – Lack of Legal/Regulatory Framework – Unstable Macroeconomic Environment
[20]	Congestion of transmission lines.	– System Restrictions – Lack of Infrastructure
[12]	Lack of recent, detailed and accurate wind data; subsidies to conventional energy sources; weak grid infrastructure; high upfront capital costs; inadequately designed support instruments and limited access to wind farms.	– Lack of Information and Knowledge – High Transaction Costs – Favoring conventional energy (subsidies) – High Capital Cost – System Restrictions – Lack of Infrastructure – Unstable Macroeconomic Environment – Uncertainty of Governmental Policies

The Fossil Fuel Consumption Account for Isolated Systems (CCC-Isol) was created with the objective of subsidizing the annual costs of electricity generation in areas not yet connected to the National Interconnected System (Law n. 5.899, 1973). According to the National Electric System Operator [22], the supply of these Isolated Systems is predominantly based on thermal plants that use diesel oil as fuel and are characterized by the high number of small generating units and the great difficulty of supply logistics. In 2020, the budgeted subsidies for CCC, approved by the National Agency of Electric Energy [23] through Resolution No. 2,664/2019 were of R$ 7.5 billion.

Martins and Pereira [3] mentioned that the government subsidy policy for conventional fuels in remote areas is a barrier to the growth of renewable energy, such as wind power, in Brazil. Silva, Oliveira and Severino [13] indicated that renewable energy is at a disadvantage compared to fossil fuels because of government subsidies and suggest that new policies should be created to encourage the use of renewable energy to serve isolated communities, especially in the northern region of Brazil where there are currently high levels of poverty and social underdevelopment. Diógenes et al. [12] pointed out that the subsidy for conventional power generation allows this form of power generation to dominate the market because of significantly lower tariffs. Therefore, renewable energies (such as wind) are unable to compete in this scenario unless these advantages are eliminated.

As for not considering externalities, Jong, Kiperstok and Torres [15] estimated that the Belo Monte dam (in northern Pará) will produce approximately 1 million tons of carbon dioxide equivalent emissions per year during the first 10 years of operation. Because of the construction of the Belo Monte dam, many people had to be relocated.

Table 5. Summary of the Main Barriers to the Expansion of Wind Energy in Brazil.

Type of Barrier	Specific Barrier
1. Market Failure / Imperfection	Lack of information and knowledge
	High transaction costs
2. Market Distortions	Favoring conventional energy (subsidies)
	Non-accountability of externalities
3. Economic and Financial	High initial capital cost
	Unstable macroeconomic environment
4. Institutional	Lack of legal regulatory framework
	Lack of research and development culture
	Lack of government interest and/or commitment
5. Technical	System restrictions
6. Social, Cultural and Behavioral	Lack of social acceptance
7. Other Barriers	Uncertainty of government policies
	Lack of infrastructure

Another important factor are the costs caused by losses during transmission of energy from the northern region to other regions of the country. The authors also point out that the social and environmental costs will have significant negative impacts in the coming years and have not been measured nor included in the economic feasibility calculations.

Silva et al. [13] mentioned that one of the barriers to the dissemination of renewable energy in Brazil is the high cost when compared to conventional sources, but if the way of evaluating sources of energy generation took into account environmental costs (externalities) and the advantages of renewable energy, this scenario would change.

Jong et al. [15] concluded that considering all externalities (transmission system, social and environmental) with a discount rate of 10%, the evaluated wind farms would be significantly more competitive than hydropower plants and have the lowest LCOE among all case studies that were analyzed. The LCOE (Leveled Cost of Energy) of wind power is less than half that of coal-fired power and at least 40% cheaper than nuclear power.

The studies show that cost calculations for new ventures for electricity generation in Brazil generally do not take into account social and environmental externalities and energy transmission costs. Even hydroelectric plants that have a lower unit cost of energy, due to their scale, have a large environmental impact during the construction, commissioning and operation of the enterprise.

3.2.3 Economic and financial

The high initial capital cost for investors was the most indicated barrier regarding the economic and financial aspect. The works of Martins and Pereira [3], Diógenes et al. [12] and Jong, Kiperstok, Sánchez, Dargaville and Torres [16] mentioned the high cost of capital as a barrier to the expansion of wind energy in Brazil. Martins and Pereira [3] indicated that this constitutes a market distortion that discriminates against renewable energy, in addition to the subsidies given to other conventional power generation sources. 13 argued that wind farm developers need substantial financial sources to implement wind farms, and often these costs need to be financed by the wind farm owners themselves, since they cannot get loans at attractive rates.

