

Review

Onshore Wind Power Generation and Sustainability Challenges in Northeast Brazil: A Quick Scoping Review

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Abstract: Onshore wind energy has been one of the most promising new renewable energy sources in the Northeast region of Brazil. This technology has generated long-term energy without serious socio-environmental impacts for some and, therefore, has been considered clean, renewable, and sustainable. However, given its spatial complexity, water scarcity, and social poverty of indigenous populations, the development of wind energy in vulnerable areas of this region raises socio-ecological concerns. Hence, studies of sustainability challenges are essential. The aim of this article is to systematically review the main multidimensional sustainability challenges of studies on onshore wind power generation, resulting in a quick scoping review of the literature. The study highlighted the promise of onshore wind generation in the current period of climatic and socio-ecological crises, but also highlighted some resulting socio-ecological problems, such as: deforestation for the construction of wind farms, expropriation of subsistence arable land, generation of turbine noise, insignificant employment, maintenance of inequalities, rural–city migration, extinction of cultural traditions, and food insecurity. This review offers an overview of wind energy generation, aiming to inform society and decision makers about the nature of challenges that lead to unsustainability arising from wind energy technology.



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1. Introduction

Renewable energy has become the most prominent planetary source of energy generation and socioeconomic development in recent times, mainly because it accounted for more than 62% of new energy production capacity between 2009 and 2018 [1]. Included among the non-hydro renewable technologies that grew the most and gained a reputation (due to the aspects of safety, cleanliness, and abundance) in this period, is onshore wind energy—generated by wind turbines placed on land—which achieved significant growth in renewable energy generation capacity, of between 13% and 24%, during this period [2]. All targets set for the generation of wind energy technology have been exceeded worldwide.

In the case of Brazil, the installed capacity of wind energy has recently increased to more than 20.10 GW (accounting for 11.46% of the country's energy matrix), represented by about 8800 wind turbines in 751 wind farms in operation, and mostly installed in coastal areas, under beaches, dunes and hills, and in the interior of the semi-arid area in mountains and plateaus. The Northeast region of the country is the area with the largest installation (accounting for over 87% of the country's wind farms), generation, and socioeconomic dynamism of wind energy technology, according to the Brazilian Wind Energy Association (ABEEólica). It is also worth noting that Brazil is ranked 7th in the world in terms of installed wind energy capacity. In 2012, it was ranked 15th, as reported in Infovento 23 by ABEEólica [3]. In addition, since 2018, wind energy has been the second greatest source of electricity generation in Brazil and, on record days, it reached about 20% of the country throughout the day and, in 2021, it broke the record to supply the entire geographic area of the Northeast region, during an entire day, more than once [3].

As mentioned above, in relation to the Brazilian territory, wind energy technology has grown in recent years. Installed power growth increased in 2021, and was higher than in 2016, according to the National Electric Energy Agency (ANEEL). Data from this agency show that 7562.08 megawatts (MW) was added to the Brazilian energy matrix (more than 82.96% of the electric energy in operation comes from the generation of renewable sources) during the period—57.8% more than the 4790.4 MW set as a target last January. For this Brazilian agency, this was the second largest increase in the historical series measured since 1997, only behind that of 2016, when the increase was 9528 MW, as mentioned by ANEEL in the context of the expansion in the Brazilian energy matrix [4]. For this agency, 2021 experienced the greatest increase in the installed capacity of wind power in the country, during which the commercial operation was expanded to 3694.32 MW in terms of installed capacity.

However, although the growth in wind energy generation in Brazil has been promoted by its socioeconomic and environmental gains or advantages (e.g., low environmental impact of its installation and operation; non-CO₂ emitting wind farms; better cost-benefit in the energy tariff; income-generating and life-enhancing effects for landowners, with leases for tower placement; coexistence of activities, allowing the landowner to continue with plantations or animal husbandry; job generation; payment of leases to landowners; possibility of coexistence of agriculture and livestock activities with wind farms; collaboration with people in the countryside and consequent training of local labor; and positive impacts on the HDI and GDP of municipalities [5]), according to ABEEólica [5], it also exposes challenges that may compromise the sustainability [6,7] of this renewable technology and the society linked to it, in a turbulent period facing great sustainability challenges, such as the Anthropocene [8]. Many of the challenges arising from the development of wind energy technology can become unsustainable problems for societies, so it is expected that immediate and concerted actions can be undertaken to face these challenges [6]. In this sense, some scholars recommend exploring new paths beyond the economic model based on mere growth, aimed at a more socio-ecological transition, care, and more responsible forms of interaction that contribute to the well-being of society and its living environment [6,7]. Therefore, wind power generation technology, despite being considered renewable, clean, promising, and low cost, requires an evaluation of the volume and characteristics of information conveyed about the potential challenges of this energy source. This should be undertaken in relation to achieving the objectives in an economically and socially user-friendly and desirable manner, in line with Goal 7 of the United Nations 2030 Agenda, i.e., to ensure access to affordable, reliable, sustainable and modern energy for all. In this context, assessments of data and information about this form of renewable energy have become an innovative and essential field of research, driven by global movements towards more sustainable and lasting energy systems.

In Brazil, the Northeast region (consisting of nine states) is the territorial area with the largest generation of onshore wind energy in the country, accounting for more than 87% of the country's wind farms, and having the highest percentages of installed capacity by state among the 12 producers of this type of energy (Table 1). This concentration results from the constant presence of suitable winds in this region, which have an unchanged speed and do not change direction quickly or frequently. Today, some say that the Northeast region is moved by the wind! Of the 751 wind farms installed in Brazil, 655 are located in this region.

However, few studies published to date have sought to reveal challenges and/or socio-ecological solutions for the generation of wind energy in onshore areas, in the region of greatest production in Brazil, with a view to genuine sustainability. Therefore, the objective of this study was to systematically review the main multidimensional sustainability challenges identified in studies on onshore wind power generation in Northeast Brazil, thus producing a quick scoping review (QSR) of the literature.

Table 1. Distribution of wind farms and installed capacity by Brazilian state, according to ABEEólica [3].

