CHAPTER 148

Marine impacts caused by technological advances of Offshore power plants in Brazil and possible environmental damage

https://doi.org/10.56238/alookdevelopv1-148

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ABSTRACT
Offshore wind power plants have been growing worldwide, with 2021 being a historic year for this modality, considering that energy from renewable sources strongly contributes to a more sustainable future. China is the country with the largest number of plants of this type along with Brazil having the highest energy potential. However, Brazil does not yet have any plant in operation. However, the prediction of the serial impacts that may exist that can be generated from the implementation phase to the deactivation phase, but there are no conclusive studies regarding the damage caused to the unique marine ecosystems existing in Brazil. In this sense, a review is being presented demonstrating the promising prospects of creating wind power plants related to the existence of 66 projects registered with IBAMA, however, there are still no in-depth studies on the possible environmental impacts.

Keywords: Wind farms, Renewable energy, Impacts, Marine ecosystems, Environmental damage, Energy potential.

1 INTRODUCTION

Offshore wind farms, according to IBERDROLA (n.d.), are formed by a grouping of wind towers installed at sea; whether fixed or floating. The first plant of this type was installed in Denmark in 1991, called the "Vindeby offshore Wind Farm". Since then, this type of plant has been widespread, especially in Europe, where there are geographical limitations, leading countries such as the United Kingdom and Germany to invest both in construction infrastructure, as well as in licensing mechanisms (NETO E MONTEIRO, 2023).

The year 2021 was a historic milestone for renewable energy around the world. According to GWEC, 21.1 GW of offshore wind has been added worldwide. Having as a country highlighted China that, since 2018 has been growing its offshore wind energy potential and that in 2021, of the 21.1 GW that were added to the grid, 80% are of its share.

In Brazil there is still no offshore wind power plant installed. However, according to the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), Brazil already has 66 projects in the licensing phase. What leads companies to seek this type of venture in Brazil is the high energy potential present along the coast; potential that is higher in the Northeast, Southeast and South regions (GORAYEB *et al.*, 2022).

However, environmental damage can be caused both in the construction of the structures and can extend to the maintenance and decommissioning phase. Among the main damages are, oil spill, chemical spills, noise and alteration in nearby ecosystems; it can also generate climate change (FADIGAS, 2011).

The varied endemic and migrant species on the Brazilian coast, as well as coral reefs, benthic and pelagic biota and microbiota, may suffer negative impact during the implementation phase of the plants. Seabirds are affected animals when they cannot deviate from structures, suffering collisions, in addition to having their migration routes altered, requiring more flight time and energy expenditure (BUGONI et al., 2022).

Another impact generated is the noises, which produce behavioral and physiological changes, affect mammals with sensitive auditory system and some species of fish. Among these impacts are local avoidance, panic and increased intensity of vocal communication (BUGONI et al., 2022).

What draws attention is the lack of more detailed studies by companies seeking the installation of this type of structure, and the lack of participatory spatial planning on the Brazilian coast. Taking into account the unique endemic species and the ecosystem richness present throughout the coast and the lack of conclusion about the potential cause of damage to these structures, irreversible damage can be caused (GORAYEB *et al.*, 2022).

2 CONCEPT AND OFFSHORE WIND FARMS AROUND THE WORLD

2.1 OFFSHORE WIND FARM CONCEPT

The term "offshore" in literal translation means "off the coast". According to IBERDROLA (n.d.), offshore wind is characterized by the deployment of large wind turbines at sea, having as a differential the use of wind from the high seas; This one having greater speed, constancy and stability, which is due to the lack of geographical barrier. The construction of these plants requires a more complex construction process in view of the difficulties imposed by the environment.

2.2 ADVANCEMENT IN THE USE OF WIND ENERGY AND OFFSHORE POWER PLANTS IN THE WORLD

The industrial revolution, set in England at the end of the nineteenth century, was a milestone of change in the economic dynamics of the whole world (ALVES; SHAH; MAARRA, 2011). This change in dynamics also boosted the search for energy sources; highlighting the use of fossil fuels (oil, natural gas, coal, among others) as an energy source, in view of its great energy value (CUNHA *et al.*, 2019).

However, the environmental impacts caused by the use of these energy sources have generated debates and the search for renewable energies. Thus, in 1888 the American Charles Bruch developed the first wind turbine (CUNHA *et al.*, 2019).