It is worth noting that financing through the National Development Bank (BNDES) has been essential for the growth of the national wind industry. Martins and Pereira [3] mentioned that Brazil has developed an industrial model of high quality and competence to produce wind turbines from 250W up to 3MW, aimed for the domestic and international markets. In 2018, disbursement for energy projects totaled more than R$15 billion (National Development Bank) [BNDES] [24]. Maceron and Quintairos [25] emphasized that BNDES' credit lines are fundamental for investments related to the expansion of the wind power segment in Brazil.

Scale production of wind turbine components and BNDES financing for national components may allow the reduction of the initial cost for the construction of wind farms. Additionally, as described by Herrera, Díaz and Cosenz [20], with the recovery of the Brazilian economy (GDP growth), the Brazilian wind industry should continue to expand rapidly, driven by low-cost financial loans and high demand for energy.

3.2.4 Institutional

Four barriers to the growth of wind energy were identified from an institutional point of view: unstable macroeconomic environment, lack of legal regulatory framework, lack of research and development (R&D) culture, and lack of governmental interest and/or commitment.

The study by Diógenes, Claro and Rodrigues [19] reported that the crises that have affected Brazil in recent years have been affecting the implementation of wind energy through four aspects: demand for new wind farms, availability of financing, unstable wind turbine prices, and outdated power transmission infrastructure reforms. The

authors also mention that the economic crisis resulted in reduced industrial activity in the country, which consequently reduced the demand for electricity and the need to develop more wind farms. Herrera et al. [20] pointed out that Brazil faces a reduction in auctions in the short term, which poses a major challenge for wind energy investments. However, there will be new asynchronies when the economy recovers again. Diógenes et al. [12] mentioned the high inflation rate and unstable currency as macroeconomic weaknesses in Brazil.

In Brazil, the development of wind energy began with the search for alternatives for the expansion of generation after the energy crisis of 2001. From 2015 to the present day, Brazil has been facing several economic crises: Fiscal Crisis (2015), Crisis of the Impeachment of President Dilma Rousseff (2016), Coronavirus Crisis (2020), among others. The crises resulted in the loss of value of the Real (R$) against other currencies. As part of the components used in wind farms come from abroad, the national wind industry is directly affected. In addition, most of the owners of the Brazilian wind farms are foreign companies, so a fraction of the profit generated by the enterprise must return to the holding companies and be distributed to the shareholders in the form of dividends. The exchange rate variation has resulted in the loss of a significant part of the return on investment. Finally, as described by Diógenes et al. [19], national economic crises have reduced the government's ability to offer competitive interest rates to wind farm developers.

Regarding the lack of regulatory legal framework, Diógenes et al. [19] mentioned that regulations for obtaining land, environmental, and archaeological permits represent a barrier: land regularization is a major bottleneck in the selection of sites for wind farm implementation, and in the process for issuing environmental permits. Current national legislation categorizes wind farms at the highest level of archaeological impact because of the foundation required for the building of the towers.

The impacts in time and cost due to the obtaining of licenses are not exclusive to the wind sector in Brazil. The study by Gomide and Pereira [26] empirically assessed whether licensing negatively interfered with the execution of six projects: two power generation projects, two transportation projects, and two urban mobility projects. With the exception of the BR-163 project, in all other projects environmental permits had an impact (small or high) on the delay of construction. The reasons were several: poor quality of the technical studies, delay by the developer in sending the documentation, delay in the issuance of licenses, excessive bureaucratic requirements, three-phase system of licenses (municipal, state, and federal), among other reasons. Diógenes et al. [19] mentioned that in the process building wind farms, especially in the case of environmental and archaeological licensing, the inspections regarding public licensing need to be carried out properly, avoiding unnecessary interruptions and, consequently, negatively affecting the confidence of the wind developer.

As for the lack of research and development culture, the study by Diógenes et al. [19] identified that the country lacks technology centers designed specifically to promote research and development (R&D) development. Martins and Pereira [3] mentioned that the development of domestic wind technology requires large upfront investment both to build infrastructure and to develop essential technological knowledge and human resources.