Brazilian States/Region	Power (MW)	Wind Farms	Wind Turbines
Rio Grande do Norte/NE	6,082,825	201	2.571
Bahia/NE	5,395,545	204	2.287
Ceará/NE	2438.14	94	1.107
Piauí/NE	2354.65	81	1.007
Rio Grande do Sul/S	1835.89	80	830
Pernambuco/NE	798,365	34	417
Maranhão/NE	426	15	172
Paraíba/NE	469.05	25	211
Santa Catarina/S	238,499	14	173
Sergipe/NE	34.5	1	23
Rio de Janeiro/SE	28.05	1	17
Paraná/S	2.5	1	5
Total	20,104.01	751	8.820

Brazilian regions: Northeast (NE); South (S); North (N); Midwest (MW); Southeast (SE).

2. Materials and Methods

The QSR approach was adopted to carry out this review based on the step-by-step guidelines proposed by Colling et al. [9] and Pham et al. [10]. This type of relatively new approach, which is now becoming more common, allows for a rapid assessment of the peer-reviewed and non-peer-reviewed literature, seeking to “provide an informed conclusion about the volume and characteristics of an evidence base and a synthesis of what that evidence indicates in relation to an issue” [9]. In this context, this approach allows us to answer the main question of this QSR, which was: “what are the main multidimensional sustainability challenges present in studies on onshore wind power generation in the context of the socio-spatial reality of the Brazilian Northeast?” Therefore, the main steps adopted were: definition of the study question; a literature search; screening of the results found; and summarize and report on the main results.

Three databases were defined for the selection of the main literature: Google Scholar (GS), Portal de Periódicos da Capes (Capes Periodical Portal), and Scopus. Google Scholar was chosen because it allows access to gray literature (required in quick scoping reviews) and specific studies published in qualified journals at local, regional, national, and international levels on the topic addressed in this study. The Capes Periodicals Portal was also chosen because it is the largest official database in Brazil, in which more than 45 thousand periodicals, national and international, with open and free access are available. This source also allows access to several other publications and databases that bring together academic and scientific works, in addition to patents, theses, and dissertations, among other types of material, from all areas of knowledge and, in particular, about the study in question. Scopus was also chosen because it is the largest database in the world of abstracts and citations in the peer-reviewed literature (scientific journals, books, congress proceedings, and publications), and was used to validate and qualify the search of the two previously mentioned databases.

The literature survey was undertaken from December 2021 to 13 January 2022. Initially, we aimed to search in the Google Scholar electronic database for published studies through the broad expression “sustainability challenges of wind energy generation”, due to the production of onshore wind energy, in coastal and semi-arid areas of the Brazilian Northeast, which had been publicized as being promising and considered to be clean, renewable, and sustainable. Subsequently, an attempt was made to better systematize the search of this scientific database using some advanced search aspects (https://scholar.google.com/schhp?hl=en#d=gs_asd, accessed on 13 January 2022), to identify studies in the database containing a combination of different keywords, or descriptors, used anywhere in the document (with highlights for title, abstract, and keywords, for example). The terms used in these searches were the following: wind energy (alternating searches for combinations such as “wind power generation” or “wind farms”); sustainability challenges (or “socio-

environmental impacts”); and Brazil (or “Northeast Brazil”). During the searches, the Boolean operator “AND” was used to identify combinations, and, in other cases, these terms or keywords were connected through the Boolean operator “OR”, evidencing the union of the sets. After removing duplicates and screening the titles and abstracts, observing the developed inclusion and exclusion criteria of the searches, 25 studies written in English or Portuguese (the vernacular language of the socio-spatial reality of the study) were considered eligible for the review.

In addition to the Google Scholar searches, new searches were carried out in the Capes Periodical Portal (the largest virtual library of scientific information in Brazil—<https://www.periodicos-capes.gov.br/ezl.periodicos.capes.gov.br/index.php?>, accessed on 13 January 2022) and Scopus (one of the largest international, expertly curated electronic databases of abstracts and broad citations—https://www.elsevier.com/solutions/scopus?dgcid=RN_AGCM_Sourced_300005030, accessed on 13 January 2022), using the same terms cited above. No new or different studies from those identified in Google Scholar emerged. In other words, the few scientific articles retrieved by the Portal de Periódicos da Capes (5 articles) and Scopus (4 articles) were the only articles published by periodicals, and were already selected by the first database initially mentioned.

Therefore, the review included peer-reviewed journal articles identified in Google Scholar and published between 2016 and 13 January 2022, the period in use in the United Nations 2030 Agenda for Sustainable Development. This agenda conveys an action plan aimed at people, the planet, and prosperity, which includes the generation of renewable energy, such as wind. This energy source is presented from the perspective of being promising, accessible, and sustainable, especially relating to the eradication of the greatest challenge of sustainability, i.e., poverty in all its multidimensional forms, with the aim of leaving no one behind. QSRs are used to map and organize the available literature on a given topic. Therefore, an overview and summary of the steps of this QSR are simplified in Figure 1 below.

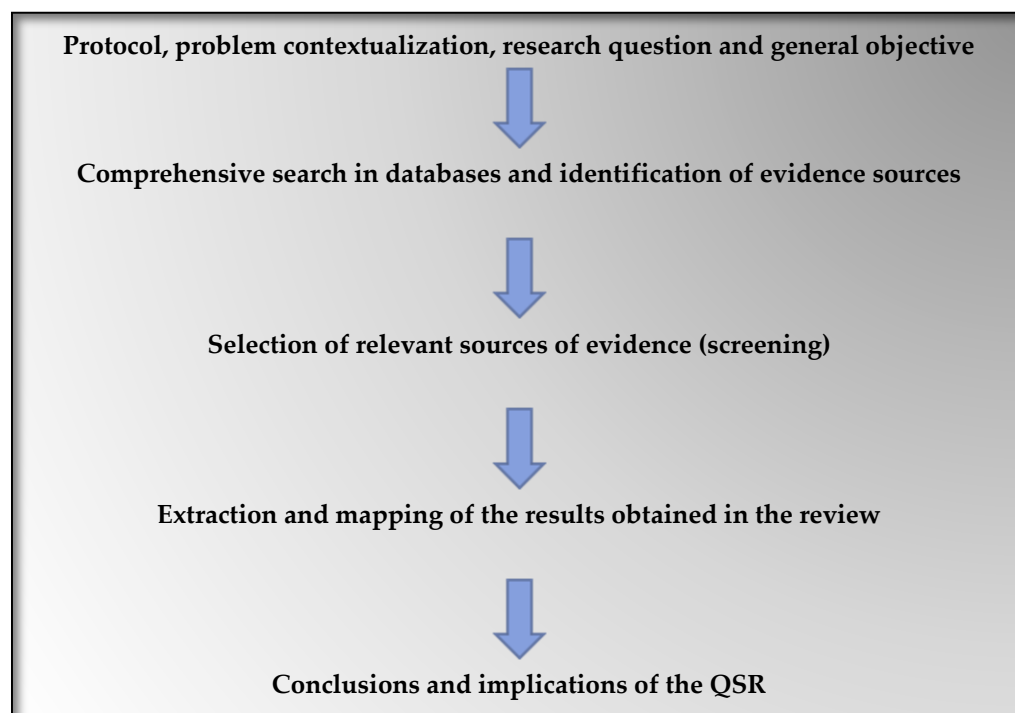


Figure 1. General structure of the steps carried out in the QSR.