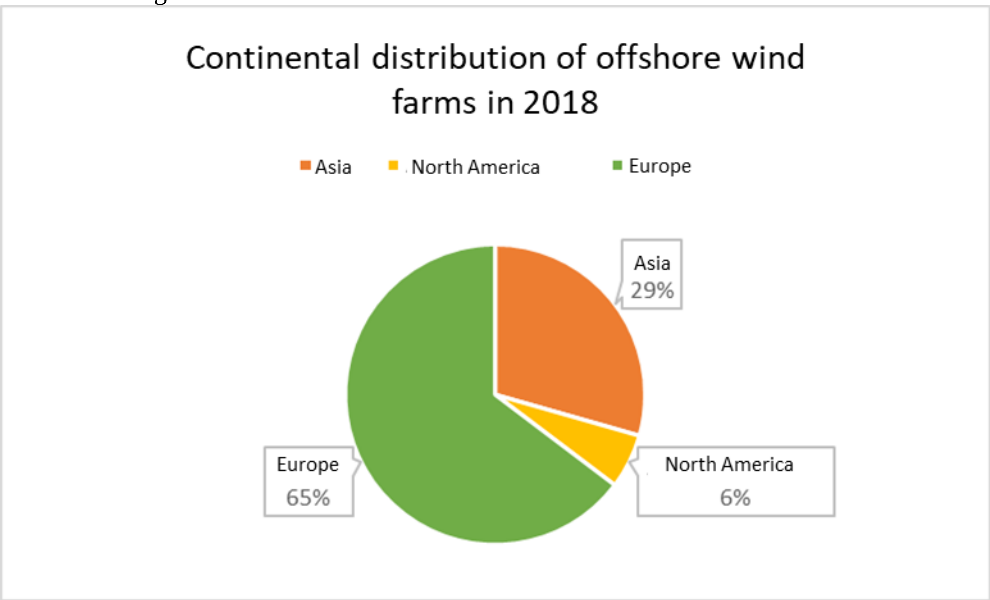
Almost a century later, because of the difficulties generated by the oil crisis in the 70s, the manufacture and optimization of what would come to be called a wind generator was being done on a commercial scale (CUNHA *et al.*, 2019). With mass production the number of turbines jumped from 150 in 1981 to 16000 in 1985; a significant leap in four years (CUNHA; *et al.*, 2019).

In order for advances in the implementation of wind farms to occur, investments in research and development programs needed to be made, as well as changes in legislation in order to generate resources. In this way, developed countries have emerged in this technology, while advances in underdeveloped countries were slower (CUNHA; *et al.*, 2019).

In 1991, in Denmark, seeking greater energy capacity and use of winds from the open sea, the first offshore wind farm in the world was built; being a pilot project that sought to analyze the energy and economic feasibility, called "Vindeby offshore Wind Farm" (NETO and MONTEIRO, 2023).

Since the installation of the first offshore wind farm in Denmark, the search for the use of this technology in the world has intensified; especially in European countries, where the geographical issue, smaller coastal zone, and energy end up leading these countries to opt for this technology (NETO and MONTEIRO, 2023). The disposition of offshore wind farms in the world in 2018 is presented in Figure 1.

Figure 1 - Continental Distribution of Offshore Wind Farms in 2018



Source - Global Wind Report – (GWEC, 2022)

What can be observed is the disparity in the distribution of offshore wind farms around the world. Countries located on the European continent totaled 11 parks. Within this amount, the United Kingdom and Germany stand out with a total of three-quarters of all power generation, with the other amount divided by Belgium, Denmark and the Netherlands (NETO and MONTEIRO, 2023).

With 165 turbines, the largest offshore wind farm is located in Denmark, with a potential of 1.32 GW, and can provide energy to 2.3 million homes (NETO and MONTEIRO, 2023).

The Global Wind Energy Councs (GWEC) is a board made up of the entire wind energy industry, representing a total of 1500 wind energy companies. Annually they conduct studies and compile them into a document entitled Global Wind Report.

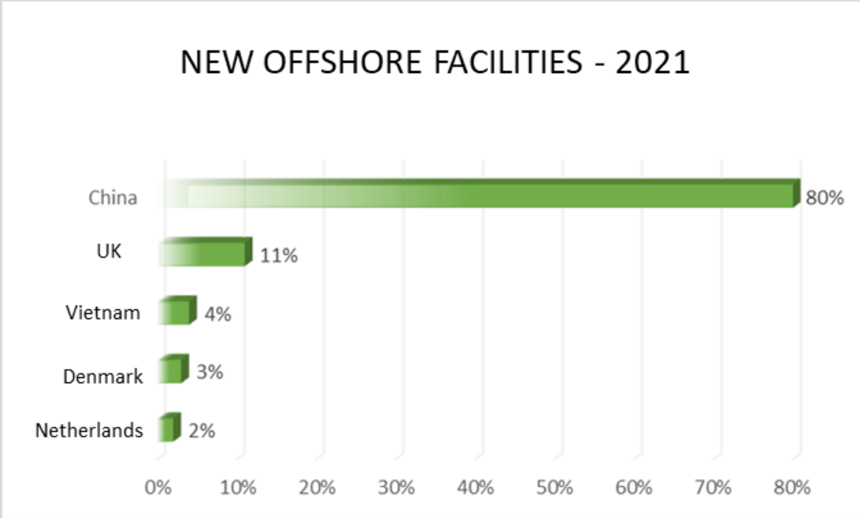
It was found by GWEC that the year 2021 for offshore wind was a historic year. For, 21.1 GW of offshore wind power has been connected to the grid in the world. As a result, offshore wind capacity grew to 57.2 GW by the end of 2021.