At this point, it is worth noting that on August 22, 2018, through its corporate website, Petrobras reported that it was developing the first offshore wind energy pilot project in Brazil [27]. The company stressed that, in line with the Business and Management Plan (PNG) strategy, it would install Brazil's first offshore wind power plant by 2022, at the Guamaré hub in Rio Grande do Norte. However, in 2020, Petrobras notified IBAMA (the agency responsible for issuing the environmental license) of the suspension of the pilot project. This pilot plant would allow promoting research and development (R&D) of the offshore wind industry in the country. This decision was, without a doubt, a great loss for the advancement of research and development in the national wind industry.

As for the lack of government interest and/or commitment in the expansion of sustainable energy generation, even though the significant growth in wind power generation in recent years has already been mentioned, the federal government has shown less commitment to meeting the Paris agreement targets on carbon emissions [1,2]. This represents a potential threat [3].

3.2.5 Technical

With regard to technical feasibility, most of the studies that were analyzed indicate that system constraints are the main barrier to the expansion of wind energy in the country.

Martins and Pereira [3] mentioned the technological difficulties in connecting the intermittent supply of wind energy to the distribution grid. The study by Jong et al. [16] estimated that by the end of 2020, the energy used in the Northeast could come exclusively from renewable sources: wind (55%), hydro (40%) and biomass (5%), thus reducing the need for fossil fuel electricity generation. Furthermore, assuming that most of the contracted wind farms would be commissioned on schedule, wind power penetration would exceed 50% in the Northeast subsystem of Brazil and the surplus could be exported to other states. However, in order for this to be possible, the transmission infrastructure would need to be upgraded to allow for this balancing. Köberle et al. [18] concluded that interconnection problems with the national electricity system have led to delays for the start of operation of wind farms, even in smaller projects in Brazil.

Diógenes et al. [19] concluded that the weakness in terms of infrastructure for high-voltage power transmission is a constraint affecting several countries – including Brazil – and compromises the integration of wind power into the grid. This problem inhibits the implementation of new wind farms, or even restricts existing ones, leading to large revenue losses. Simulations performed by Herrera et al. [20] led the authors to conclude that the growth of wind farms should be synchronized with the evolution of transmission infrastructure in the Northeast region of Brazil to avoid significant congestion and high electricity prices. Diógenes

et al. [12] concluded that even if the economy entered a period of rapid recovery and auctions restart with the appropriate frequency, auctions for new wind farms in the states of Rio Grande do Norte and Bahia would not be possible due to the lack of capacity of the power transmission networks.

Bayer, Berthold and Freitas [28] mentioned that Brazil has chosen to develop wind systems interconnected to the national main grid (*Sistema Interligado Nacional*) with the aim of complementing hydrology (precipitation) with wind regimes. However, Diógenes et al. [19] suggested an alternative: the liberalization of the energy distribution market (free trade), where consumers can elect from which supplier, they wish to purchase energy. This would allow for the loss of monopoly of distributors and the expansion of renewable energy such as wind energy. Consumers could choose to purchase energy with a green seal, for example. Wind energy could also benefit from its modular characteristic (wind farms can be installed near consumer centers), allowing the reduction of losses and transmission costs. Based on this context, it can be inferred that public policies that allow the sale of energy generated from wind power, without having to go through the National Interconnected System, will allow the expansion of wind power in Brazil.

3.2.6 Social, cultural and behavioral

The lack of social acceptance was a fact observed by a few authors as a barrier to the growth of wind energy in Brazil. The construction of wind farms has as positive aspects the creation of new jobs, generation of investments in disadvantaged areas, and benefits to the owners of the land where the park will be installed, among others.

In contrast, as described by Silva, Rosa, Freitas and Pereira [14], the implementation of wind farms can lead to local conflicts due to the misappropriation of collective use land areas and the co-optation of local government entities. The authors indicate that the implementation of some parks is not carried out with the active participation of the community and that local social conflicts can occur such as those observed in Caeté (Bahia), Trairi (Ceará) and Galinhos (Rio Grande do Norte).

The study by Brannstrom et al. [17] was conducted in two communities in Ceará. In Xavier, the wind farm project has created roadblocks that do not allow Xavier residents access to the Amarelas district, making it difficult for them to access public services such as transportation to school, sanitation, garbage collection, and access to healthcare. Xavier residents have been suffering from food deficits because they cannot have access to local lakes, in order to fish. Additionally, residents have reported discomfort with the noise of the turbines and fear of accidents with the turbines. In Aracaú, residents reported difficulty in accessing mangroves because of the removal of vegetation associated with the wind farm development; prohibited access to mangrove areas for subsistence activities such as fishing; and the false promises of economic benefits to the region, such as a future improvement in quality of life, jobs, and local benefits.

