OPPORTUNITIES AND CHALLENGES FOR OFFSHORE WIND POWER PRODUCTION IN BRAZIL AND THE PRODUCTION OF LOW CARBON HYDROGEN

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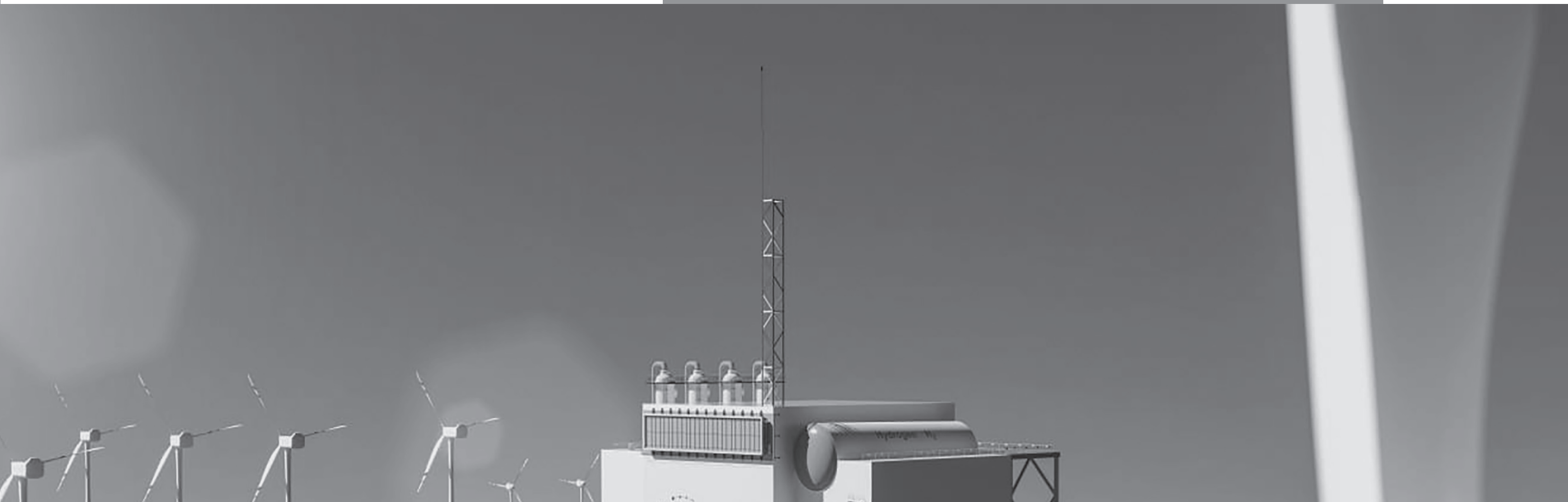

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SUMMARY

PRESENTATION

Brazil, with its long coastline and favorable wind conditions, is well positioned to become a leading country in offshore wind power generation. This modality, which brings many benefits, is an integral part of the Industry strategy for a Low Carbon Economy and its promotion is one of the priorities of the Industry Recovery Plan.

Offshore wind farms worldwide supplied 21 GW of energy in 2021 – the number of systems tripled compared to the previous year. It is estimated that 260 GW of new capacity could be added by 2030, bringing total global capacity to 316 GW by the end of this decade. To achieve this, investments of up to $1 trillion are planned.

The successive world records have not yet had a major impact in Brazil, as the offshore energy potential of around 700 GW has not yet been fully explored. The projects are multiplying – there are 170 GW in environmental permit applications at Ibama – but the rules for implementing the wind farms are unclear.

Consolidating this value chain in Brazil could stimulate the economy and facilitate the resumption of industrialization. In addition to providing a clean and renewable source of energy, the sector is expected to create jobs, promote technological and scientific development, reduce dependence on non-renewable sources, and contribute to the country's energy security.

As the main raw material to produce low-carbon hydrogen, offshore wind power enables the implementation of new business models to serve both domestic and export markets.

There is room for all players in the chain to thrive, but there is an opportune time for companies to make investment decisions and a finite flow of resources to fund this market. The logistical complexity and costs associated with the installation and maintenance of offshore wind farms require significant contributions and a favorable regulatory environment.

This study identifies the main regulatory, market, infrastructure, and technological barriers to the exploitation of offshore wind potential in Brazil. It also includes recommendations on how this energy source can become one of the most important factors for the consolidation of the low-carbon hydrogen segment in Brazil.

Enjoy your reading.

Robson Braga de Andrade
President of CNI

EXECUTIVE SUMMARY

Brazil could take a leading role in offshore wind power generation by taking advantage of the benefits this industry can offer. Consolidating the offshore wind power value chain in Brazil could stimulate the economy and facilitate the resumption of industrialization. In addition to providing a clean and renewable source of energy, the sector is expected to create jobs, promote technological and scientific development, reduce dependence on non-renewable sources, and contribute to Brazil's energy security.

An estimated 260 GW of new offshore wind power capacity could be added worldwide by 2030, bringing the total number of offshore wind installations to 316 GW by the end of this decade. To achieve this, investments of up to $1 trillion are planned. The successive world records have not yet had a major impact in Brazil, as the offshore energy potential of around 700 GW has not yet been fully explored. The projects are multiplying – there are 170 GW in environmental permit applications at Ibama – but the rules for implementing the offshore wind farms are unclear.

The implementation of offshore wind farms to generate electricity offers the country the opportunity to produce low-carbon hydrogen not only for the domestic market but also for export. However, there are still many regulatory, market, infrastructure, and technological challenges in exploiting the potential of offshore wind power that need to be studied in more detail and discussed with society. The aim of this study is therefore to provide a diagnosis of the opportunities and main obstacles to the development of offshore wind projects for the production of low-carbon hydrogen in Brazil, as well as to provide suggestions and recommendations for the creation of an offshore wind power and low-carbon hydrogen market in Brazil.

Offshore wind power is an integral part of the Industry Strategy for a Low Carbon Economy and unlocking this agenda is one of the priorities outlined in the Industry Recovery Plan.

Potential and costs

According to EPE (2020), offshore wind power has a potential of around 700 GW, which may vary depending on technical, environmental, and economic constraints. In some cases, there are sites that are not suitable for the implementation of projects.

Offshore wind power has been following a cost reduction trend for the past eight years. In 2021, it saw increasing cost declines globally, despite supply chain constraints and inflation, as well as tougher source competition related to the energy transition.

The levelized cost of electricity (LCOE) for projects commissioned in 2020 decreased to levels just below $95/MWh, with a range of $78/MWh to $125/MWh globally, mainly due to technology improvements and increasing industry maturity . Capital expenditures (CAPEX) are the most representative life-cycle cost of offshore wind farms and include all costs incurred before commercial operation begins.

After a period of increase between 2014 and 2015 (Musial et al. 2017), CAPEX have declined, reaching around $3,750/kW globally in 2020. In turn, operating expenditures (OPEX) are more relevant for offshore wind power than for onshore wind power, with annual benchmark values in the range of $70-80/kW for offshore and $30-40/kW for onshore (Lazard, 2020).

Offshore wind power value chain

Offshore wind projects use similar technology to onshore wind projects (EPE, 2020), the main difference being the foundation. Since the commercialization of wind power technology began in the 1980s, there have been many developments and improvements, and the offshore wind power sector is a major contributor and has excelled in innovation and technological improvements over the past 30 years.

There are different types of foundations for offshore wind turbines, but three main types could be mentioned: monopile, jacket, and floating. Each of them, with its advantages and disadvantages, has a direct impact on the safety and maintenance of offshore structures. Currently, the most common foundation type for offshore wind turbines is the monopile: a single pile with a diameter of six to eight meters and a length of 20 to 30 meters under the seabed. Jacket foundations also stand out, and their use is expected to more than quadruple in future projects. As wind farms move further out to sea and into deeper waters, the use of floating wind turbines is expected to increase.

Essentially, the offshore wind power value chain consists of the following elements:

- Design, development, and engineering;
- Offshore logistics: marine services;
- Manufacture and supply: wind turbines; foundations; substations and submarine cables;
- Construction and installation of wind turbines; foundations; substations and laying of submarine cables;
- Commissioning;
- Operation and maintenance of wind turbines and plant balance (foundations, substations, and submarine cables); and
- Decommissioning.

Synergies between the oil and gas and offshore wind power value chains have been consolidated in several areas of activity that rely on the adaptation of known solutions. These include project planning, installation of connections to the power grid (substations and submarine cables), and operations and maintenance. As with any emerging offshore wind power market, the supply chain in Brazil must be widely developed to reap the maximum local benefit from the growth of this industry.

Offshore wind power regulation

Offshore projects are subject to a specific regulatory structure that may contribute to investments in some pilot plants in the coming years. Decree 10,946, dated January 2022, provides the rules for "assignment of use of physical spaces and the exploitation of natural resources in inland waters under the control of the Federal Government, in the territorial sea, in the exclusive economic zone, and on the continental shelf for the generation of electricity from offshore projects". It specifies that it must be free of charge, when focused on research and development (R&D), or for consideration, when focused on operating a generation facility. In addition, it may also be planned or independent, depending on how the prisms or polygons are provided.