Within the prospect of increase, China has outperformed other competitors for four consecutive years and now has a total of 27.7 GW of offshore wind installed, doing what GWEC says Europe has spent three decades to achieve. China, working intensively, has been approving projects, according to GWEC, since before 2019, taking as a reference two offshore wind provinces, Jiangsu and Guangdong, which, adding the energy potential, together have a capacity of 26 GW.

2.2.1 New Offshore Wind Power Plant Projects

In the big picture, according to GWEC, China leads in number of projects, having a percentage of 80% of all offshore projects in the world. Next up is the United Kingdom, with 11%. It is worth mentioning the participation of Vietnam which, among the others, appears ahead of the Netherlands and Denmark in number of projects (**Figure 2**).

Figure 2 – Distribution in several countries of new Offshore installations in 2021



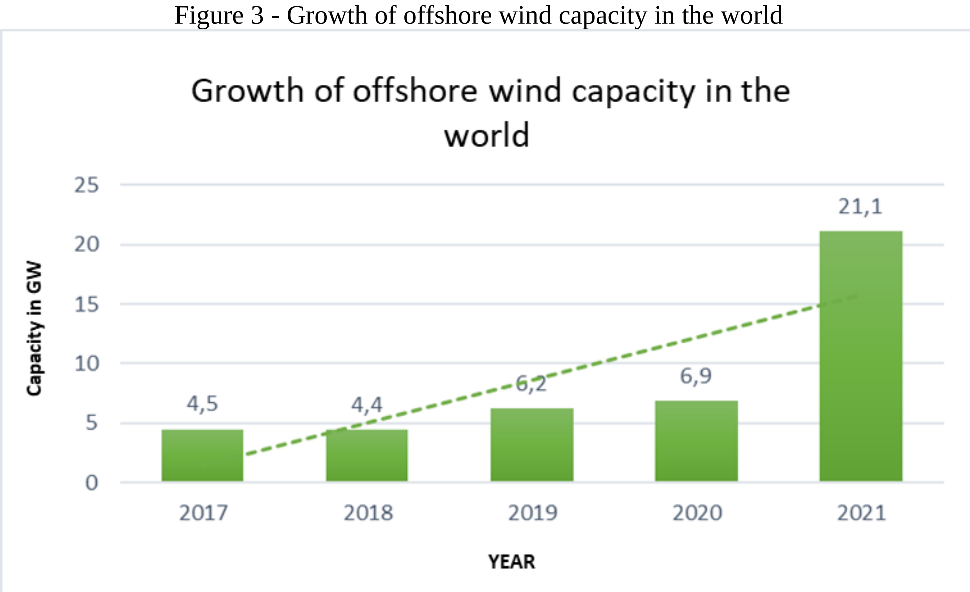
Source - Global Wind Report - (GWEC, 2022).

GWEC also states that the rest of the world, without determining which countries enter this panorama, figures with only 1% in relation to new offshore wind farm projects.

2.2.2 Offshore wind power plants operating around the world

According to GWEC, 96.6 GW of wind power capacity was connected to the grid worldwide in 2021. Within this capacity, 21.1 GW correspond to offshore wind power plants and 72.5 GW correspond to onshore plants. There is still a very large disparity, however offshore companies have been growing since 2017, as shown in Figure 3.