As described by Brannstrom et al. [17], wind energy must be adjusted to the physical and human environments to avoid territorial conflicts with traditional resource users, who can spread a highly negative view of wind energy generation. Silva et al. [14] indicated that the efforts that have been made to promote community acceptance have been insufficient. The authors pointed out that the association of benefits, such as increased income or the creation of local jobs, can help promote acceptance and the expansion of the use of wind technology. A compensation plan for the damage caused by the installation of the venture should be considered, in order to minimize the impact caused to the environment and to the local population.

3.2.7 Other barriers

Regarding other barriers to the expansion of wind energy in Brazil, this study identified the uncertainty of government policies and the lack of infrastructure as relevant aspects.

Martins and Pereira [3] highlighted as an important issue for the expansion of wind energy in the country the promotion of energy auctions on an annual basis with bids for installed capacity of at least 1GW/year with a minimum award term of 10 years to encourage investments in this area. Diógenes et al. [19] mentioned that despite the recognition that the current auction system is the main driver of wind energy expansion in the country, the uncertainty in the occurrence of auctions negatively influences the interest of wind developers to continue investing in this industry. The authors also pointed out that with the constant cancellation of auctions, the government's credibility with wind farm developers has significantly decreased.

As for the lack of infrastructure, it has already been mentioned how the deficiency in the transmission system can represent a barrier to the growth of wind energy in Brazil. Another no less relevant aspect related to the lack of infrastructure in Brazil refers to the precariousness roads, especially in the northeastern region of Brazil that currently holds the largest amount of wind farms in the country. Diógenes et al. [19] mentioned that the main problem faced in the logistics of wind turbines is the fact that the roads in some regions are not dual carriageways, so it is necessary to request the public department to block traffic, a slow and bureaucratic process. Brannstrom et al. [17] warned that the construction of access roads for wind farms has caused the disappearance of lakes and that the equipment has removed dune vegetation in Ceará.

As demonstrated by Lako, Koyama, Simbolotti and Tosato [29], the rotor diameter and capacity of wind turbines have increased considerably in recent years. Thus, it is important that the condition of the country's roads, bridges, and tunnels keep up with this development so that they are not a limiting factor for the development of wind farms.

4 Discussion

In this section, the barriers were categorized into two groups: Brazil (country-related) and wind sector (industry-related). The level of complexity of the barrier was also assessed (a measure of "difficulty to overcome" the barrier),

Table 6. Summary of the main barriers to the expansion of wind energy in Brazil.

Specific Barrier	Solution	Classification	Complexity
Lack of information and knowledge	Development of a private database.	Wind Sector	Low
High transaction costs	Government should invest in upgrading and building efficient power transmission system and Coordination between new wind farms auctions and new transmission lines construction.	Brazil	High
Favoring conventional energy (subsidies)	Eliminate subsidies to conventional energy sources	Brazil	Medium
Non-accountability of externalities	Increase subsides to Renewable Energy to encourage investments and stimulate growth.	Brazil	Medium
High initial capital cost	Provide Investment in R&D for wind energy and get financing from green funds (lower interest rates)	Wind Sector	Medium
Unstable macroeconomic environment	Monitor the exchange rate variation and choose the best time to buy foreign devices.	Brazil	High
Lack of legal regulatory framework	Reduce Bureaucracy in the licensing process in Brazil −should be an agile and simple procedure.	Brazil	High
Lack of research and development culture	Increase investment in R&D and partnerships with foreign manufacturers to improve the adaptation of technology to local winds.	Wind Sector	Medium
Lack of government interest and/or commitment	Press the government to reinstate auctions on a regular basis and to improve transmission infrastructure auctions.	Brazil	High
System restrictions	Similar to high transaction costs (see above).	Brazil	High
Lack of social acceptance	Creation of a voluntary code of conduct and investment in local social projects.	Wind Sector	Low
Uncertainty of government policies	Similar to lack of government interest and/or commitment (see above)	Brazil	High
Lack of infrastructure	Similar to high transaction costs (see above).	Brazil	High

based on the studies that were analyzed. Possible ways to eliminate or reduce the more complex barriers are suggested. Table 6 displays a summary of the main barriers to the expansion of wind energy in Brazil.