Complementary to Decree No. 10,946/2022, two regulations were published in the Official Gazette of the Federal Government in October 2022. Normative Ordinance of the Minister's Office of the Ministry of Mines and Energy (GM/MME) No. 52/2022 deals with the "assignment of use for consideration for the operation of an offshore power generation facility within the framework of independent power production or self-production of energy", and Joint Ordinance of the Ministry of Mines and Energy and the Ministry of Environment and Climate Change (MME/MMA) No. 3/2022 creates the Unified Portal for Managing the Use of Offshore Areas for Power Generation (called PUG-offshore).

PUG-offshore is intended to be a "one-stop store" for projects, through which all assignments of use applications must be processed. The aim is therefore to avoid overlapping projects in the same area, reduce information asymmetry between the private and public sectors, and thus ensure greater transparency in the market.

The decree and the two Ordinances seek to exclude the possibility of creating a market for the assignment of use of areas in order to reduce the risk of speculation. These non-statutory instruments contribute to legal certainty but are not legally binding. In this case, the Brazilian Congress is currently processing Bill of Law (PL) No. 576/2021, which follows the procedural rules of the Legislature Power.

The question remains whether the law adopted based on this PL will contradict these Ordinances and the Decree. Since the market participants involved in drawing up the regulations are the same, it is to be expected that the regulatory instruments that have already been adopted and are being examined will be aligned if necessary.

Offshore wind power for low-carbon hydrogen production

As of December 7, 2022, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) had 70 offshore wind projects pending environmental permitting procedures, totaling 176,581 MW of installed capacity (IBAMA, 2022). The key question is how the electricity sector will absorb all these expected developments and expansions in electricity generation. Low-carbon hydrogen is one way to make these projects profitable.

Brazil has the potential to lead the world in low-carbon hydrogen production. The country has great renewable energy potential, an extensive coastline, and a privileged location to access the markets with the greatest demand for hydrogen imports. On June 23, 2022, the Brazilian National Council for Energy Policy (CNPE) published Resolution No. 6, which created the National Hydrogen Program (PNH2) and established the leadership structure of the initiative. On August 17 of the same year, GM/MME Ordinance No.164 was published, which established the composition of the Management Committee for the National Hydrogen Program (Coges-PNH2). This will be crucial for the development of the market in Brazil.

Although there is still no fixed roadmap in Brazil, the market has already evolved. A consumer market for low-carbon hydrogen is unlikely to emerge for another 2-3 years, but the agreements, MOUs (Memorandums of Understanding), and infrastructure development must begin for Brazil to position itself in the market. Several projects have been announced in the last two years.

In 2010, 95% of the hydrogen (H_2) used in Brazil was produced from fossil sources (CGEE, 2010). This represents a major opportunity for Brazilian industry to advance decarbonization, maintain its relevance in view of the energy transition, and play a leading role in the development of the low-carbon hydrogen market. It is also envisaged that production will be destined for foreign markets, particularly Europe. The hydrogen produced in the country also has the potential to develop the market for fertilizers, as most of these products contain nitrogen and use ammonia as the basis for the manufacturing process.

In the steel industry, low-carbon hydrogen can be used to produce the steel known as “green steel”, which is proving to be a major opportunity worldwide to replace fossil fuels in industrial processes. Like the steel industry, refineries are also large consumers of gray hydrogen. Gray hydrogen produced by reforming natural gas could be replaced with low-carbon hydrogen. Another alternative to decarbonization that is considered very powerful is the production of methanol using low-carbon hydrogen, in addition to its applications in the transport sector and electricity storage.

For the production of hydrogen from the electrolysis of water using offshore wind power to become sustainable, the learning curve must evolve significantly over the next 10 years, just as it has with onshore wind and solar photovoltaic power over the last 20 years .

Project proposals

Based on the data presented in this document, project proposals were made for the areas with the greatest potential for hydrogen production projects with offshore wind power in Brazil. The first step is to look at the potential for offshore wind power and the demand for hydrogen for both foreign and domestic markets.

The Northeast region has the greatest potential for wind power production in Brazil, including offshore. It is the region with the highest average annual capacity factor due to better wind consistency and has areas of great potential for which permits have not yet been issued. Due to its proximity to the countries of the northern hemisphere, northeastern Brazil is particularly suitable for the export of H_2. An example is the port of Pecém, which has invested in becoming an H_2 hub, also for exports.

In the Southeast region, there are several areas with overlapping permit applications. There are ports such as Açu, Macaé, Rio de Janeiro, Itaguaí, and Angra dos Reis that could also be developed into H_2 hubs. In addition, there is the construction of Porto Central, which is located on the border between the states of Rio de Janeiro and Espírito Santo and is intended to become an energy hub. The state of Rio de Janeiro has important highways that can facilitate the creation of these hubs and connections to industry, including those in São Paulo and Minas Gerais.

In the South region, the potential of Rio Grande do Sul (RS) is practically reduced to Lagoa dos Patos lagoon when environmental, economic, and technical constraints are applied, since the coast of this state has a large conservation area mapped. Anticipating steps in this direction, the RS Secretariat of Environment and Infrastructure (Sema) has completed the preliminary study for the future public notice to assign the use of areas (lots) in the lagoon. It can be said that from the demand perspective, the South region's vocation for using offshore wind power is more geared towards the electricity-intensive industry.

Barriers and recommendations

In order for the great potential for the exploitation of offshore wind power in Brazil to be realized, the following are required: (i) overcoming some regulatory and institutional barriers to create a safe environment for investors; (ii) creating a new market inside and/or outside the country for the consumption of the energy produced; (iii) investing in infrastructure so that this energy is competitive; and (iv) improving the country's technological infrastructure so that this industry performs in a way that makes it competitive.

In this study, we address and discuss the main barriers related to (i) regulatory, (ii) market, (iii) infrastructure, and (iv) technological aspects. Environmental aspects were considered in the discussions and addressed within the regulatory framework. To overcome such barriers, recommendations were made aimed at mapping opportunities for using offshore wind power generation to produce low-carbon hydrogen.

Ten regulatory barriers were identified and 10 recommendations were made to overcome these barriers. For the 9 market barriers identified, 10 recommendations were proposed to address them, in addition to 10 recommendations for the 7 infrastructure barriers identified. Finally, 4 technological barriers were identified and 6 recommendations were made to overcome them.

Recommendations for further study

According to the study, to further the discussion and present a detailed diagnosis of the barriers encountered, the following is still needed:

- Mapping the stakeholders involved in this market so that conflict points and possible alliances between them can be assessed.
- Clearly defining the criteria to solve the problem of overlapping assignment of areas with a permit application at IBAMA.
- Reducing uncertainties in the cost of offshore wind projects for hydrogen production, using simulations methods to better estimate these costs, including the evaluation of technological alternatives.
- Exploring alternatives for economic and financial incentives to make offshore wind projects viable for hydrogen production, taking into account international experiences.

1 INTRODUCTION

Brazil, with its long coastline and favorable wind conditions, is well positioned to become a leading country in offshore wind power generation and take advantage of the benefits this industry can offer. Offshore wind power is an integral part of the Industry Strategy for a Low Carbon Economy and unlocking this agenda is one of the priorities outlined in the Industry Recovery Plan.

The expansion of renewable energy is also part of Brazil's commitment to the Paris Agreement, the main goal of which is to reduce greenhouse gas emissions and limit global temperature rise. To achieve this goal, the countries that have signed this agreement have established their Nationally Determined Contributions (NDC). Brazil's current NDC establishes that the country must reduce its greenhouse gas emissions by 37% by 2025 and 50% by 2030, based on 2005 emissions. Furthermore, in 2022, Brazil committed to achieving net zero emissions by 2050 (BRAZIL, 2022).

Offshore wind power generation can make an important contribution to the expansion of renewable energy production in Brazil. According to EPE (2020), wind power has a potential of around 697 GW, which is certainly well beyond current electricity needs and represents a major opportunity for low-carbon hydrogen (H_2) production.

If this potential is properly harnessed, the hydrogen produced from offshore wind power can not only supply the domestic market, but its derivatives can also be exported. This is an opportunity to increase the competitiveness of Brazilian industry, attract large amounts of foreign investment, and create new business models with greater added value in the country, with new clean technologies and innovations.

Achieving this requires addressing a range of regulatory, market, infrastructure, and technological challenges.

In the wake of the pandemic and given the ongoing war between Russia and Ukraine, uncertainties surrounding the renewable energy production value chain have intensified. Some parts of the systems are imported from Asian countries, primarily China, and there is already a noticeable increase in prices on international markets, which is reflected in the levelized costs of wind power production. A study conducted by Bloomberg New Energy Finance (BNEF, 2022) shows that the cost of new onshore wind farms has increased by 7% in recent years, while the cost of solar farms has increased to 14%, temporarily falling back to 2019 levels (Canal Energia, 2022). However, the cost increase was partially offset by higher plant efficiency.

The estimated investment costs of offshore wind farm projects are about twice those of onshore projects (EPE, 2020), with total installation costs of about US$2,850/kW (IRENA, 2018). Such values are high mainly due to the cost of foundations, installation, and transportation of structures, which is one of the main challenges in realizing offshore wind power investments in the country (EPE, 2020). Therefore, building a global supply chain is one of the most complex issues related to the development of a global offshore wind power industry (GWEC, 2019). The European market succeeded in increasing the competitiveness of offshore wind power by creating a supply chain, which required large volumes of investment.