3. Results and Discussion

This section presents the main results of the evidence base on the studies included in this QSR. In the initial phase of QSR systematization, about 371 studies were obtained from

Google Scholar, five articles from Scopus, and four articles from Portal de Periódicos da Capes (Capes Periodical Portal), through the search engines noted in Section 2. Several studies were removed from the review for reasons such as duplication, publication outside the specified period, inaccessibility of full text, and failure to address the central theme of the research. This resulted in 25 articles [11–35] after the screening and search for evidence on the topic under discussion.

Studies on wind power generation in the geographic reality of the Northeast have become more common over the last few years. This is a promising trend for this field of research (Figure 1).

Appendix A presents the main characteristics of the 25 studies selected for the QSR. The studies were published between 2016 and 2022. The appendix contains important information for mapping the available literature on the topic under analysis in the review, such as: title, authors' names, year of publication, citation count in Google Scholar data, and general objective and main purposes of each reviewed study.

The 25 studies of this QSR were published in 19 national and international journals (Figure 2), were peer reviewed, and were from different areas of knowledge, indicating an interdisciplinary approach. All the studies analyzed were characterized as methodologically qualitative studies, because the great majority (78%) used inquiry strategies involving autochthonous subjects in the socioecological reality of the area of wind energy generation in the Northeast region of Brazil. Of the total number of studies, 78% were characterized as empirical research and 22% as bibliographic studies. Most were classified as case studies about phenomena directly related to the generation of wind energy at a location in the Brazilian Northeast.

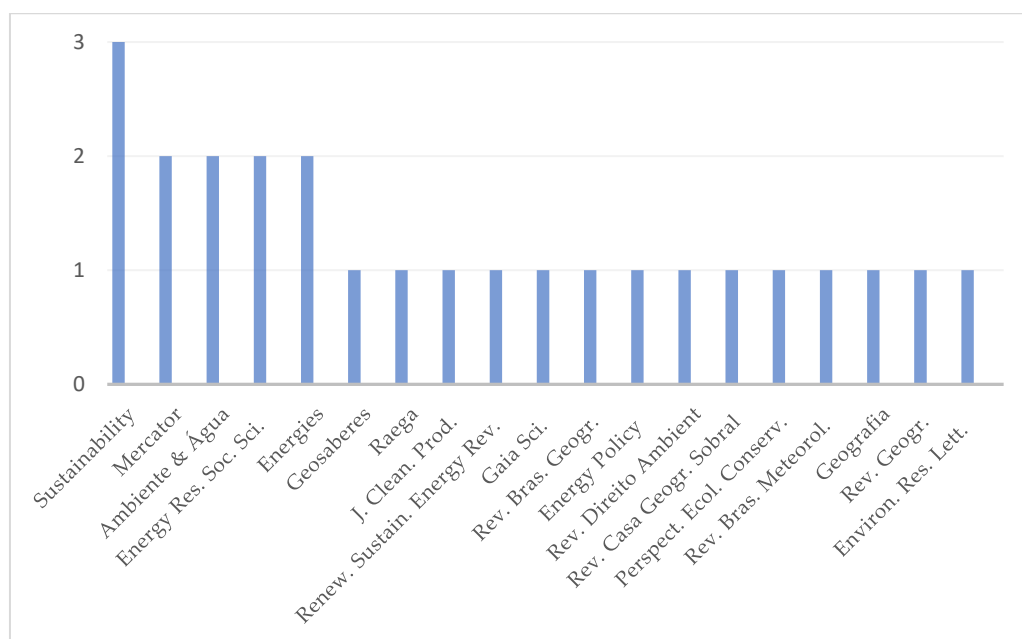


Figure 2. Publication of articles in 19 national and international journals.

During the search for evidence on sustainability challenges resulting from the wind power generation industry, in order to contribute information for the formulation of public policies and for decision makers, it was found that the reviewed studies show a growing interest in onshore wind generation in the current period of climatic and socio-ecological crises. However, these studies also highlight socio-ecological problems, such as deforestation for the construction of wind farms, expropriation of subsistence arable land, generation of turbine noise, insignificant employment, maintenance of inequalities, rural–city migration, extinction of cultural traditions, and food insecurity.

One of the first studies to highlight the importance of the benefits of wind energy generation emphasizes that this form of energy generation is linked to a series of challenges or socio-ecological impacts, which need to be addressed through more sustainable actions for the implementation of wind farms on the coast of the State of Ceará, such as: legal security of land tenure by traditional communities; payment of royalties and rents to community associations; lowering the energy bills of local residents; creation of permanent education programs and the promotion of good practices aimed at the local community; construction of legal provisions that regulate the implementation of wind energy at state and municipal levels, based on the elaboration of municipal laws and plans; elaboration of environmental impact studies that are based on public awareness, broad information, and communication strategies about the benefits and possible damage to the natural and social environment and to human health; and construction of state zoning that identifies levels of compatibility of the regions in the state with the implementation of wind farms, with broad social participation [11].

Another study sought to analyze, through participatory methodologies, the problems associated with the implementation of one of the largest wind energy production centers in the State of Ceará, specifically in the community of Praia de Xavier, Camocim. The findings showed that this economic activity has presented numerous socio-environmental problems, among which the following stand out: lack of basic infrastructure and employment; road closures; fear of accidents on the part of residents; and the socio-environmental degradation resulting from the dismantling of dunes, backfilling of ponds, and privatization of common areas for the community [12].