Two barriers were classified as low complexity. Regarding the lack of information and knowledge, this study identified that there was a 15-year gap in updating the Brazilian Wind Atlas. The suggestion is that wind farm developers could install anemometric towers in several locations with wind potential and thus create a private database with wind characteristics in regions with potential to receive wind farms. An industrial wind cluster with interested companies could be developed in order to reduce the risks and costs of this option. In relation to lack of social acceptance, it could be created a voluntary code of conduct driven by the Brazilian Association of Wind Energy. This code would define examples of good practices to guide the wind farm developers, for example investment in local social projects.

Four barriers were identified as being of medium complexity. As for favoring conventional energy (subsidies), the Brazilian government should design an effective subsidy elimination reform to non-renewable energy. Additionally, part of the financial resources from the Fossil Fuel Consumption Account for Isolated Systems (CCC-Isol) should be invested in research and development in order to develop cheaper small wind turbines that could be used in the remote areas from Brazil and eliminate the need of using inefficient and polluting power generation systems.

Regarding externalities, in terms of discount rates, wind power could become significantly more competitive than other power generation sources in Brazil [15]. The government, through wind energy subsidies could make this adjustment. Increase subsidies for Renewable Energy would encourage investment and stimulate renewable energy growth in the country.

As for the high capital cost and lack of research and development (R&D), the studies have shown that an increase in the investment in R&D has allowed for a reduction in the cost of components used in wind farms. Brazil has developed a strong national wind industry in recent years that should work together with universities and research centers in order to develop components that could be adapted to the regional wind conditions from Brazil. Additionally, it is very important to develop partnerships with other manufacturers that are interested in bringing the cutting-edge technology for the Brazilian territory. On the other hand, the developers of wind farms should look for international "green funding" entrepreneurs who are interested in investing in renewable projects in order to get attractive returns on investment – especially those funds that prioritize the ESG initiatives in their business.

Seven barriers were identified as of high complexity. The barriers system constraints, high transaction cost, and lack of infrastructure are interrelated. Most studies in the systematic review reported the difficulty in interconnecting the power generated at wind farms to the National Interconnected System. Most of the electricity loss happens during power transmission. So, the Brazilian government should invest in upgrading and building an efficient power transmission system (smart grids). This involves replacing obsolete lines, using more efficient power converters, as well as installing modern safety systems to act in case of network overloads. Furthermore, it is important that a coordination between new wind farms auctions and new transmission lines construction exist. In general, different companies are the winners of the project electricity generation and the transmission projects in the country. Due to the complexity of the construction of transmission lines, these projects usually present delays (due to environmental licenses), and end up impacting the projects.

As for the unstable macroeconomic environment, monitoring the exchange rate variation and choosing the best time to sign contracts with foreign wind turbine manufacturers would be a valid solution. However, the sequence of crises that the country has faced in the recent years has significantly increased inflation and affected the population and companies.

Regarding the lack of governmental interest and/or commitment and political uncertainties, pressing the government to reinstate auctions on a regular basis and to improve transmission infrastructure auctions could be a solution. For that, the developers should be well organized. The creation of an industrial wind energy cluster would be beneficial.

As for the lack of legal/regulatory framework, it is worth mentioning the importance of reducing bureaucracy in the licensing processes in Brazil, making the procedure more agile and simple. According to the World Bank survey, Brazil ranks 124 in terms of the ease of doing business, and in the item "obtaining a building permit" the country ranks 170 [30]. In Brazil, it is necessary to obtain state and federal licenses. A procedure that is cost-intensive and time consuming. It affects all kinds of new enterprises. The government should design agile and simple procedures for licensing, in order to attract new investments in the country. The benchmarks could be taken from the top five ranked countries by as divulged by the World Bank, providing a direction to define the new Brazilian Model. On the other hand, the developers of wind farms interested in the construction of an enterprise in Brazil could hire consulting firms and specialists to conduct the studies to obtain the license.

The relative distancing of the government from the commitment to meet the goals of the Paris Agreement has already been mentioned [1,2]. The election of governments committed to expanding the use of renewable energy is an important factor that has the potential to determine success or failure in achieving these goals.

5 Conclusion

This study showed that despite the relevant growth in wind power generation in the country after the 2001 energy crisis, there are a number of barriers that may limit the diffusion of wind power in Brazil in the coming years in a possible scenario of economic growth with scarcity of the hydro source.