The technologies used in onshore and offshore wind projects are similar. Offshore turbines offer some advantages, such as the ability to use more constant and higher wind speeds (EPE, 2020). Knowledge of the operating conditions of these turbines at sea has improved. In addition, foundation structures of offshore wind projects have evolved to meet the new requirements associated with installation in deeper waters and increasingly larger and heavier turbines (NREL, 2017). As shown in the methodology of the International Renewable Energy Agency (IRENA, 2016), although the main concepts used in offshore wind platforms are already known to the oil and gas exploration sector, adaptations are needed to account for different dynamics and different efforts, which has already been the case for foundations in shallow water and transition zones.

In terms of infrastructure, it is essential that the ports support construction, assembly, and transportation services. In part, the existing structure to serve the oil and gas industry in some regions can be used, but the world is seeing the construction of facilities specifically designed to meet the needs of the offshore wind industry (EPE, 2020). The trend is to implement offshore wind projects in locations further and further away from the coast. Therefore, logistical challenges arise in the construction and maintenance of these structures. At the same time, new opportunities are emerging for companies operating in the Brazilian oil and gas market as they have deepwater expertise.

As far as regulation is concerned, in 2022 the first signs were set for those who want to invest in offshore wind power in Brazil, with the adoption of Decree No. 10,946, which regulates the assignment of use of physical spaces and the exploitation of natural resources in inland waters under the control of the Federal Government, in the territorial sea, in the exclusive economic zone (EEZ), and on the continental shelf.

The Decree was regulated by the GM/MME Normative Ordinance No. 52/2022 regarding the legislation on the assignment for consideration, which provides a possibility of exploiting the source for the production of low-carbon hydrogen. Despite the positive signs to the market given by the Decree, there was a lack of legal certainty and predictability of the guarantees that investors need to pioneer projects of this type in Brazil. Meanwhile, there have been a number of research and development (R&D) projects in this area that could bring more expertise and accelerate the implementation of wind farms once market conditions consolidate.

As for environmental regulations, in 2020 Ibama published a Term of Reference (TR) for the Environmental Impact Study (EIA) and an Environmental Impact Report (RIMA) for offshore wind farms, which can support those interested in investing in this sector. The number of projects whose permit process has started at Ibama amounts to a total of 176.5 gigawatts (GW) of installed capacity (IBAMA, 2022). This is almost equal to the centralized installed capacity of the Brazilian electricity mix, which, according to Aneel, exceeded 190 GW in March 2023. Dealing with this demand for projects therefore represents a major challenge.

This study analyzes the scenario from different perspectives and diagnoses the opportunities and main obstacles for the development of offshore wind projects to produce low-carbon hydrogen in Brazil, as well as provides suggestions and recommendations for the consolidation of a market for offshore wind power and low-carbon hydrogen in the country.

2 OFFSHORE WIND POWER

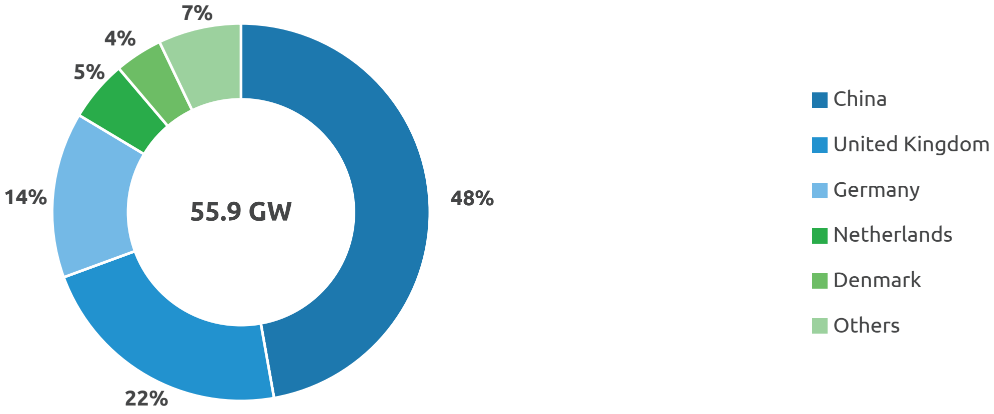
This chapter is dedicated to (i) analyzing the potential of offshore wind power in Brazil and around the world; (ii) technical aspects of turbines when installed in offshore projects; (iii) evaluating the offshore wind power value chain; and (iv) discussing generation costs.

2.1 POTENTIAL OF OFFSHORE WIND POWER IN THE WORLD

The global offshore wind power market has grown significantly in recent years, by about 36% per year over the last decade, reaching the level of 56 GW of installed capacity at the end of 2021, or about 7% of total wind power (onshore and offshore). An increase of at least 260 GW is expected by 2030 (4C Offshore, 2022[a]; Bloomberg NEF, 2021[a]), doubling the number of countries currently generating energy from offshore wind in the next decade (Ferris, 2022).

In 2021 alone, about 21.1 GW of offshore capacity came online, a threefold increase from 2020 (GWEC, 2022). Europe and Asia dominate the map of offshore wind generation, with Europe having dominated in the past. Nevertheless, China overtook the United Kingdom in 2021 with 17 GW of installed capacity, taking the position of the country with the largest installed capacity (Figure 1). The country is expected to consolidate Asia at the top of the global ranking in a short period of time.

FIGURE 1 – Distribution of offshore wind power by region (GW)



Source: Adapted from GWEC, 2022.

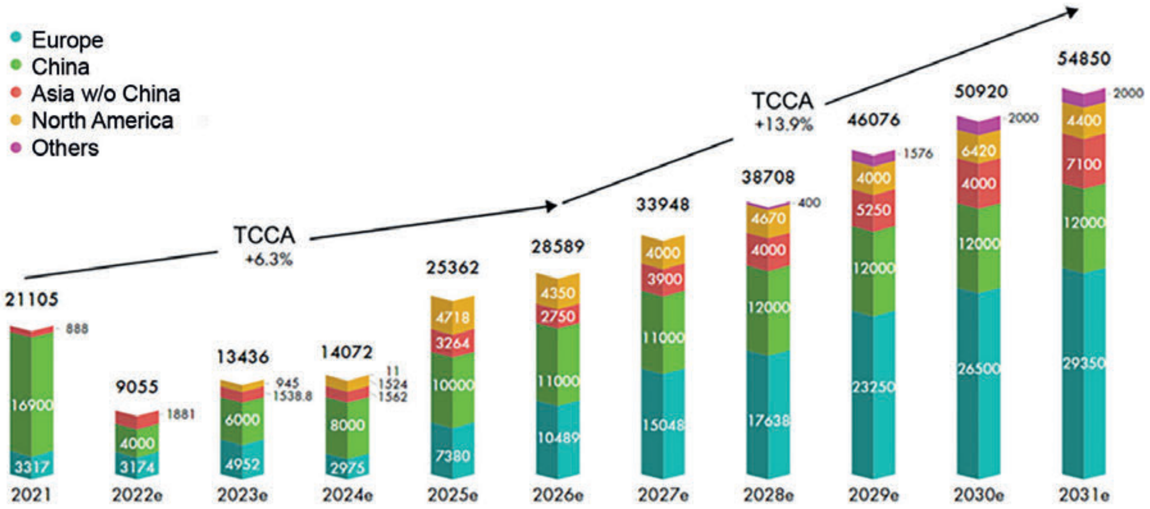
The offshore wind power industry has gained prominence in plans to implement new decarbonization targets around the world. Events that combine political alignment and compromise between countries, such as COP26 in Glasgow, are contributing to increased efforts by leaders to improve targets, which appears to be a response to recent energy crises.

According to the GWEC, an average annual growth rate of 6.3% by 2026 and of 13.9% by the beginning of the next decade is expected in terms of new installations, which should see the offshore wind sector exceed 30 GW by 2027 . The annual volume of offshore wind power plants is expected to more than double from 21.1 GW in 2021 to 54.9 GW in 2031, increasing the offshore share of new global wind turbines from 23% in 2021 to 32% in 2031.

According to the GWEC, more than 315 GW of new offshore wind power capacity is expected to be installed over the next decade (2022-2031), bringing the total installed capacity to 370 GW by the end of 2031. It is estimated that 29% of this new volume will be installed in the first half of the decade (2022-2026).

Figure 2 illustrates the sector's global growth prospects over the next decade, where the term TCCA corresponds to the Compound Annual Growth Rate indicator, which refers to the expected average rate of new offshore wind installations per year (GWEC, 2022).

FIGURE 2 – Expected average annual growth for the offshore wind power sector over the next decade (MW)



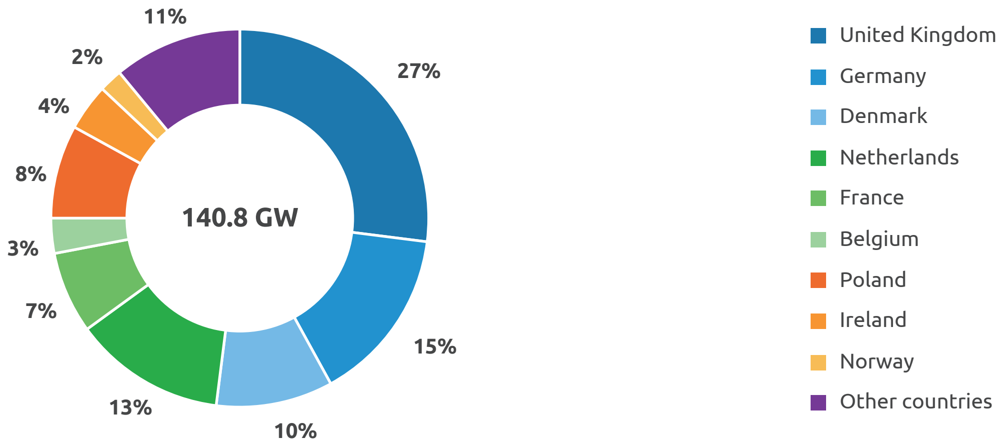
Source: Adapted from GWEC, 2022.