One of the studies of this QSR undertook an international comparison of the development of wind energy in wind farms in Texas (USA) and the State of Ceará (Brazil). The results showed that the sustainability challenges of this technology and of the societies directly involved would be affected if the security of land tenure, the strengthening of economic institutions, and the degree of social acceptance in the implementation of this energy activity were not considered. Furthermore, the authors pointed out that, in Texas, land lease contracts and royalties have benefited private landowners and produce fees, whereas, in Ceará, socioeconomic advantages are restricted to local elites [13].

The article entitled “Sustainable development: case study in the implementation of renewable energy in Brazil” is yet another publication in which authors, aware of the high demand for new and renewable sources such as wind energy, reveal how the surrounding communities are positively and/or negatively affected by the installation of technological projects in wind farms. Among the biggest challenges of park installations in Brazil is the lack of training and sustainable plans for rural communities. As a result, the authors proposed 22 guidelines and good practices that contribute to the sustainability of communities directly affected by wind power generation [14].

Another study included in the QSR, motivated by the question “Is Brazilian wind power development sustainable?”, contributes with data and information about the successful responses of the wind power generation program in Brazil. It also points to the challenges and conflicts of this clean and renewable technology, specifically, on dune fields and the coastal area of the State of Ceará, which is a pioneer in the development of wind energy in Brazil. The study evidences that environmental impacts have led to territorial challenges, and erosion of livelihoods and policy responses, contradicting claims of sustainability and the promising development of wind energy [15].

It is known that wind energy has been the fastest growing energy source in Brazil, as pointed out by another study in this review [16], which highlighted the local energy market and its socio-environmental impacts. The study highlighted that wind energy generated in Brazil is a promising alternative to help reverse the current energy crisis, which results from the scarcity of water resources and the growth in greenhouse gas emissions due to the increase in the use of fossil fuels in the Brazilian electricity matrix. However, the article warned that, like any other economic activity, wind energy generation can cause socio-environmental impacts that must be analyzed and mitigated. The study presented

some worrying challenges associated with energy generation, which are the environmental, visual, and landscape impacts; noise; electromagnetic interference with birds and animals; social issues; and inadequate use and occupation of land.

Based on opinions and testimonies from residents around the Delta do Parnaíba wind farm, located on the coast of the State of Piauí in Northeast Brazil, another article [17] presented significant challenges arising from the implementation of wind farms in the community. These must be observed as compromising the achievement of socio-ecological sustainability, and include noise pollution, burying ponds, and removing vegetation, as indicated by the perception of local residents. For the authors of this article, the implementation and operation of local wind farms have been unsustainable productive processes, due to the proliferation of several negative socio-environmental impacts, combined with a high degree of social dissatisfaction because of the way in which the wind power generation uses natural resources.

The study called “Geographical perspectives on the transformations of the Brazilian coast by wind energy” [18] warned about the implementation of wind energy on the Brazilian coast, specifically in the Northeast region, and was concerned with the transformation of the area’s socio-environmental conditions. Using spatial analysis provided by a Geographic Information System, the study showed that almost 50% of the wind turbines located in the States of Rio Grande do Norte and Ceará are located within 25 km of the coastline, and 26% are located within 5 km of the coastline. Based on field research in six specific cases, the study demonstrated the existence of conflicts between communities and enterprises as the greatest challenge of this energy activity.

In another article, the sustainability challenges arising from the generation of wind energy were highlighted through a critique of the planning processes for the implementation of this energy in Northeast Brazil [19]. Critically, the authors state that “wind energy went wrong”, showing the main challenges that have occurred with wind energy policies in the Brazilian Northeast. The study emphasized issues related to the lack of security of land tenure in traditional, coastal communities, and the fragility of the judicial systems to guarantee the rights of the residents of these communities.

The article entitled “Procedural and distributive justice inform subjectivity regarding wind power: a case from Rio Grande do Norte, Brazil” [20], published in the *Energy Policy* journal, showed that energy planners have foreseen that, in the Brazilian territory, wind energy will increase from 13.19 GW in 2018 to 28.47 GW in 2026. However, it emphasized that socio-ecological conflicts focused on wind farms are emerging in Brazil, and that a social justice perspective has not yet been applied to analyze the conflicts generated by wind energy. The study, using the Q method, presented four factors or social perspectives in a coastal community in the State of Rio Grande do Norte: (1) Questioning the Benefits of Wind Energy; (2) Wind Farm Boosters; (3) Compensated by Energy; and (4) Questioning of Wind Farm Processes. The article highlighted that the identification of social perspectives can improve the capacity of the decision-making process for procedural and distributive justice.

The deployment of wind energy technology has gained a global reputation as an alternative to the source of challenges driving climate change because the technology does not emit greenhouse gases. This discussion was highlighted by the study “The implementation of wind farms and the socio-environmental impacts on indigenous and traditional populations” [21], published in *Revista Direito Ambiental e Sociedade*. However, the article warned that this technology has caused a series of socio-environmental impacts that cannot be ignored. The article showed that, despite legal norms protecting indigenous people from most of the impacts caused by the implementation of wind farms, traditional non-indigenous populations are vulnerable, and may even be removed from their lands to enable the development of this technology. Therefore, the study in question warned that the EIA/RIMA impact study, important for the environmental licensing of wind farms, constitutes an essential instrument to protect these people and resolve the socio-environmental challenges that can affect human sustainability.

Another article identified in the QSR analyzed the implementation of wind farms on the coast of the State of Ceará (on the beach of Volta do Rio in the municipality of Acaraú), in Northeast Brazil. The study highlighted the importance of considering the erosion processes in fragile and dynamic environments such as those located in coastal areas, especially if an activity of socioeconomic relevance is performed, such as the installation of wind farms, which are currently resources for the production of alternative energy having less environmental impact [22]. Using topographic data, the study found that wind activity can cause environmental degradation processes at the installation site, mainly due to tidal forces. As a solution to this environmental problem, the study noted the placement of concrete blocks at the location of the wind farms, which is already being undertaken to contain the sea. The study also warned that it is important to monitor erosion processes through topographic measurements and the use of aerial images. Among others, these tools can be used to observe the process and identify solutions to maintain the well-being of the coastline in place, without affecting its natural dynamics.