Figure 3 - Growth of offshore wind capacity in the world



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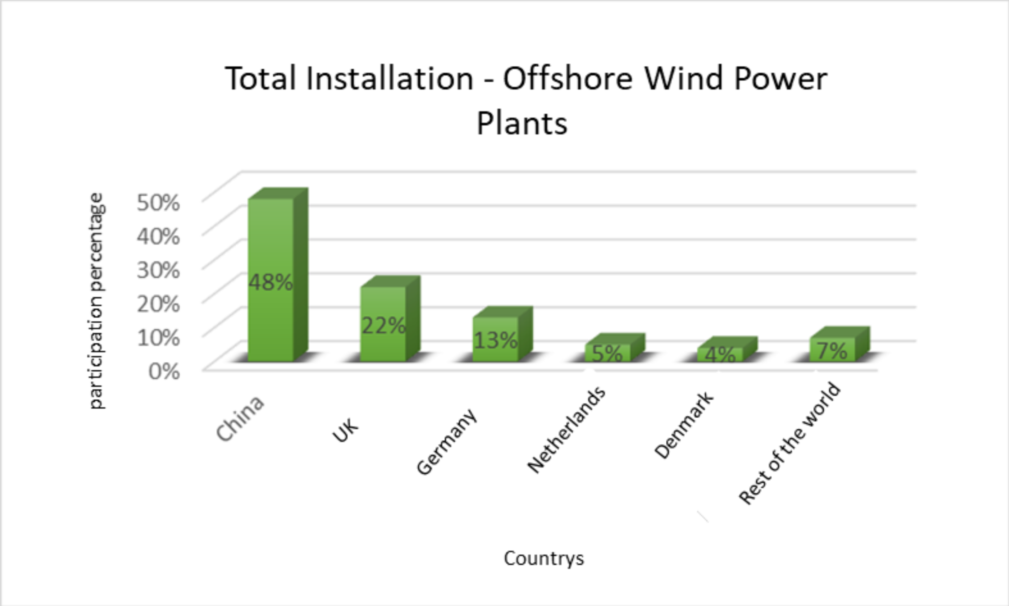
Source - Global Wind Report - (GWEC, 2022).

As you can see, the jump between the years 2020 and 2021 is large and considered historic, which demonstrates the growing evolution and application of this type of wind farm. It is also interesting to say that, according to GWEC, China holds 48% of all offshore wind farms in the world, followed by far by the UK (22%), Germany (13%), the Netherlands (5%) and Denmark (4%). It is noteworthy that GWEC states that the rest of the world owns 7% of offshore wind farms (Figure 4).

Figure 4 – Percentage of installations of offshore wind farms in the world.



Source - Global Wind Report - (GWEC, 2022).

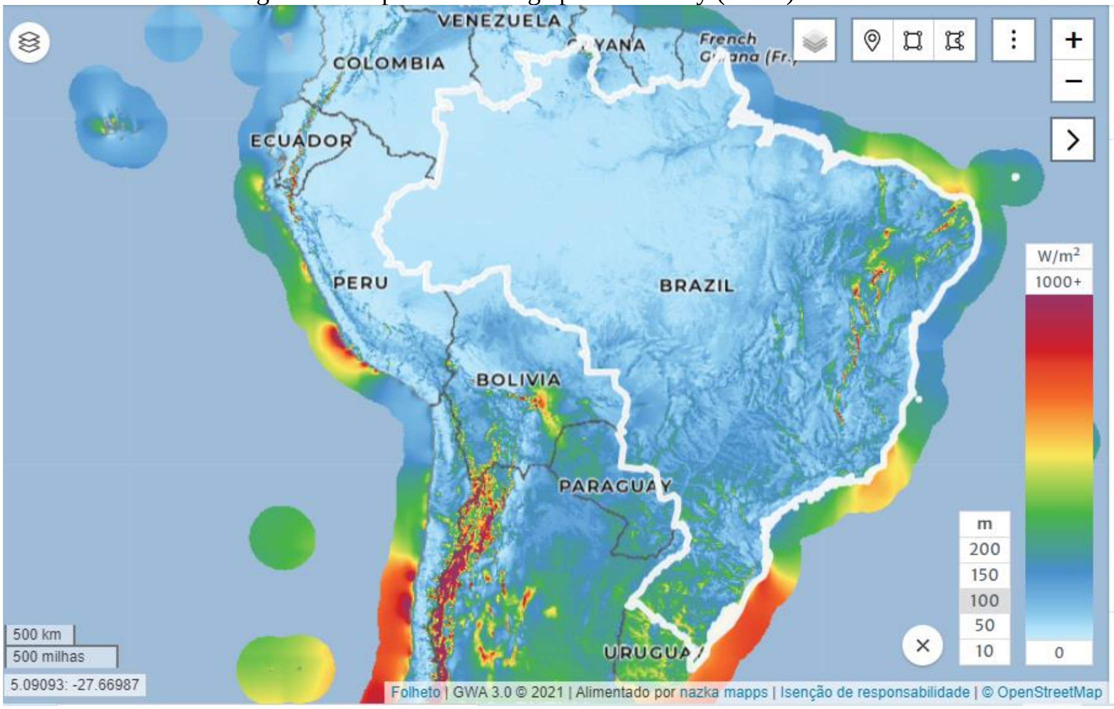
2.3 OFFSHORE ADVANCEMENT AND PROJECTS IN BRAZIL

Brazil has an attractive energy potential for the construction of offshore wind farms. Adding the coast of the South, Southeast and Northeast regions has a potential of approximately 3 TW and an estimated average annual production of more than 14,800 TWH; calculations made based on the height of the towers and the wind speed (GORAYEB *et al.*, 2022).