2.1.1. OFFSHORE WIND POWER IN EUROPE

Recently, the European Commission launched the REPowerEU plan, which aims to make Europe independent of fossil fuels from Russia by 2030. The plan aims to advance offshore wind power technology across the continent. Other agreements have been made, such as the Esbjerg Declaration, consolidated in 2022, in which the governments of Denmark, Belgium, Germany, and the Netherlands committed to gradually replace fossil fuels with renewable energy produced in the North Sea, with a focus on offshore wind power and low-carbon hydrogen. With this agreement, the countries have set a new target of 150 GW of offshore wind power by 2050. Also on the European continent, the British government has increased its target for offshore wind power by a further 10 GW to 50 GW by 2030.

The United Kingdom has been the market leader in offshore wind power in Europe since 2009. Despite having lost its top spot to China at the end of 2021, progress made over the past 12 months indicates that offshore wind power growth is likely to pick up. In 2021, the UK selected three floating wind demonstration projects (placed on buoys) for commercial leasing in the Celtic Sea. In early 2022, the UK government announced plans to hold annual auctions starting in 2023 to increase the country's renewable energy supply. Later that year, the results of the Scottish sea territory lease round launched in the summer of 2021 were announced: 17 projects totaling 25 GW, including 15 GW of floating wind power. In addition, the UK has also completed the second phase of its negotiations with the private sector to implement plans for leasing floating offshore wind turbines in the Celtic Sea with a capacity of up to 4 GW. According to the plan presented in April 2022, which revised the 10-year target for the UK offshore wind power sector, the market is expected to reach the share of 50 GW in 2030, instead of the previously established 40 GW, of which 5 GW should represent floating generation units. This is the second time in the last two years that the UK has increased the target for offshore wind power.

FIGURE 3 – Projected growth of the offshore wind power sector in Europe from 2022 to 2031



Source: Adapted from GWEC, 2022.

After unfavorable market conditions and a lack of medium-term visibility slowed the development of the offshore wind power sector in Germany, more favorable legislation was passed in the country in the last two years, opening up new growth prospects. The 2020 amendment to the Offshore Wind Energy Act (WindSeeG) increased the country's offshore wind power target from 15 GW to 20 GW by 2030 and set a target of 40 GW of installed offshore capacity by 2040. The German government amended offshore wind energy legislation in April 2022 with the "Easter Package", setting a target of 30 GW by 2030, 40 GW by 2035, and at least 70 GW by 2045. The key to the success of offshore wind power seems to be clear in the country and largely depends on how quickly the German Federal Maritime and Hydrographic Agency issues permits for additional offshore wind projects and opens new tenders to ensure attractive market conditions.

Denmark has significant potential for the development of offshore wind farms in both the North and Baltic Seas, which led the government to decide in 2020 to establish two energy "islands": areas for the concentration of offshore wind farms in each sea. The total potential of the energy island in the North Sea is currently estimated at around 10 GW. In 2022, the country hosted an important milestone in international cooperation in the field of offshore wind power, welcoming three more North Sea countries to the Esbjerg Offshore Wind Summit. In mid-2022, the government presented a proposal to increase its 2030 offshore wind power target by 45% to a total of 12.9 GW.

The offshore wind power market in Europe is expected to grow by around 3.7 GW by 2024. This growth is likely to be concentrated in established markets such as Germany, Denmark, and Belgium. However, the European offshore market is expected to accelerate from 2025 when tenders for projects in Germany, France, and Poland resume.

For the current decade, the growth rate of the offshore wind power sector is expected to remain in double digits for several reasons: (i) fixed-base offshore wind power has become the most competitive power generation technology after onshore wind and photovoltaic power; (ii) the continued progress in the trading of floating wind power, which is expected to unlock the potential of the deep water modality; and (iii) the European Commission's presentation of an offshore renewable energy strategy as part of its "Green Deal" in November 2020, setting a target of 300 GW by 2050 on the continent. This makes this modality a strategic tool to achieve ambitious emission reduction targets, reaching net zero emissions by 2050.

Although Asia is expected to overtake Europe as the largest regional offshore wind power market by cumulative installations by the end of 2022, Europe is expected to regain this position from 2031, with an annual increase in offshore wind installations expected to exceed the milestones of 10 GW in 2026 and 25 GW in 2030. Figure 3 illustrates the expected growth of the offshore wind power sector in Europe, showing the share by country.

2.1.2. OFFSHORE WIND POWER IN ASIA

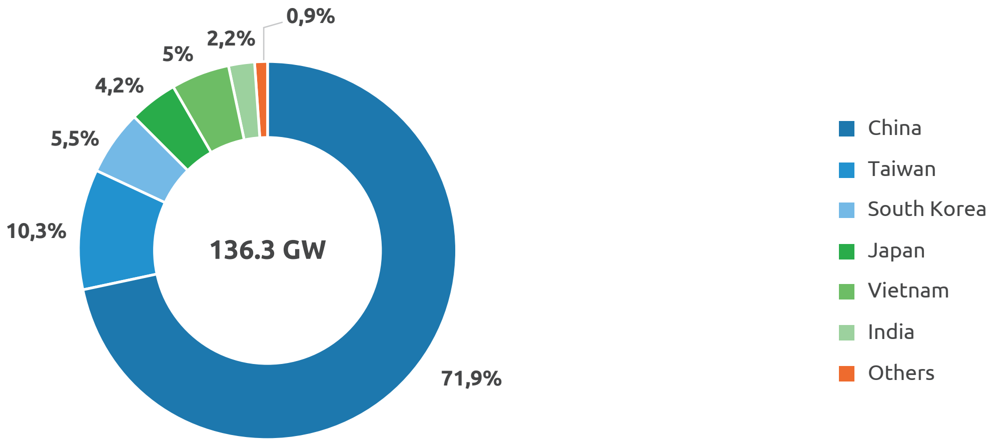
The first offshore wind project to be built on the continent has been operational for almost two decades. However, the development of these types of projects remained slow until 2018, when China overtook the UK as the world's leading market in terms of annual new installations. In 2020, a major paradigm shift occurred when Asia replaced Europe as the leading regional offshore wind power market in terms of new installations for the first time.

It seems clear that China will continue to play the dominant role in this region over the next five years (2022-2026), followed by Taiwan. Figure 4 shows the expected outlook for offshore wind power sector growth in the Asian continent from 2022 to 2031.

China experienced accelerated growth in the offshore wind power sector, reaching 17 GW in 2021. In 2022, this growth slowed due to the end of a massive federal funding cycle. The growth of the sector in the country from now on will largely depend on investments from coastal provinces such as Guandong, Zheijiang, and Shandong. Given that the target set for the offshore wind power sector by 2030 should exceed 150 GW, GWEC Market Intelligence forecasts that the annual average of offshore wind power installations in China should exceed 10 GW between 2025 and 2031, which will help the country further consolidate its position as a global leader in this segment.

Taiwan is on track to establish itself as the second most important country in the offshore wind power market on the Asian continent. Despite discreet growth in 2021, according to the latest renewable energy development status update from the Bureau of Energy, Taiwan is expected to add 2 GW of offshore wind power capacity by the end of this year, putting the country on track to reach 5.6 GW of offshore wind power capacity by 2025. In 2022, the government officially announced its plan to allocate offshore wind power between 2026 and 2035. With projects expected to be allocated in the next round of the offshore wind power auction, Taiwan is likely to exceed the 2030 targets set by South Korea and Japan.

FIGURE 4 – Projected growth of the offshore wind power sector in Europe from 2022 to 2031.



Source: Adapted from GWEC, 2022.