The study called “Analysis of the Levels of Alteration of Aquifers Caused by the Installation of Wind Farms on Dunes on the Coast of Ceará, Brazil” [23], which was concerned with the sustainability of society and the generation of wind energy, evaluated the levels of alteration of aquifers caused by the installation of wind farms in dune areas on the coast of Ceará. The study used the GOD and POSH methods to assess vulnerability and underground flow, and applied multivariate analysis to the monitoring of the quality of groundwater in the municipality. The multivariate analysis evidenced that the groundwater characteristics were strongly related to the geological formation of the wells (dunes and barriers), and found that all samples were within the maximum tolerable values for human consumption for Total Dissolved Solids, hardness, turbidity, and pH. Therefore, the article emphasized that it is important to carry out preliminary studies of the aquifers underlying the areas where wind farms are to be installed, considering the levels of vulnerability and the risks to pollution and the alteration of the water supply.

The article “Green versus green? Adverting potential conflicts between wind power generation and biodiversity conservation in Brazil” warned about the levels of overlap between wind power generation development plans and the conservation goals of the Caatinga biome (composed of xerophytic plants), which is the only biome situated exclusively in Brazil and is the most diverse dry forest in the Americas. This biome is home to more than 70% of the installed and planned capacity in wind energy in Brazil. However, most of the wind farms in operation, or planned to be installed, are in areas that have already been mapped and selected as being of high and very high priority for the conservation of biodiversity. Therefore, the expansion in wind energy must be further considered, and accompanied by greater protection of biodiversity and steps to reduce poverty, in order to achieve the goals of sustainable development and sustainability. The study claimed that wind-energy-producing organizations seek to publicize their expansion plans and make public commitments to safeguard natural ecosystems, thus avoiding an undesirable conflict of interests [24].

In the studies analyzed above, the generation of wind energy in the State of Ceará, in the Northeast region of Brazil, has been the most investigated in recent years due to the state’s privileged geographical position in terms of the generation of wind energy. However, through the comparative analysis of the wind farms of Beberibe and Fleixeiras I, the study entitled “Socioeconomic, Environmental and Technological Impacts Caused by the Installation of Wind Farms in Ceará” [25] presented the socioeconomic, environmental, and technological impacts originating from the implementation and operation of the wind power plants on the coast of Ceará. The study listed the main socio-environmental challenges resulting from the generation of wind energy, such as the reduction in fauna and flora; wear and tear of access roads; production of noise; de-characterization of the natural landscape; limitation of the right to “come and go”; and cracking of houses. The economic impacts were more significant during the construction of the parks and decreased gradually over time. The article also indicated that, in relation to technological aspects,

it can be seen that the greater the height of the towers and the diameter of the rotor, the greater the amount of energy generated.

A case study was undertaken of a wind farm located in the municipality of Galinhos in the State of Rio Grande do Norte. The study emphasized that wind technology is a viable option that can be adopted in the context of the converging narrative that proposes an energy transition with a view to replacing fossil fuels with renewable energies. The article showed that Brazil produced 14.8 GW of wind energy in 2019, of which, 85.7% was produced in the Northeast Region. However, the article showed that the socio-environmental weaknesses of local communities, who have been neglected in planning, have led to mounting opposition to the implementation of wind farms. The study contributed with information regarding the implementation of wind energy, and dialogues about the demands of the communities living in the surroundings of the projects and the repercussions for institutional, socioeconomic, and environmental development. The perceptions gathered by this study showed that the local wind farm has not changed the socioeconomic conditions of the population, and environmental issues have become more acute and require assessments by the responsible institutions. The article showed the materiality of the narrative that justifies the expansion in wind farms in the Brazilian Northeast [26].

The article on the “Chapada do Piauí I wind farm: social benefits and environmental impacts in the municipality of Marcolândia, State of Piauí” [27] showed that the search for new alternatives for generating energy from renewable and clean sources aims to mitigate the impacts of environmental problems caused by the use of fossil fuels. In this context, wind power generation has gained prominence in Brazil, especially in the Northeast, due to the region’s spatial characteristics, which favor the development of wind power. However, the study sought to highlight, above all, the socio-environmental challenges arising from the implementation of the Chapada do Piauí I Wind Complex, in communities located in the municipality of Marcolândia, with a view to correlating the advantages of wind energy generation with environmental conflicts that were identified and materialized in loco. The implementation of the wind farm has contributed little to the local economic dynamism and changes in the landscape. The study proposed contributing to other studies that seek to discuss the transformation of the local landscape from a socio-environmental perspective, based on the implementation of wind farm technologies as an energy matrix.

The identification of connections between wind energy, poverty, and social sustainability in the Brazilian semi-arid region, resulting from a case study in the State of Rio Grande do Norte, was the subject of another article eligible for this QSR [28]. This study showed that the generation of wind energy, which has been undertaken in an overwhelming and abundant manner, has not had a positive impact on the investigated socio-spatial reality, which has been marked historically by poverty. The article also indicated that the wind projects implemented in the study area disregarded the desire for development of local communities. After a decade of technological development, these projects did not promote inflections in the family well-being curve, thus constituting a significant challenge for social sustainability. The study aimed to innovate by approaching the relationship between poverty and energy, thus going beyond the frontier of the “Energy Poverty” discussion, because access to electricity is universal throughout the Brazilian territory.

The article on environmental licensing and social opposition to wind energy in a coastal community in Ceará, Northeast Brazil, showed that there has been community opposition to the project. This opposition was rooted in claims for the loss of part of the traditional territory and its natural resources, specifically, a perennial lagoon used for generations for fishing and leisure that was suppressed during the construction works of the wind farms [29]. The study pointed out that the mitigation efforts led by the social and legal assistance institutions, together with the Public Ministry, produced contradictory results. In addition, the study showed flaws in the environmental licensing process, and that the consequences of the efforts culminated in wear and tear and internal conflicts, affecting the community at various levels. It should be noted that the exposed situation is

also probably present in other places where wind energy parks are installed, but this issue is still poorly reported in the national academic literature.