Among the thirteen barriers identified, nine are related to Brazil's economic context and four are related to the wind sector. Therefore, public policies must be implemented to attract local and international investors to undertake the risks arising from this type of enterprise. The lack of interest of governments in meeting the Paris agreement targets, derived from the lack of social pressure and the election of uncommitted leaders, is a potentially important problem to be taken into account.

Based on the systematic literature review presented here, the barriers with high complexity (the most difficult to overcome) and most critical to the expansion of wind energy in Brazil are: unstable macroeconomic environment, government policy uncertainty, system constraints, and lack of infrastructure. It can be concluded that all the most important barriers to wind energy expansion in Brazil need government intervention to be removed or mitigated, since the electricity market is highly regulated and complex in the country. The first requires the development of a state with a strong and stable currency and less bureaucracy. The second requires long-term energy planning that is shielded from crises and changes in government. The third and fourth are capital intensive and require government authorization and investment to upgrade and expand the current transmission infrastructure.

Among the measures identified to circumvent the barriers found in this study, the most relevant are: development of long-term energy programs; the re-establishment of wind energy auctions on a regular

basis and investments not only in the optimization of generation, but also in the improvement of transmission and distribution infrastructure.

We hope that the identification of barriers and perspectives for the expansion of wind energy in Brazil will not only add knowledge to the literature on the topic, but also help decision makers to promote better public policies. Public policies such as tax incentives for wind power generation, after the 2001 electricity crisis, have been responsible for increasing investments in this type of energy in Brazil. Additionally, they allowed the diversification of the electrical matrix through a renewable source, with low carbon emissions and abundant in the country. Such policies have contributed to solving a national electrical problem, which is still ongoing, and are also enabling the country to achieve the commitments made in the Paris Agreement. The perspectives indicated here might contribute to provide further material to substantiate future governmental decisions.

Future studies could be empirical in nature and could rank and analyze more deeply the barriers that were identified here, through interviews with stakeholders (equipment manufacturers, non-governmental organizations, customers, companies that operate and maintain the equipment, among others) and visits to wind farms.