> China and Brazil have the highest energy potential with more than 7,000 TWH/year of electricity generation; having in return a high cost to achieve this generation (GORAYEB *et al.*, 2022).

Observing the map generated from the Global Wind Atlas that demonstrates through colors the average power density in W/m² generated from winds at 100 meters high; The parts closest to the red color are those with the highest average power density.

Figure 5 - Map of the average power density (W/m²) - 100m.



Source - Global Wind Atlas (Self-Authored) (2023).

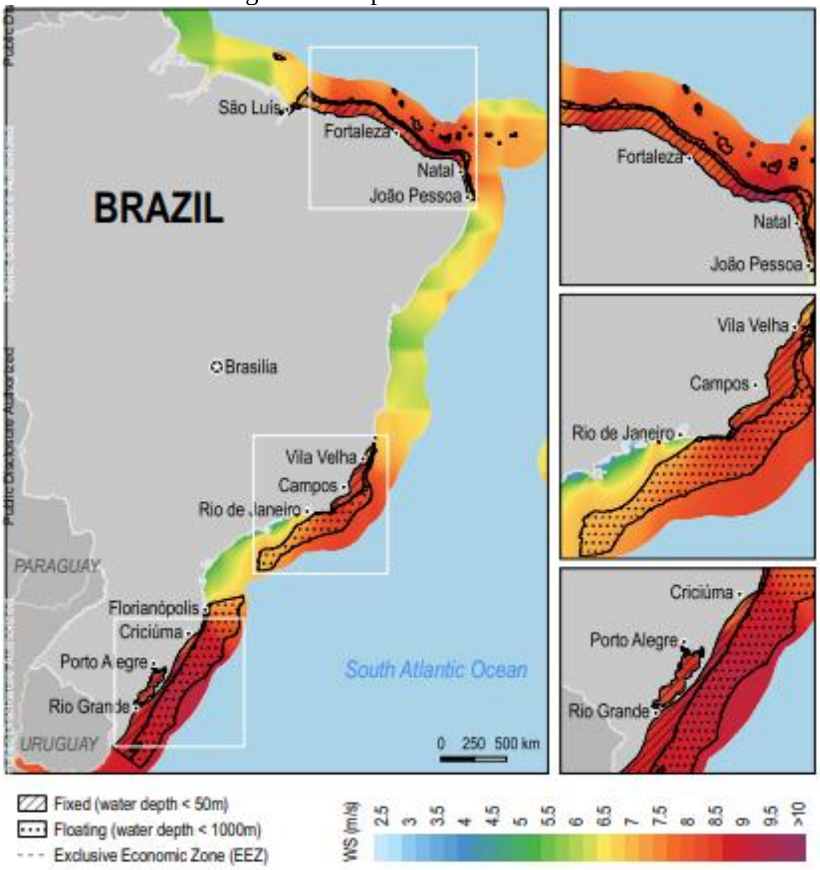
Figure 5 shows the map obtained through the Global Wind Atlas, which highlights the regions of the Brazilian coast where the greatest energy potential is found; containing a sample of the estimated technical potential for offshore wind farms, both floating and fixed, over a distance of up to 200 kilometers from the coast.

As shown in Figure 6, the map of the Northeast, Southeast and South regions stand out in relation to the others; Both have greater energy potential, attracting investments and studies for the installation of offshore wind farms.

Brazil does not yet have any offshore wind power plant in operation, however, there are several projects aimed at the construction of plants. According to GORAYEB *et al.* (2022), the number of projects has been increasing since 2020, with 6 initial projects in the environmental licensing phase. A year later, in 2021, Brazil already had 25 projects. Also according to GORAYEB *et al.* (2022), in January 2022, Brazil had 37 projects, increasing this number later, in April of the same year, to 46 projects.