Another article significant to the review in question sought to address the issue that wind energy, despite being considered clean and renewable, has negative impacts on the socio-ecological context, and significantly alters the coastal and inland areas of the Brazilian Northeast due to the new uses of land arising from the installation of wind towers. The study analyzed changes in land use and occupation of agricultural areas exploited by wind energy, identified the potential of these agricultural areas for the construction of wind farms, and verified the conciliation between wind and agricultural activity. The study emphasized that: the installation of wind farms caused few changes in the classes of use and occupation of the soil; the agricultural areas of Serra do Mel have great potential for wind energy due to the speed of the winds and the condition of the terrain; and there is the possibility for conciliation between agricultural and wind activity [30].

The article “Sustainability challenges in the implementation of wind energy on the coast of the State of Ceará, Brazil” [31], published by the magazine *Sustentabilidade*, noted that sustainable and socially just decarbonization faces numerous challenges, due to the high demand for land for wind farm construction and weak economic and political institutions. Through an analysis of 18 “simplified” environmental impact reports, which created a legal path for the construction of wind farms, and by conducting qualitative interviews in host communities on the coast of the State of Ceará, in Northeast Brazil, the study revealed that companies appropriated and manipulated the “crisis” in their environmental impact reports. Furthermore, interviews with members of the host community revealed that the themes of ecological damage, fear, privatized land, employment, migrant workers, and noise are challenges that afflict socio-ecological life and sources of active resistance to wind farms. The study recommended stricter licensing procedures to reduce corrupt practices, and offered avenues for community participation in decision-making processes and eventual benefits from wind farms.

The article entitled “Bigger is not always better: review of small wind in Brazil” [32] highlighted the significant expansion in the wind energy market, but noted that the vast majority of these technological investments in this form of energy are concentrated in large wind turbines. The authors strongly emphasized that small wind turbines have not followed this virtuous path, especially in the Brazilian reality. Therefore, the article evaluated the current situation regarding the wind energy market for small wind turbines (SWTs) in Brazil and their future prospects, identifying the main characteristics of the sector, and its challenges and socio-ecological opportunities. The study provided objective evidence that the production of knowledge on the use of SWTs in the case of Brazil remains limited, and is colored by the impressive progress registered by the main wind farms in the country, despite all of the potential and socioeconomic and environmental attractions.

Another study included in this QSR revealed how wind energy has expanded spatially in Brazil and the impacts on land use that have accompanied this expansion. The article sought to show that, although wind power is a low-carbon renewable energy technology with a relatively small land footprint, the expansion in necessary infrastructure still has land-related environmental impacts. The study highlighted that little is known about the challenges and impacts of wind power generation in Brazil compared to other regions of the world, despite the fact that the Brazilian wind infrastructure is concentrated in the least-protected ecosystems, which are prone to degradation, desertification, and species extinction. This study focused on the land use impacts of wind power generation development in four northeastern Brazilian states, covering over 80% of the country’s installed capacity. The study questioned the sustainability of the historic expansion in wind energy in Brazil in terms of land use impacts [33].

A recent study on the “Perception of environmental impacts of wind farms in agricultural areas in Northeast Brazil” [34] analyzed the development of wind technology, showing its growth as an alternative to diversify the country’s energy matrix and mitigate the emission of energy pollutants derived from fossil fuels. The article revealed that the

State of Rio Grande do Norte, in Northeast Brazil, has considerable potential for wind energy generation due to the occurrence of strong winds in many areas along the coast, and in the interior of the state, in places with higher altitudes. The study was carried out in the municipality of Serra do Mel, in the western region of the State of Rio Grande do Norte, and comprised a case study based on a survey with local farmers. The study found that local farmers experience serious problems, but no apparent conflicts with wind farms, and have little knowledge about the environmental impacts resulting from the wind farms. Based on the perceptions of most farmers, the study showed that negative environmental impacts are little noticed or still do not result in damage to most local residents.

The article entitled “What explains the community acceptance of wind energy? Exploring benefits, consultation, and livelihoods in coastal Brazil” [35], published in *Energy Research & Social Science*, explored the results of a study carried out in three host communities of wind farms in the State of Ceará, Northeast Brazil. The comparative case study showed a wide variation in wind farm support among host communities in terms of benefits gained. The results of this study suggest that perceived or actual economic benefits have generated support for wind farms, especially when these benefits strengthen the livelihoods and security of land tenure of host communities, where livelihoods depend on fisheries and agriculture, and there are few job opportunities.

It was found through this QSR that most authors, from different areas of knowledge, warned in their articles about the need to observe the socio-ecological difficulties and challenges that arise from the installation of wind farms, which are compromising, in particular, the genuine sustainability of populations and the communities hosting wind turbines. However, the authors have not only highlighted the challenges of sustainability, but have noted in an oriented way, as in the case of this last article [35], the solutions to the serious problems of wind energy generation through actions and practices that enable the promotion of complete sustainability [6]. In other words, the study showed the promising growth of onshore wind generation technology in Northeast Brazil, in the current period of acute climatic and socio-ecological crises, but also highlighted some resulting socio-ecological problems, such as: deforestation for the construction of wind farms; expropriation of subsistence arable land; generation of turbine noise; insignificant employment; maintenance of inequalities; rural-to-city migration; extinction of cultural traditions; and food insecurity, among countless others.

The information provided by the articles of this QSR enables political and practical decision making to be better supported by the data and findings of this quick scoping review, which aimed to provide evidence about the sustainability challenges arising from the implementation of onshore wind energy. Above all, the aim was to drive the creation of well-planned, effective, and efficient policies and interventions needed to quickly respond to the challenges of social transformation [6] towards socio-ecological sustainability.

Considering the low scientific production of research about the sustainability challenges linked to wind energy technology, the journals that stood out the most are cited in the corpus of this QSR (Figure 2). However, among the authors who have published most often, and have been concerned with issues/problems related to the sustainability of this technology and the closest local societies, the authors Christian Brannstrom (Texas A&M University, College Station, TX, USA) and Adriane Gorayeb (Universidade Federal do Ceará, Fortaleza, Brazil) deserve to be highlighted.

4. Conclusions

This study reviewed 25 publications based on a specific design and thematic criteria focused on multidimensional sustainability challenges, conveyed by studies of onshore wind power generation in Northeast Brazil, thus producing a quick scoping review of the literature. By addressing the sustainability challenges arising from the generation of wind energy in this study, it was found that the QSR can be a path to the development of more sustainable solutions because it can support societies’ and policyholders’ decisions with data and information to face the problems that most afflict the populations that live near

wind farms. In this way, it will be possible to prevent the main challenges that generate unsustainability arising from wind energy technology.