2.1.3. OFFSHORE WIND POWER IN NORTH AMERICA

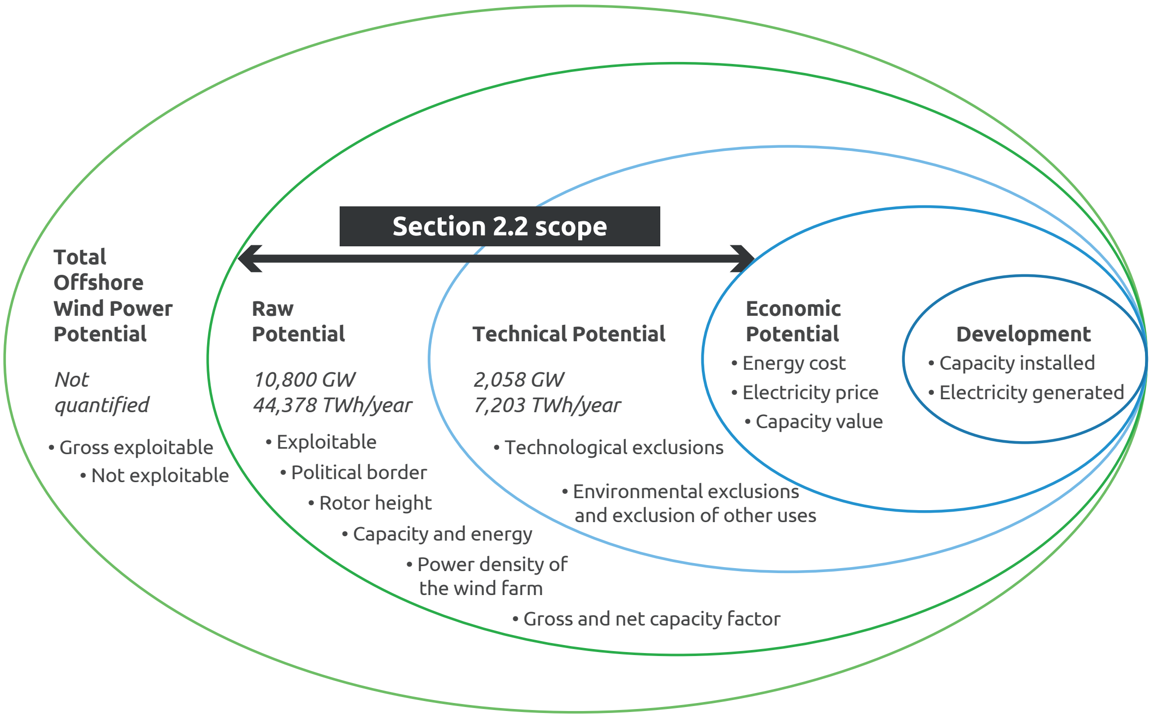
North America is currently the only region outside the Europe-Asia axis with operating offshore wind farms. In 2021, only two small offshore projects are operational, both in the United States: The 30 MW Block Island in Rhode Island and the 12 MW Dominion Virginia (demonstration). Based on the latest project development timeline in this sector, it is unlikely that the next commercial offshore wind project in North America will be operational before 2023. In total, 31.9 GW of offshore wind power is expected to be built in the region over the next decade (2022-2031), 99% of it in the United States and just 400 MW in Canada. North America is expected to remain the third largest offshore wind power market through 2031, followed by the Pacific region and Latin America.

In the United States, announced targets for offshore wind power procurement at the state level have increased by 28.6%, reaching nearly 50 GW by 2022. There are currently only 42 MW of offshore wind power capacity in operation in the U.S., but development has gained momentum over the past 12 months. In May 2021, the 800 MW Vineyard Wind 1 project received approval from the Bureau of Ocean Energy Management (BOEM), and construction began on the wind farm in Massachusetts in November of the same year. That same month, the 132 MW South Fork wind project also received approval from the BOEM, making it the second offshore wind project in the U.S. to enter the construction phase.

2.2 POTENTIAL OF OFFSHORE WIND POWER IN BRAZIL

Mapping the potential for offshore wind power generation in Brazil is crucial to assessing the most viable areas for these projects. Theoretical potential shows the amount of power the technology could generate in general, while the technical potential excludes areas with limitations and reflects the generation potential only in the remaining areas. In addition, it is possible to move further to economic potential and finally to market potential, i.e., to what would actually be developed as a business. In this context, Figure 5 illustrates these potentials.

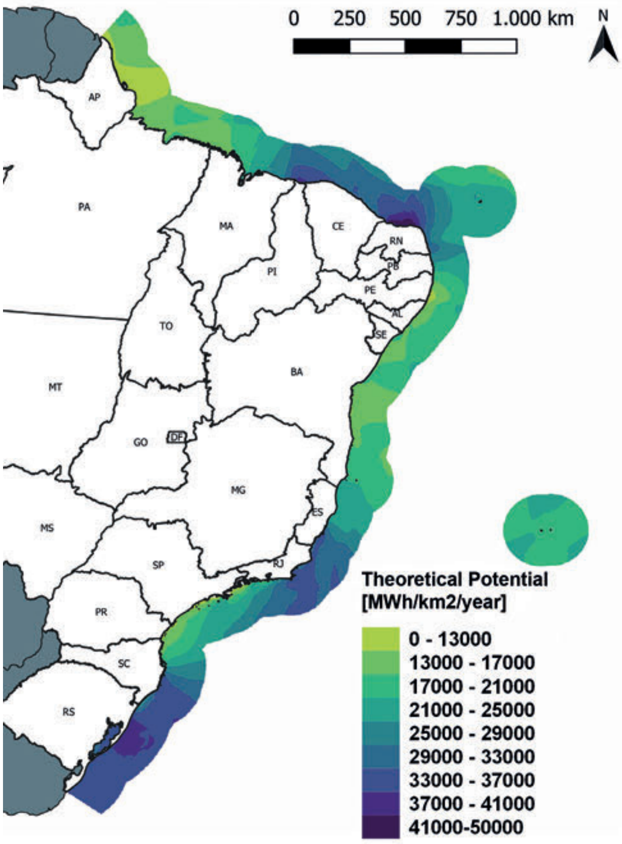
FIGURE 5 – NREL terminology for offshore wind power potential levels



Source: Adapted from Musial et al. (2016) and Vinhoza, 2019.

Figure 6 shows the map[1] developed for this study with the theoretical potential for projects built within 200 km off the Brazilian coast. The map shows that there is great potential in the states in the Northeast region, especially Rio Grande do Norte, Ceará, and Piauí, and in the states in the South of the country, especially Rio Grande do Sul and Santa Catarina. It should also be noted that the state of Rio de Janeiro, in the Southeast region of Brazil, also has significant potential.

FIGURE 6 – Map of the theoretical potential to generate electricity with offshore wind sources in Brazil



Source: Adapted from Azevedo et al. (2022ª)

Based on this raw potential map, a simulation was performed to represent the potential and the area as a function of the capacity factor[2]. Figure 7 shows that the lower the minimum capacity factors, the higher the potential, as more areas are considered.

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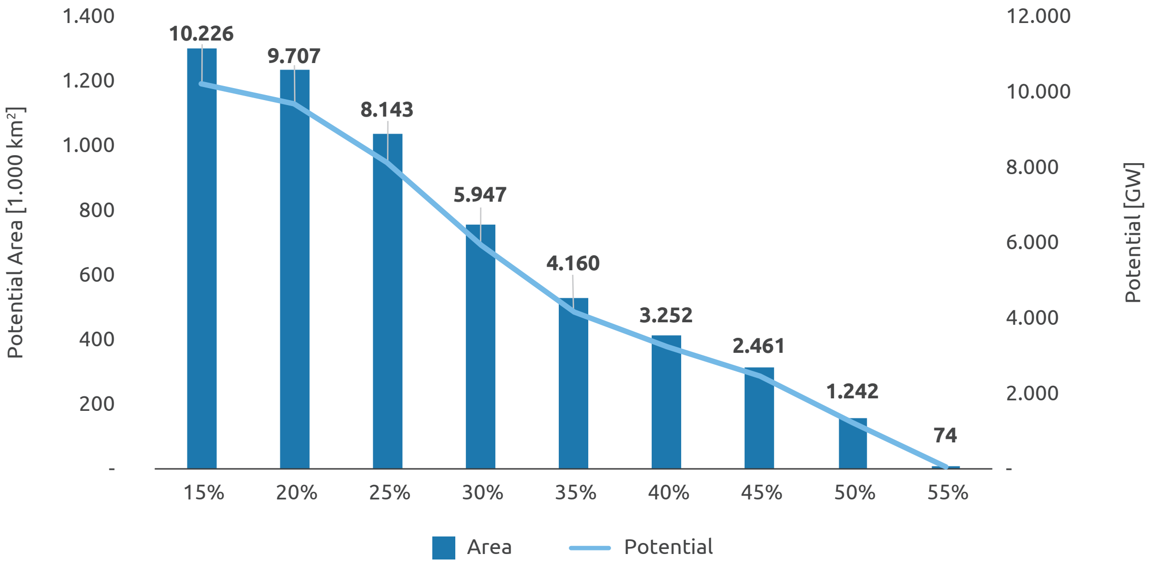
[1] The map was created from georeferenced data considering the capacity factor for IEC-1 turbine classes with wind measurements at 100 m height, provided by Global Wind Atlas 3.1 (DTU, 2019). To calculate the potential per area, the IRENA methodology was used to arrange the turbines so as to reduce the effects of wind drag (IRENA, 2014). The power and rotor diameter of the Vestas V112-3.45 MW™ wind turbine model were used to calculate the model parameters (Vestas, 2022).

[2] The capacity factor of a power generation plant is estimated by dividing the effective production of the plant in each period by its maximum total capacity in the same period.

FIGURE 7 – Map of the theoretical potential to generate electricity with offshore wind sources in Brazil



Source: Prepared by the author.

According to NREL (National Renewable Energy Laboratories) terminology, offshore wind power potential can be divided into several phases with subsequent constraints, starting with a theoretical raw potential (Figure 6) and ending with a technical potential. In order to create the map of technical potential, the constraints in the coastal area must be taken into account. For this purpose, georeferenced mapping of the constraints listed in Table 1 was carried out.