References

1. N. Pontes, *Ex-potência climática, Brasil se afasta cada vez mais do Acordo de Paris* (2020). Retrived May 17, 2021, from https://www.dw.com/pt-br/ex-pot%C3%AAncia-clim%C3%A1tica-brasil-se-afasta-cada-vez-mais-de-metas-do-acordo-de-paris/a-55910741?maca=pt-BR-Whatsapp%20Web-sharing
2. J.A. Thomas, *Analysis: with new law, Brazil seeks to boost payments for protecting nature* (2021). Retrived May 17, 2021, from https://www.reuters.com/article/us-brazil-environment-lawmaking-analysis-idUSKBN2BH2WQ
3. F.R. Martins, E.B. Pereira, Enhancing information for solar and wind energy technology deployment in Brazil, Energy Policy **39**, 4378–4390 (2011)
4. T.M. Letcher, *Wind energy engineering: A handbook for onshore and offshore wind turbines* (Academic Press, 2017)
5. S.S.F. da Silva, A.C. Alves, Â.M.C. Ramalho, Energia eólica e complementaridade energética: estratégia e desafio para o desenvolvimento sustentável na região nordeste do Brasil, Qualitas Rev. Eletr. **19**, 53–72 (2020)
6. K. Kaygusuz, Energy for sustainable development: a case of developing countries, Renew. Sustain. Energy Rev. **16**, 1116–1126 (2012)
7. Energy Research Institute Balanço energético nacional 2019 2020; https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-377/topico-470/Relat%C3%B3rio%20S%C3%ADntese%20BEN%202019%20Ano%20Base%202018.pdf
8. Brazilian Association of Wind Energy Boletim anual de geração eólica 2019 2020; http://abeeolica.org.br/wp-content/uploads/2020/06/Boletim-Anual-de-Gera%C3%A7%C3%A3o-2019v.pdf
9. E.B. Pereira, Segurança energética – perspectivas no enfrentamento às mudanças climáticas globais, *Proceedings of the Conferência Internacional do INCT para Mudanças Climáticas*, São Paulo, SP, Brazil, 2016 (2016, September)
10. Energy Research Institute *Roadmap eólica offshore Brasil – perspectivas e caminhos para a energia eólica marítima* 2020; https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-456/Roadmap_Eolica_Offshore_EPE_versao_R2.pdf
11. J.P. Painuly, Barriers to renewable energy penetration; a framework for analysis, Renew. Energy **24**, 73–89 (2001)
12. J.R.F. Diógenes, J. Claro, J.C. Rodrigues, M.V. Loureiro, Barriers to onshore wind energy implementation: a systematic review, Energy Res. Soc. Sci. **60**, 101337 (2020)
13. S.B. Silva, M.A. de Oliveira, M.M. Severino, Economic evaluation and optimization of a photovoltaic-fuel cell-batteries hybrid system for use in the Brazilian Amazon, Energy Policy **38**, 6713–6723 (2010)
14. N.F. da Silva, L.P. Rosa, M.A.V. Freitas, M.G. Pereira, Wind energy in Brazil: From the power sector's expansion crisis model to the favorable environment, Renew. Sustain. Energy Rev. **22**, 686–697 (2013)
15. P. de Jong, A. Kiperstok, E.A. Torres, Economic and environmental analysis of electricity generation technologies in Brazil, Renew. Sustain. Energy Rev. **52**, 725–739 (2015)
16. P. de Jong, A. Kiperstok, A.S. Sánchez, R. Dargaville, E.A. Torres, Integrating large scale wind power into the electricity grid in the Northeast of Brazil, Energy **100**, 401–415 (2016)
17. C. Brannstrom, A. Gorayeb, J. de S. Mendes, C. Loureiro, A. J. de A. Meireles, E.V. da Silva, A.L.R. de Freitas, R.F. de Oliveira, Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state, Renew. Sustain. Energy Rev. **67**, 62–71 (2017)
18. A.C. Köberle, R. Garaffa, B.S. Cunha, P. Rochedo, A.F. Lucena, A. Szklo, R. Schaeffer, Are conventional energy megaprojects competitive? Suboptimal decisions related to cost overruns in Brazil, Energy Policy **122**, 689–700 (2018)
19. J.R.F. Diógenes, J. Claro, J.C. Rodrigues, Barriers to onshore wind farm implementation in Brazil. Energy Policy **128**, 253–266 (2019)
20. M.M. Herrera, I. Dyner, F. Cosenz, Assessing the effect of transmission constraints on wind power expansion in northeast Brazil, Util. Policy **59**, 100924 (2019)
21. O.A.C. Amarante, M. Brower, J. Zack, A.L. Sá, *Atlas do Potencial Eólico Brasileiro* (Ministério de Minas e Energia, Brasília, 2001)
22. National Electric System Operator *Plano anual da operação energética dos sistemas isolados para 2020* 2020; http://www.ons.org.br/AcervoDigitalDocumentosEPublicacoes/DPL-REL-0248-2019%20-%20PEN%20SISOL%202020.pdf
23. National Agency of Electric Energy *Informativo ANEEL de deliberações da diretoria – dez2019 e jan 2020* 2020; https://www.aneel.gov.br/documents/654778/19224298/Info+-+Nov19+e+Jan20.pdf/1ccbc940-e3c7-5a1f-7313-70ac88252d5c
24. National Development Bank *Relatório Anual Integrado 2018* 2019; https://web.bndes.gov.br/bib/jspui/bitstream/1408/18800/1/PRPer161100_Annual%20Report%202018_BD.pdf
25. O. Maceron, Filho, P.C.R. Quintairos, Fontes de recursos do BNDES: Um estudo sobre energia eólica, Rev. Bras. Gestão Desenvolvimento Regional 12 (2016)

26. A.D.Á. Gomide, A.K.E. Pereira, Governança da política de infraestrutura: condicionantes institucionais ao investimento (Ipea, Rio de Janeiro, 2018)
27. Petrobras *Estamos desenvolvendo o primeiro projeto piloto de energia eólica offshore do Brasil* 2020; https://petrobras.com.br/fatos-e-dados/estamos-desenvolvendo-o-primeiro-projeto-piloto-de-energia-eolica-offshore-do-brasil.htm
28. B. Bayer, L. Berthold, B.M.R. de Freitas, The Brazilian experience with auctions for wind power: An assessment of project delays and potential mitigation measures, Energy Policy **122**, 97–117 (2018)
29. P. Lako, M. Koyama, G. Simbolotti, G. Tosato, *Wind power: Technology brief* (2016) Retrived May 15, 2021, from https://irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA-ETSAP_Tech_Brief_Wind_Power_E07.pdf
30. World Bank *Classificação das economias* 2019; https://portugues.doingbusiness.org/pt/rankings

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