Therefore, knowledge of the main sustainability challenges linked to the development of wind energy technology, which was provided by the scientific articles presented in this QSR, allows the analysis of the socioecological dynamism of the relationship between nature and society as a whole. The biggest complaint from society is that the generation of wind energy, in the geographical area experiencing the greatest poverty in Brazil, has contributed little to the sustainability of people and their living spaces. Therefore, the growth and dynamism of installed technology for wind power generation is not enough. It is also necessary to contemplate actions aimed at improving the quality of life of people and indigenous communities that are most affected by the mere growth of this energy activity, as claimed by the above articles and their authors. Finally, due to the significant quantity of information they provide, the articles make it possible to contribute to the increasing impetus of the development of wind energy in Northeast Brazil. However, a focus must remain on the concerns regarding genuine sustainability of the people and their living territories.

This study highlighted the main sustainability challenges linked to onshore wind energy generation, from the perspective of qualitative approaches, and lacked the synthesis of quantitative evidence. However, this study may stimulate the debate from the perspective of the effective synthesis of the knowledge presented by the reviewed qualitative research and from different theoretical–methodological approaches. The current article provides the scope for building future evidence-based reviews.

Finally, this quick review suggests that further systematic reviews (focusing on qualitative and critical analysis of documents), empirical research, and interventions are needed, with a focus on more specific questions about each sustainability challenge arising from the wide diffusion of onshore wind technology. Such studies will be able to make a concrete contribution to strategies aimed at increasing the sustainable development of this promising and competitive onshore renewable energy sector in Brazil and, consequently, in other locations or socio-spatial realities (local, regional, national, and international).

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Appendix A

Table A1. Overview of the main studies selected for the RSR.

Title	Authors	Year of Publication	Citations GS	General Purpose of the Study
Paths to participatory resource management of renewable energy sources (wind farms) in Northeast Brazil	Adryane Gorayeb; Christian Brannstrom	2016	23	Review deployment policies of the wind power matrix in Brazil, focusing on the Northeast region, with the aim of pointing out ways to a better planning of this activity, considering the problems linked to the implementation of enterprises in Ceará, responsible for a large part of the environmental and social impacts of traditional coastal communities today.
Participatory diagnosis and social cartography applied to impact studies of wind farms on the coast of Ceará: the case of Xavier beach, Camocim	Jociléa de Sousa Mendes; Adryane Gorayeb; Christian Brannstrom	2016	30	To analyze, through participatory methodologies, the problems established with the implementation of one of the largest wind energy production centers in Ceará, in Xavier beach community, located in Camocim, Ceará, Brazil.
Comparative analysis of wind energy deployment policies and social outcomes in Ceará (Brazil) and Texas (USA)	Caroline Vitor Loureiro; Adryane Gorayeb; Christian Brannstrom	2017	10	To make a comparison between the region of Nolan County in West Texas (United States) and the west coast of Ceará (Brazil), as a way of qualifying the direct and indirect impacts on the social environment, resulting from the installation of this activity, and to reflect on its real degree of socio-political sustainability.
Sustainable development: case study in the implementation of renewable energy in Brazil	Mario Orestes Aguirre Gonzalez; Joeberson S. Gonçalves; Rafael M. Vasconcelos	2017	65	Propose a set of guidelines and best practices to public managers, public authorities and wind farm owners about the perspectives of communities' sustainability.
Is Brazilian wind power development sustainable? Insights from a review of conflicts in Ceará state	Christian Brannstrom; Adryane Gorayeb; Jociléa de Sousa Mendes; Caroline Loureiro; Antonio Jeovah de Andrade Meireles; Edson Vicente da Silva; Ana Larissa Ribeiro de Freitas; Rafael Fialho de Oliveira	2017	82	To analyze the development of Brazilian wind energy and its sustainability through a review of conflicts in the state of Ceará
The Brazilian wind energy market, social and environmental impacts	Lucía Iracema Chipponelli Pinto1; Fernando Ramos Martins; Enio Bueno Pereira	2017	34	Promote the dissemination of acquired knowledge and instigate curiosity for new issues that can provide sustainability for the expansion of electricity generation from wind energy in Brazil.

Table A1. Cont.

Title	Authors	Year of Publication	Citations GS	General Purpose of the Study
Perception of the socio-environmental impacts resulting from the implementation of the Delta do Parnaíba wind farm	Maria Bernadete de Carvalho Bezerra; Dênis Barros de Carvalho; Wilza Gomes Reis Lopes; Teresinha de Jesus dos Santos Sousa; Francisco das Chagas Vieira Santos; Anderson Guzzi	2017	4	To analyze the perception of the community of Pedra do Sal on the socio-environmental impacts resulting from the implementation of the Delta do Parnaíba wind farm
Geographical perspectives in the transformations of the Brazilian coast by wind energy	Christian Brannstrom; Adryane Gorayeb; Wallason Farias de Souza; Nicolly Santos Leite; Leilane Oliveira Chaves; Rodrigo Guimarães; Dweynny Rodrigues Filgueira Gê	2018	12	Synthesize the socio-environmental impacts of wind energy on the Brazilian coast, identify the main causes for the negative and positive experiences and understand the main knowledge gaps to be deepened by future research.
Wind power gone bad: Critiquing wind power planning processes in northeastern Brazil	Adryane Gorayeb; Christian Brannstrom; Antonio Jeovah de Andrade Meireles; Jociléa de Sousa Mendes	2018	49	To analyze wind energy planning processes in Northeast Brazil, emphasizing the negative impacts of a wind farm in the state of Ceará, Brazil.
Procedural and distributive justice inform subjectivity regarding wind power: a case from Rio Grande do Norte, Brazil	Cláudio Albuquerque Fratea; Christian Brannstromb; Marcus Vinícius Girão de Moraes; Armando de Azevedo Caldeira-Piresc	2019	19	To analyze views on distributive and procedural justice of wind farms among community residents, municipal officials and wind energy investors in Brazil, focusing on the case of a controversial wind farm built next to a fishing and tourism park. dependent community, Galinhos, in Rio Grande do Norte, Brazil's main wind power state.
The implementation of wind farms and the socio-environmental impacts on indigenous and traditional populations	Márcia Dieguez Leuzinger; Gabriel Leuzinger Coutinho	2019	–	Analyze the socio-environmental impacts related to the construction and operation of wind farms; evaluate the effects of installing these parks in areas occupied by indigenous or traditional populations or close to them; examine whether and how these groups are protected from these impacts by the regulations in force.
Analysis of coastal morphodynamics and socio-environmental impacts of large coastal developments: case study, Volta do Rio beach, Acaraú-CE	Otávio Augusto de Oliveira Lima Barra; Fábio Perdigão Vasconcelos; Danilo Vieira dos Santos; Adely Pereira Silveira	2019	–	Analyze coastal morphodynamics and socio-environmental impacts of large coastal developments: case study, Volta do Rio beach, Acaraú-CE

Table A1. Cont.