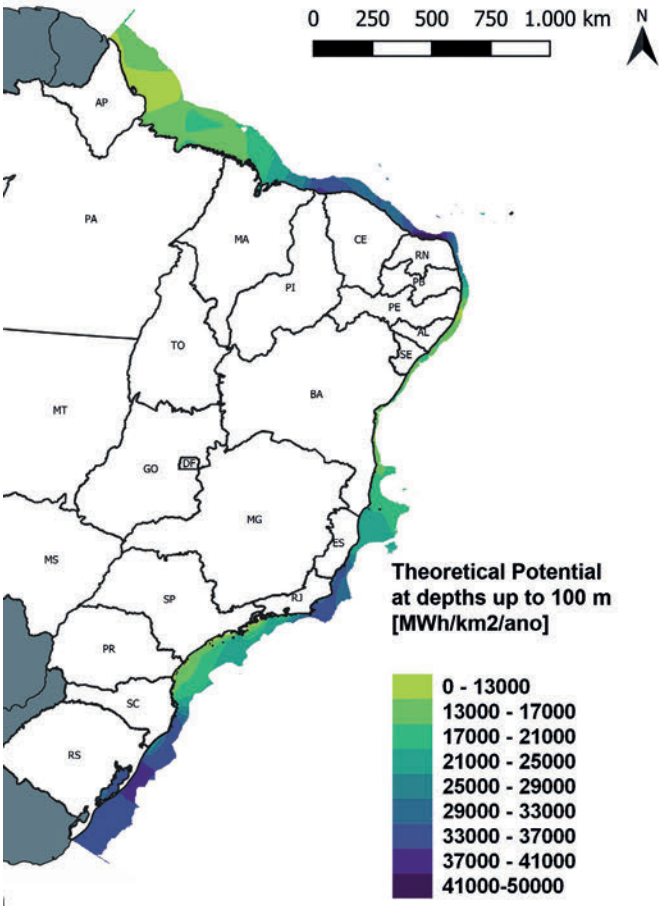
TABLE 1 – Constraints used for the technical potential map

Category	Type	Constraint	Reference
Technical	Depth	Areas with a depth of less than 100 meters due to the current technical issue with the installation of offshore wind turbines.	Geological Survey of Brazil (CPRM)
	Distance from the coast	Limited to 200 km due to current technical limitations of offshore wind projects and lack of data on wind potential.	Global Wind Atlas (GWA 3.1)
Environmental	Conservation Units (CUs)	Exclusion of fully protected and sustainable use CUs at federal, state, and local levels.	Ministry of the Environment (MMA)
	Priority areas for biodiversity protection	Exclusion of all priority areas classified as high, very high, and extremely high.	Ministry of the Environment (MMA)
Economic	Oil and gas	Exclusion of exploration blocks under concessions and oil and gas production fields.	Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP)

Source: Prepared by the author.

Regarding the technical depth constraint, Figure 8 shows the theoretical potential with limitation for depths up to 100 meters. There is potential with the addition of exploitable areas more concentrated on the coast of the South region of the country.

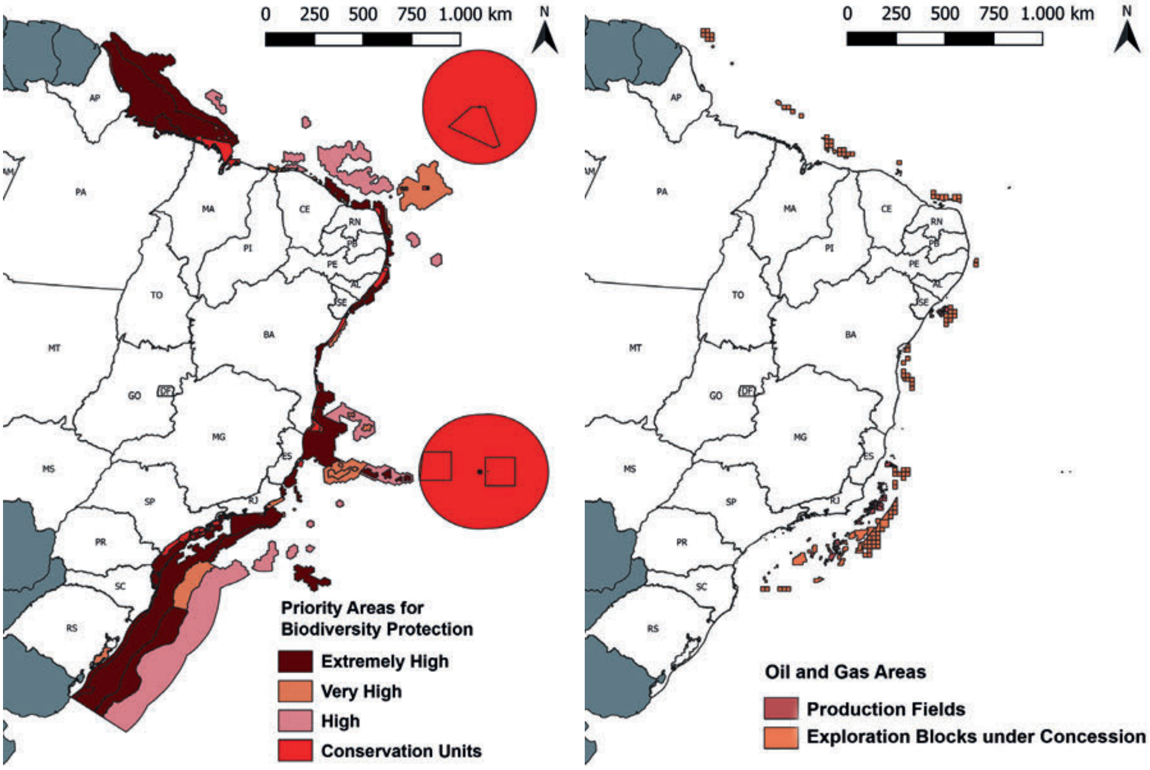
FIGURE 8 – Map of the theoretical potential to generate electricity with offshore wind sources in Brazil with technical limitations of depths up to 100 m



Source: Adapted from Azevedo et al. (2022ª)

In terms of ecological and economic constraints, each is shown in Figure 9. On the left side, all priority areas for biodiversity protection are divided into three priority categories (extremely high, very high, and high), as well as the conservation units of the coastal marine biome. The map on the right shows all oil and gas production fields and current exploration blocks under concession.

FIGURE 9 – Map of environmental and economic constraints on the Brazilian coast



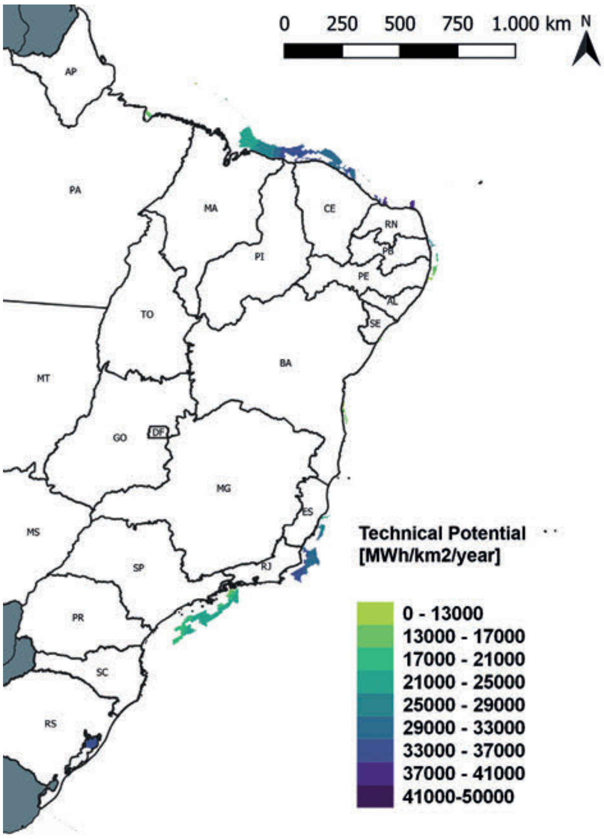
(a) Environmental constraints

(b) Economic constraints

Source: Azevedo et al. (2022^{a})

By applying all the constraints considered in Table 1, it is possible to create a map of the technical potential for offshore wind power production off the Brazilian coast. Figure 10 shows the areas with the greatest potential for offshore wind projects in Brazil. Taking into account the constraints imposed, the technical potential shows that there are very few viable locations for offshore wind projects. However, there is a large area in the Northeast region of the country, off the coast between the states of Piauí, Ceará, and Rio Grande do Norte, that is viable. There is also an area of great interest in the Southeast region, between the states of Rio de Janeiro and Espírito Santo. To the South region, there appears to be an area with potential in the state of Rio Grande do Sul, in the Lagoa dos Patos lagoon. However, since it is a lagoon, this location must be analyzed with caution, as there may be some constraints that have not been considered in this study.

FIGURE 10 – Map of the technical potential to generate electricity with offshore wind sources in Brazil



Source: Adapted from Azevedo et al. (2022a)

It is worth mentioning that there are constraints that may not have been considered in this study. For example, from a technical point of view, other existing offshore infrastructures, other projects authorized in the analysis area, pipelines, cables and active underground structures, shipping routes, locations of military ammunition depots, bathymetric contours below 200 m depth, oceanic conditions (e.g., tides, waves), seafloor morphology, and sediments, among others.

From an environmental point of view, one could also take into account constraints on marine archaeology; commercial fishing; aquaculture; benthic habitats (including those listed in Annex I of the Habitats Directive); ornithology; fish ecology; among others.