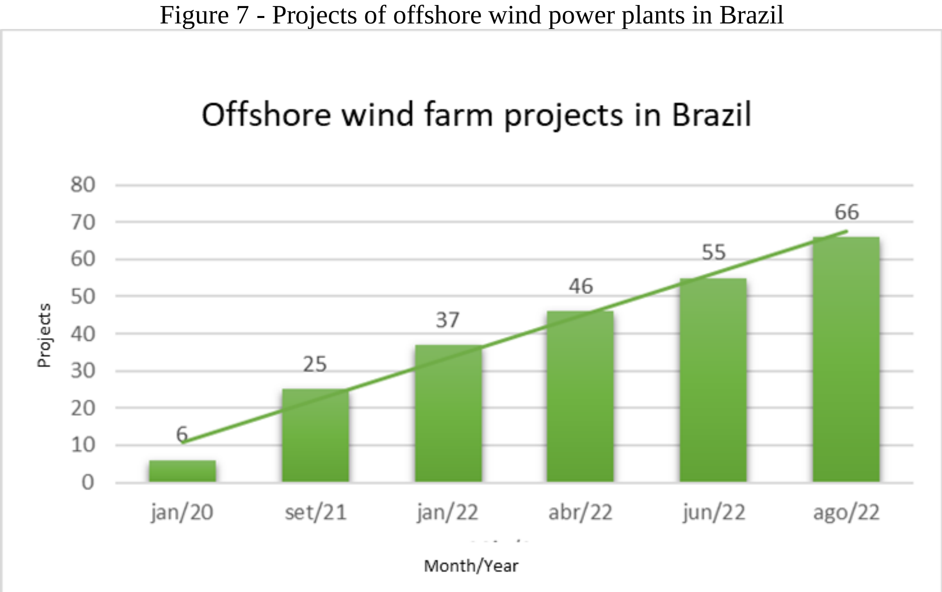
According to the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), in August 2022 Brazil already had a total of 66 offshore wind power projects, with a total combined power of 169,441 MW.

Figure 6 - Map 2 - Areas of interest



Source - Global Wind Atlas (2023).

Figure 7 - Projects of offshore wind power plants in Brazil



Source - SEI/IBAMA (2022).

2.4 LACK OF IMPACT STUDIES AND REGULATION

Brazil is rich in marine biodiversity and has unique species and elements throughout its coastline. For this reason, there are questions related to the damage that can be caused with the installation of offshore wind farms. In a list, the Energy Research Company (EPE), also mentioned that, in relation to the installation of this type of structure, what worries is the imprecision related to the potential socioeconomic clashes that may figure in these scenarios (GORAYEB *et al.*, 2022).

Second Gorayeb *et al.* (2022), when analyzing the licensing applications through the SEI of IBAMA, it can be seen that in relation to the Environmental Impact Study (EIA) there were no in-depth or conclusive studies in relation to the potential damages to ecosystems and communities near the projects. It is worth mentioning that even having a legal framework for offshore wind energy, which is Decree No. 10,946 of January 25, 2022, there is no participatory planning of marine space in Brazil (GORAYEB *et al.*, 2022).

It is interesting to mention that, according to Gorayeb *et al.* (2022), based on data from the SEI/IBAMA, among the projects analyzed, there was one that in its study of environmental impacts (EIA) had performed superficial diagnoses and with analysis flaws regarding the marine environment. This project had its application for a prior license (LP) denied, due to the lack of a series of important steps such as marine environmental zoning, monitoring measures, among others. This demonstrates that, if there is flexibility for the installation of this type of plant, irreversible damage to the Brazilian marine environment can be caused.

3 SOCIO-ENVIRONMENTAL IMPACT OF OFFSHORE COMPANIES IN THE BRAZILIAN NORTHEAST

3.1 IMPACTS DURING THE IMPLEMENTATION PHASE

According to Fadigas (2011), the construction of a wind farm is composed of several stages that generate many environmental impacts. In the construction phase, the main impacts are caused by the processes are presented in Table 1.

Table 1 - Processes and activities carried out in the construction phase of a wind farm

PROCESS	ACTIVITY
Rehabilitation of paths:	Lane widening, rectification of curves, regularization/reinforcement of pavements and drainage works.
Opening of paths:	Land clearance/deforestation, removal and deposit of vegetable land, excavation/landfills/compaction
Execution of drainage system:	Construction of ditches, aqueducts, pontoons, and in certain situations paving (gravel, asphalt.
Transport of materials:	Transportation of clay, vegetable land and rock, among others.
Trenching of ditches:	Installation of the electrical cables for interconnection between the wind turbines and the substation and control building.
Opening holes:	For the foundations of the towers of the wind turbines.
Concrete of the massifs:	Concreting of the foundation of the towers of the wind turbines;

Implementation of the interim platforms:	Assembly of wind turbines;
Transport and assembly:	At the site of the wind turbines, perform the assembly of the tower, cabin and blades;
Construction of the substation and command building:	Transport and assembly of substation and command building equipment;
Installation of the power line:	Delivery of the energy produced by the wind farm to the receiving grid.