Title	Authors	Year of Publication	Citations GS	General Purpose of the Study
Analysis of the Levels of Alteration of Aquifers Caused by the Installation of Wind Farms on Dunes on the Coast of Ceará, Brazil	Maria da Conceição Rabelo Gomes; Adryane Gorayeb; Dimas de Brito Souza; Raquel Morais Silva	2019	1	Assess the levels of change in aquifers from the installation of wind farms on dunes on the coast of Ceará using the GOD and POSH vulnerability methods, groundwater flow and application of multivariate analysis to support the monitoring of groundwater quality in the area.
Green versus green? Adverting potential conflicts between wind power generation and biodiversity conservation in Brazil	Marlon Neri; Davi Jameli; Enrico Bernard; Felipe P.L. Melo	2019	18	Alert on potential conflicts between wind power generation and biodiversity conservation in Brazil.
Socioeconomic, environmental and technological impacts caused by the installation of wind farms in Ceará	Mônica Antonizia de Sales Costa; Monilson de Sales Costa; Maria Monizia de Sales Costa; Marcos Antônio Tavares Lira	2019	3	Present the environmental, social, economic and technological impacts originated with the implementation and operation of the Wind Power Plants in the coast of Ceará through the comparative analysis between the Beberibe and Fleixeiras I wind farms.
Wind power on the Brazilian Northeast Coast, from the whiff of hope to turbulent convergence: the case of the Galinhos Wind Farms	Eduardo Janser de Azevedo Dantas; Luiz Pinguelli Rosa; Neilton Fidelis da Silva; Marcio Giannini Pereira	2019	8	To assess how the arrival of wind power dialogues with the demands of the communities living in the projects' vicinities, as well as repercussions on institutional, socioeconomic and environmental developments.
Chapada do Piauí I wind farm: social benefits and environmental impacts in the municipality of Marcolândia, State of Piauí	Jaerle Rodrigues Câmpelo; Emanuel Lindemberg Silva Albuquerque; José Maria Marques de Melo Filho	2020	–	To analyze, in an integrated way, the socio-environmental impacts arising from the implementation of the Chapada do Piauí I Wind Complex, in communities located in the municipality of Marcolândia, with a view to correlating the advantages of wind energy generation with the environmental and social conflicts that are identified and materialized in loco.
Connections between wind energy, poverty and social sustainability in Brazil's Semi-arid	Maria Luiza de Medeiros Galvão; Marco Aurélio dos Santos; Neilton Fidelis da Silva; Valdenildo Pedro da Silva	2020	6	To understand the connections between the implementation of wind farms as sustainability promoters and the permanence of poverty levels.
Environmental licensing and social opposition to energy wind power: a case study focusing on the social gap in Coastal community of Ceará, Brazil	Adryane Gorayeb; Christian Brannstrom	2020	–	To analyze the flaws in the environmental licensing process that allowed the installation of the wind farm in Praia de Xavier, as well as the consequences of the mitigation efforts, which resulted in wear and internal conflicts that affected the community at various levels.

Table A1. Cont.

Title	Authors	Year of Publication	Citations GS	General Purpose of the Study
Sustainability challenges of wind power deployment in Coastal Ceará State, Brazil	Júlio César Holanda Araújo; Wallason Farias de Souza; Antonio Jeovah de Andrade Meireles; Christian Brannstrom	2020	3	To better understand the licensing materials for wind farms and the content of the host communities' concerns about wind farms. We analyzed 18 "simplified" environmental impact reports, which created a legal path for wind farm construction, and conducted qualitative interviews in host communities in coastal Ceará state in northeastern Brazil.
Land use and occupation of agricultural areas with wind energy	Manoel Fortunato Sobrinho Júnior; Elis Regina Costa de Moraes; Paulo César Moura da Silva	2020	1	Analyze changes in land use and occupation of agricultural areas exploited by wind energy, identify the potential of these agricultural areas for the construction of wind farms and verify the conciliation between wind and agricultural activity.
Bigger is not always better: review of small wind in Brazil	Fábio Ricardo Procópio de Araújo; Marcio Giannini Pereira; Marcos Aurélio Vasconcelos Freitas; Neilton Fidelis da Silva; Eduardo Janser de Azevedo Dantas	2021	2	At evaluating the current situation of the wind energy market for SmallWind Turbines in Brazil (SWT) and its future perspectives, identifying the main characteristics of the sector, its challenges, and opportunities
Land-use impacts of Brazilian wind power expansion	Olga Turkovska; Gabriel Castro, Michael Klingler; Felix Nitsch, Peter Regner; Aline Cristina Soterroni; Johannes Schmidt	2021	12	To analyze the land use impacts of the expansion of Brazilian wind energy in four federal states: Bahia, Ceará, Rio Grande do Norte and Rio Grande do Sul, which cover 80% of the total installed capacity.
Perception of environmental impacts of wind farms in agricultural areas of Northeast Brazil	Manoel Fortunato Sobrinho Junior; Maria Carolina Ramirez Hernandez; Sthenia Santos Albano Amora; Elis Regina Costa de Moraes	2022	–	To analyze, through the perception of the inhabitants of the agricultural areas of Serra do Mel-RN, which basically had their economy and customs linked to subsistence agriculture, the environmental impacts caused by the installation and operation of wind farms.
What explains the community acceptance of wind energy? Exploring benefits, consultation, and livelihoods in coastal Brazil	Christian Brannstrom; Nicolly Santos Leite; Anna Lavoie; Adryane Gorayeb	2022	-	To analyze the levels of acceptance of wind energy by host communities, exploring benefits, consultations and livelihoods on the coast of Ceará, Brazil.

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