2.3 TECHNICAL ASPECTS

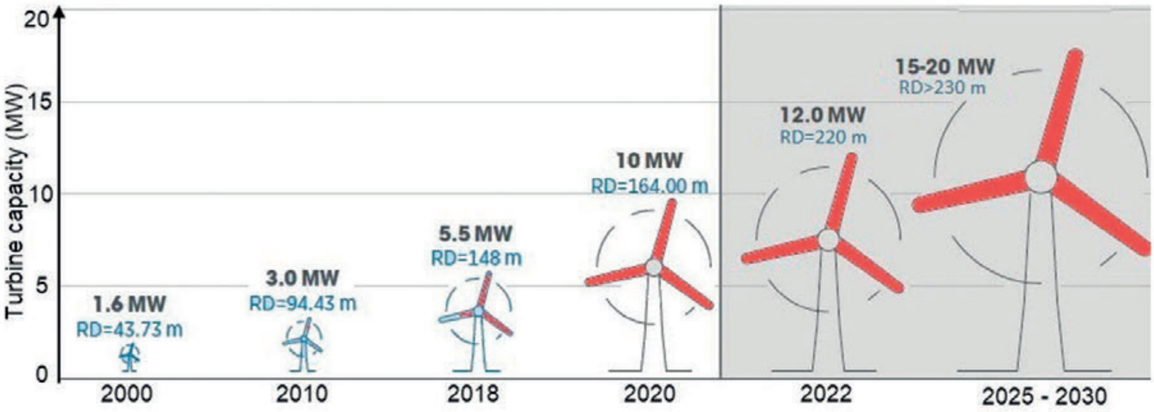
Offshore wind projects generally use similar technology to onshore wind projects (EPE, 2020), the main difference being the foundation. This section covers the technical aspects of the turbine and foundation of offshore wind projects.

2.3.1. TURBINES

Most wind turbines are characterized by large rotors that are actively yawed to maintain alignment with the wind direction. The three-bladed rotor is the most common and typically has a separate, front-mounted bearing3, with low-speed shaft connected to a gearbox that provides adequate output speed to the generators. This general architecture can be seen in Figure 11. Typically, in larger wind turbines, the blade pitch is continuously varied in an actively controlled manner to regulate the output at higher wind speeds.

Since the commercialization of wind power technology began in the early 1980s, there have been several improvements, and the offshore wind power sector is a major contributor and has excelled in technological innovation over the past 30 years. Since the installation of the first offshore wind turbine in 1991 – the 450 kW Bonus-B35 – the output of offshore wind turbines has grown significantly. The average size of offshore wind turbines worldwide was over 1.5 MW in 2000, 2.5 MW in 2005, and 6.0 MW in 2020, with an average output of 12 MW per turbine expected in 2025 (GWEC, 2022). A number of factors contribute to this phenomenon, such as the need to reduce the levelized cost of electricity (LCOE) to increase competitiveness, the desire to reduce maintenance costs (fewer turbines), and the integration of the offshore wind power grid to achieve economies of scale.

FIGURE 11 – Power output and rotor diameter of existing and planned offshore wind farms



Source: Adapted from Bošnjaković et al., 2022.

Currently, the world's largest operating wind turbine is the GE Haliade-X prototype in Rotterdam, with an installed onshore capacity of 13 MW. However, it is expected to be surpassed soon by the Vestas project which intends to develop a 15 MW wind turbine with a rotor diameter of 236 m, the prototype of which is expected to enter service in 2022

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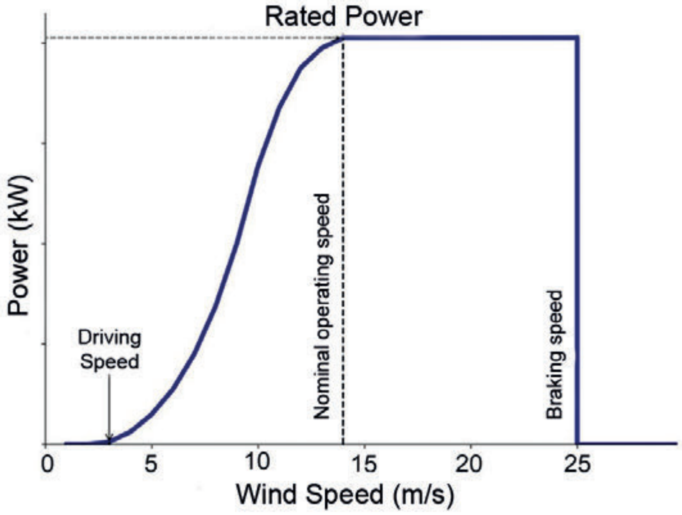
[3] Bearing is a machine element that serves as a fixed support for mechanical transmission in rotating elements (shafts and rolling bearings).

and series production in 2024. Offshore wind turbines can reach larger dimensions than onshore wind turbines because transportation to the wind farm is a less limiting factor.

The practice of increasing the power output of an existing turbine by increasing generator and transmission capacity with the same rotor is common among manufacturers in the wind power market. This is a way to increase the power output of the wind turbine on the same platform without making changes to the rotor blade design. By increasing the power output of the generator, more energy can be generated and efficiency can be improved. On the other hand, increased material fatigue due to increased load and reduced lifetime must be carefully considered.

In addition to increasing the size and installed power per turbine, further improvements are to be implemented by the end of the decade that will lead to greater efficiency, reliability, and availability of the wind farm. These include, for example, the aerodynamic improvement of the rotor blade, the wind farm's operations management system, and the maintenance and fault diagnosis system. The power curve of a wind turbine (Figure 12) shows its power output at different wind speeds. The annual electricity production of a wind turbine depends, among other things, on two important points on the power curve: (i) the wind speed at which the wind turbine is driven, and (ii) the wind speed at which the wind turbine is switched off to avoid stress and damage to the components if the wind speed continues to increase.

FIGURE 12 – Typical power curve for a wind turbine



Source: Adapted from Bošnjaković et al., 2022.

The amount of energy produced by a turbine depends on the speed limits at which it can operate. The higher the speed limit, the more energy the turbine will produce annually. However, there is also interest in developing wind turbines that produce energy at low wind speeds, which will expand the possibilities and allow wind farms to be built in areas with lower average annual wind speeds. On the other hand, it is also desirable to design wind turbines that are capable of producing power in extremely strong wind conditions (shifting the boundary to the right). It is also possible to improve the power curve of existing wind turbines by upgrading the control system. In doing so, on the one hand, the wind turbine can be exposed to strong vibrations and loads, but on the other hand, the increase in energy production is significant.

There are currently several mechanical and aerodynamic braking systems designed to prevent wind turbines from becoming overloaded at extreme wind speeds. A newer approach to solving this problem is based on aerodynamic principles and involves the formation of slots (openings) on the surface of the blades. By adding the slots, the pressure distribution on the blade surface is changed and the speed of the wind turbine is reduced within the permissible limits. In this way, the overspeed of the turbine rotor is effectively reduced without affecting energy production.

The next subsections discuss the technical aspects of the main components of the offshore wind turbine, namely blades, nacelles, and towers.

2.3.1.1 Blades

Advances in technology lead to better performance and reliability of wind farms, as well as lower component costs. To drive its technological development, the wind power industry has adopted materials, systems, and products from other fields, such as sensors in electrical engineering, aerospace technologies, and shipbuilding technologies to produce rotor blades. As technological needs increasingly transcend the boundaries of these sectors, the development of new solutions becomes necessary to drive wind turbine development.

Aerodynamics is one of the first aspects in the development of rotor blades for the offshore wind power sector and is considered a key factor for satisfactory and efficient operation. In this sense, research using numerical simulations has proven to be very useful.

The design of wind turbines with three blades predominates worldwide (Bošnjaković et al., 2022). This system is usually chosen for its efficiency, noise level within allowable limits, and durability. Many alternatives have been explored but have been rejected due to higher costs and lower efficiency. Adaramola et al. (2014) show that greater cost efficiency is achieved by building turbines with a larger rotor diameter.

However, problems related to transportation and assembly are expected to limit the increase in dimensions, so small systematic improvements in blade design are welcome. It is known that a wind turbine blade undergoes more fatigue cycles in a year than an aircraft wing does in its entire lifespan, and this is the biggest concern of turbine manufacturers and operators. Metal is inadequate in this regard, and it is common to make blades from materials such as polyester, glass fiber-reinforced epoxy, or fiberglass. Carbon fiber or Kevlar are also used as reinforcing material to protect against breakage. The Enel Green Power company is developing an innovative blade made of a special technical fabric (Enel Green Power, 2022) that allows to generate more energy, reduce manufacturing costs, and facilitate recycling at the end of the blade's useful life. Moreover, due to the orthotropic mechanical behavior of composites, the structural properties of the blade are determined by the orientation of the fibers that compose the blade. Studies have pointed out the advantages of optimizing the angle of each layer of the composite (Torregrosa, 2022). The results show that the inclined structure increases by 10% the critical wind speed for the defined control system and the electrical system, contributing to a higher efficiency of the wind turbine.