Source - FATIGUES (2011)

3.1.1 Landscape restoration of the areas intervened

In addition to the impacts listed above, during the work, the implementation of an offshore wind power plant may cause some significant environmental impacts on many species of local fauna, which suffer from the disturbance caused by the construction phase of the park. Several animals, such as mammals, reptiles and amphibians, suffer from injuries and crushes, to the disturbance of their places of feeding, rest and reproduction.

Some of the major environmental impacts that can occur during the deployment of an offshore wind farm include:

3.1.2 Disturbance of marine habitat

The installation of offshore wind turbines can disrupt marine habitats, including marine life such as fish, crustaceans, birds and marine mammals. Construction activities, such as the installation of submarine cables and the construction of anchoring platforms, can interfere with natural ecological processes and disrupt marine life.

3.1.3 Seabed erosion

The construction of anchoring platforms and the installation of submarine cables can cause erosion of the seabed, which can affect marine habitat and lead to environmental degradation.

3.1.4 Noise

Construction operations, such as drilling, pile installation and hammering, can generate high levels of noise, which can affect marine life and cause noise disturbance.

3.1.5 Oil and other chemical spills

The construction and installation of offshore wind farms can involve the use of chemicals and oil, which can pose a risk of accidental spills.

3.1.6 Ecosystem change

The deployment of an offshore wind farm can alter the marine ecosystem around the plant, affecting water circulation and the distribution of nutrients and oxygen.

3.2 IMPACTS DURING THE OPERATION/MAINTENANCE PHASE

During the operation phase of an offshore wind farm, environmental impacts can include noise generation and disturbance of marine communities.

3.2.1 Visual impact

Offshore wind farms tend to have larger and more numerous turbines than onshore developments. Despite this, the visual impact is smaller, since these structures are located at a greater distance from the coast. However, it is important to consider that the coastal landscape is often unique and valued, so it may be necessary to pay special attention to this aspect (SDC, 2005).

Offshore wind farms can affect three components of the seascape: the area of the sea, the length of the coastline, and the land area. Several elements influence the character of the visual impact of these parks, including the location and size of the park area, the size, materials and colors of the turbines, the layout and spacing of the structures, the location and size of the substations, the visibility of the navigation lights, the transport and maintenance boats, and road or trail access, as well as the requirements of access to the coast (WRATTEN et al., 2005).

The magnitude of the change in the seascape with the construction of a new offshore wind farm depends on several factors, such as the distance, the number of visible turbines, the weather conditions and the navigation lighting of the turbines. The distance between the observer and the wind farm usually has the greatest influence on the perception of visual impact, but changes in lighting and weather conditions can have different visual effects even at the same distance.

3.2.2 Noise

Open sea wind farms are located far from human populations, which are not affected by the noise generated by wind turbines. However, marine animals can be affected by underwater noise generated during the construction and operation of wind turbines (KÖLLER; KÖPPEL; PETERS, 2006).

The rotation of the propellers and the aerodynamic effect of the wind cause noise emission of 50dB near the wind towers. The minimum distance between a wind turbine and a residence is 200m, where the noise is reduced to 40 dB (CEMIG, 2012).

On the other hand, in communities near wind farms, the noise of turbines can be a factor that leads residents to constant complaints. The spread of noise is one of the main concerns of these communities, considering it as one of the most bothersome impacts. Especially at night, when the wind is more intense (GUIMARÃES, 2019). The sound, which is produced by the blades, especially at night, comes to bother the families living near the wind turbines. (GUIMARAES, 2019).

3.2.3 Underwater structures

The effect of floating structures on fish aggregation behavior was evaluated by Castro et al. (2002), who suggested that wind farms may function as fish aggregation devices, resulting in catch rates in the immediate area ten to one hundred times higher than in the open surrounding ocean. This can be attributed to a combination of shelter provided by the structures and reduced fishing effort, often observed around offshore wind farms.

3.2.4 Climate change

According to Biello (2010), when analyzing the temperature records of the Roy and Justin wind farm in San Gorgonio, USA, it was discovered that the wind generated by the turbines can cause changes in the local temperature, warming the surface at night and cooling during the day. Although this analysis suggests the presence of environmental impact of giant wind turbines, it is still necessary to investigate whether this impact is positive or negative.

According to Keith et al. (2004), the simulation of the climate impact of wind turbines was performed by changing the surface drag coefficients in two general circulation models. The results indicate that wind energy can induce climate change on continental scales, but its effect on average surface temperature is relatively low.

3.3 IMPACTS DURING THE DECOMMISSIONING PHASE

Decommissioning an offshore wind farm involves a number of impacts that need to be carefully managed. These impacts can occur at different stages of decommissioning, including the removal of equipment, the dismantling of infrastructure, and the restoration of the area.

One of the main impacts of decommissioning an offshore wind farm is the environmental impact. During the decommissioning phase, it is important to ensure that equipment is removed in a safe and efficient manner, minimizing the amount of waste and contaminants released into the environment. In addition, it is important to monitor impacts on the surrounding marine ecosystem in order to minimize disturbance of natural habitats and protect biodiversity.

Decommissioning a wind farm can generate a large amount of waste that needs to be disposed of properly to avoid environmental degradation. It is the responsibility of the industry to minimize the impact on all phases of the life cycle of a wind farm, including the post-operation phase, as highlighted by Machuca (2015).

Finally, the decommissioning of an offshore wind farm can also have impacts on maritime safety. During the decommissioning phase, it is important to ensure that the remaining infrastructure is safely removed so as to minimize the risk of accidents and ensure the safety of navigation in the area.

3.4 BRAZILIAN BIODIVERSITY

3.4.1 Fauna and flora

According to Oortman, Rhoden, Gern (2019), human action such as oil spills and industrial contaminants leads to alteration of the marine microbiome. The microbial community plays a fundamental role in the evolution and maintenance of marine ecosystems due to its essential role in processes such as nitrogen fixation, ammonification and denitrification, phosphate solubilization, sulfate reduction, photosynthesis and methanogenesis, maintaining about 98% of the carbon and nitrogen flow, in addition to nutrient cycling.

It is known that there is a huge variety of endemic and migrant species on the Brazilian coast of birds, mammals, cetaceans and sharks in addition to coral reefs, benthic biota and pelagic biota, especially at the depth of up to 50 meters, however, due to the lack of knowledge of the migratory characteristics, reproduction and seasonality of these species during the installation of wind farms, can cause negative environmental impacts (HERNANDEZ et al., 2021).

The installation of offshore wind farms causes alteration in bird habitat. Seabirds can suffer impacts of two types: by collision when birds cannot dodge wind turbines; and by relocation or displacement, when they avoid the area of the enterprise, affecting their feeding, reproduction and migration routes, requiring more time and energy for the flight (BUGONI et al., 2022).

The benthic community includes organisms such as bacteria, plants and animals from invertebrates to other species such as starfish and crabs that live in sediments, or on the seafloor. These organisms are negatively affected during the construction phase of these plants, as they are very sensitive to light, temperature and turbidity. There is evidence due to the creation of artificial reefs in the structures, providing a new habitat for benthic organisms (BUGONI, et al., 2022).

During the useful life of the park, there is the negative impact generated by sounds and vibrations, affecting sensitive animals, such as mammals, which use their auditory system for communication, orientation and hunting, which when exposed to noises, lose the ability to interpret the environment and move away from the area (HERNANDEZ et al., 2021).

4 FINAL CONSIDERATIONS

Brazil and China have great potential for offshore wind generation, however there are costs that must be taken into account. Even having great energy potential, the lack of balance between innovation and the environment, encompassing the social environment, can generate irreversible damage. Thus, the movements of machinery, as well as the preparation of construction sites for the installation of towers can generate impacts to aquatic and terrestrial ecosystems. Impacts can extend into the operation phase, where damage can be prolonged. In addition, there are several endemic species that can be affected. In this way, it is essential to carry out in-depth studies that reveal the physical, chemical and biological characteristics of the space to be used, a survey that is integrated into all phases of the project, as well as a strict supervision during construction and monitoring throughout the life of the plant.

ACKNOWLEDGMENT

The authors thank the Scholarships granted by FACEPE (Foundation for the Support of Science and Technology of Pernambuco) Process No. IBPG-2212-3.06/22 to Itamar Victor de Lima Costa; by CAPES (Coordination for the Improvement of Higher Education Personnel) Process No. 88887.829767/2023-00 to Alcides Miguel da Silva Júnior; Process No. 8888788887.840366/2023-00 to Fernanda Nathália Carneiro da Cunha; and the Grant granted by CNPq (National Council for Scientific and Technological Development) Process No. 312241/2022-4 to Galba M. Campos-Takaki and the Catholic University of Pernambuco for the availability of academic and laboratory spaces.

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