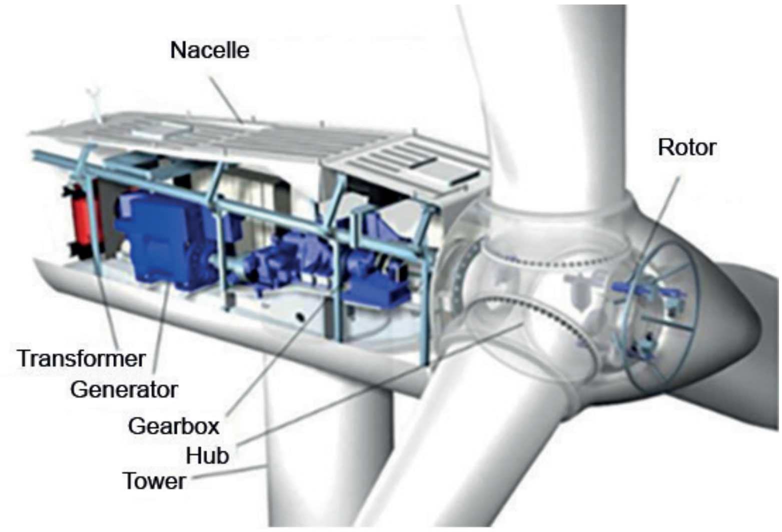
A current research topic in rotor blade design is the development of smart devices that change shape depending on wind conditions. Within this design category, numerous approaches have been considered, including aerodynamic control surfaces or materials for smart actuators. The research aims to limit the final loads and stresses that affect material fatigue or increase dynamic energy absorption (Adaramola et al., 2014). These aerodynamic control surfaces include pitch control, roll-pitch, and boundary layer control. More complex blade shapes are possible with the introduction of new shaping technologies and materials. However, the economics of production combined with the difficulty of analyzing a complex design determine the final shape of the blades. Major wind turbine manufacturers are optimizing features such as torsion angle, chord length, and blade geometry.

As for the materials used, composite materials with glass and carbon fibers are used to produce the blades to achieve higher strength, lower weight, and better corrosion resistance (Bošnjaković et al., 2022). The main problems associated with these materials are availability, biodegradability, risk to human health, and high production costs. For this reason, research is being conducted on the possibility of replacing these materials with natural fibers.

2.3.1.2. Nacelles

The basic layout of most transmission systems housed in the nacelle of wind turbines currently consists of generators connected to gearboxes responsible for accelerating the relatively slow rotation of the turbine blades (typically 5 to 15 rpm on a modern machine) to high speeds (1,000 to 1,800 rpm), an action required to generate electricity using a high-speed induction generator. With all these moving parts, the gearbox is one of the most commonly maintained parts of a wind turbine.

FIGURE 13 – Typical offshore wind turbine nacelle

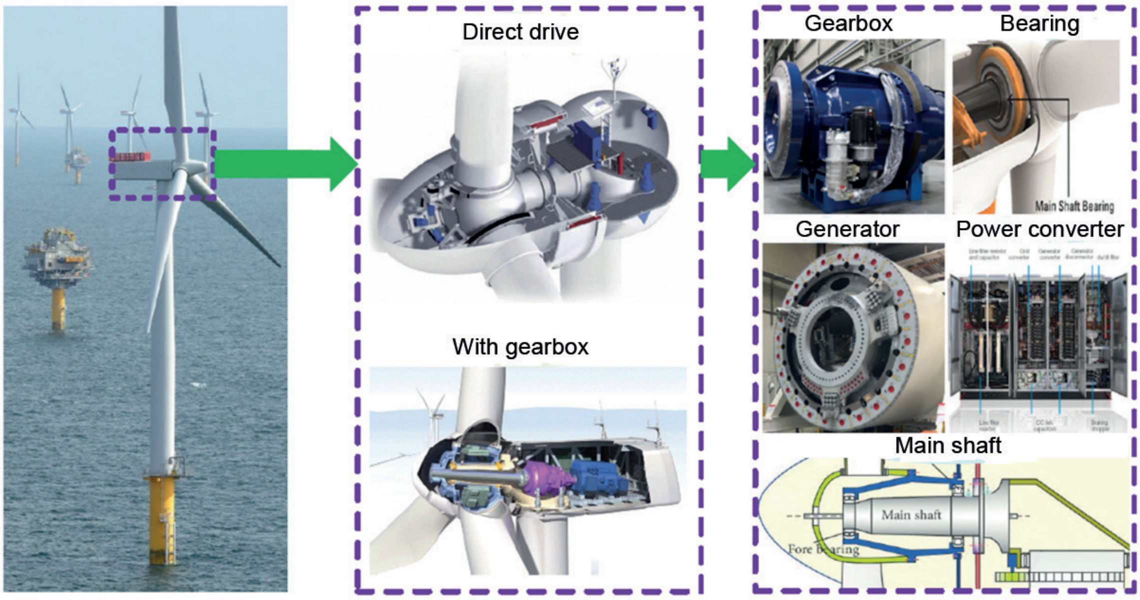


Source: Adapted from Bošnjaković et al., 2022.

An alternative is to use a **direct drive** (DI) generator, which can produce power at much lower speeds. DI systems do not require a **gearbox** and therefore have fewer moving parts. However, they generally use permanent magnets that require expensive, heavy rare earth materials such as neodymium and dysprosium, and generally require heavier generators than gear machines for a given turbine capacity.

Both represent the **two main alternatives** of the dynamic mechanism known as the turbine transmission system. This is a segment that promotes the conversion of mechanical energy into electrical energy and transfers loads from the rotor to the base and tower. The transmission system configurations and their components are shown in Figure 14.

FIGURE 14 – Transmission system configurations and corresponding components



Source: Adapted from Guo et al., 2014; OpenPR; Smalley, 2015; and Zheng et al., 2020.

There are a variety of wind turbine transmission technologies, with advantages and disadvantages for each in terms of cost, weight, size, manufacturing, materials, efficiency, reliability, and operations and maintenance (O&M). As offshore wind turbines become ever larger, the search for more compact and lighter transmission systems is practically mandatory to reduce the mass of the nacelle and, consequently, the masses and costs of the tower and the foundation or floating platform. To achieve these reductions, there is a strong tendency to increase the mechanical integration of the main bearing, gearbox, and generator (Stehouwer; van Zinderen, 2016).

Regarding the power conversion system, permanent magnet synchronous generators (PMSGs) with full power converters are becoming more common than doubly-fed induction generators (DFIGs) with partial power converter systems. The DFIG concept consists of an asynchronous slip-ring machine with a wound rotor, in which the rotor windings are connected to a converter via slip rings and brushes using a standard high-speed transmission system. The narrow speed range (approximately 30%) sufficient for the turbine allows for a small size of the converter and helps this system to be characterized by high efficiency at rated load. Unlike DFIGs, in PMSG generators, all energy produced passes through an inverter, enabling high efficiency at all operating speeds (Veers et al., 2020).

Concerns about the supply of rare earth materials commonly used in PMSGs have also sparked interest in alternative technologies, such as superconducting generators (Veers et al., 2020). Regardless of the choice of transmission system design, the loads and operating conditions to which the transmission system is subjected are derived from the design load cases described in the International Electrotechnical Commission (IEC): IEC 61400-1, the design standard for onshore wind turbines, and IEC 61400-3-1 and IEC 61400-3-2, the design standards for fixed and floating offshore wind turbines.

Modern offshore wind farms are high-value assets and there is growing interest in extending their useful life. However, the size of the turbine and the layout of the transmission system can make replacing the main bearing more difficult and expensive, usually requiring rotor removal. As a result, the main bearings are increasingly considered as part of the load structure, leading to higher failure costs.

Another consequence of the level of integration between system components is that the operational requirements of the main bearing are increasingly linked to those of other components. In some DFIG configurations, the main bearing must support not only the turbine rotor but also the generator rotor while maintaining appropriate clearance. **Combined approaches for modeling and evaluating wind turbine transmission systems will therefore become increasingly important.** Finally, new main bearing design concepts are also being developed and tested, including self-aligning asymmetric roller bearings (Loriemi et al., 2021), field replaceable main bearings, and plain bearings (Rolink et al., 2020, 2021).

Wind turbine gearbox sizes (up to 3 m in diameter) and power ratings (up to 15 MW) continue to increase (Vaes et al., 2021). Multistage gearboxes with four or more planetary systems, torque densities of 200 Newton meters per kilogram, and speed-increase ratios of up to 200 are now available (Daners and Nickel, 2021). Modular gearbox concepts have been introduced to achieve further cost reductions (Wind Energy 2021). The forecast is for a minimum service life of 20 years, as specified in the gearbox design standards.

Provisions for tower service or replacement of gearbox components are becoming more common, making them necessary for components that have a shorter service life than the gearbox. The gearbox system consists of many elements (mainly rotating shafts, gears, and bearings), which means that its reliability is the product of the reliability of all failure modes for which there is a calculation. However, for a significant portion of in-service failure modes, there is no standardized reliability calculation, resulting in a difference between the in-service apparent reliability and the calculated design reference reliability. This is not uncommon and occurs in other industries, although the impact on O&M costs is likely to be more severe for wind turbines.

Especially for large turbines, lighter and more compact designs are the most economical option. Therefore, the integration of electromechanical systems in the main bearing is a new trend. In this context, research and development has focused on the search for greater reliability and a better understanding of the failure modes in the operation of gearboxes and bearings, as well as on the development of new technologies, such as plain bearings. (Veers et al., 2020). Medium-speed concepts have proven suitable for balancing high-speed requirements and drive-drive concepts, while high-speed multi-stage gearboxes have also been a focus of research in recent years. There has recently been an upward trend in offshore turbines towards direct drive systems and PMSGs with full converter systems, to the detriment of DFIGs with partial converter systems. Superconducting generators are also considered an attractive alternative to PMSGs due to the large amount of rare earth materials required for PMSGs.

Considering the critical nature of wind turbine transmission system components, predictive maintenance is considered an essential element. Most newer and larger turbines over 2.5 MW or 3 MW have dedicated condition monitoring systems, typically covering the gearbox, main bearings, and generator.

The monitoring technologies used for wind turbine transmission systems have good accuracy in fault diagnosis, especially for high-speed components. The prognostic performance of some applications still needs to be improved, which offers a chance to surpass the progress made by the scientific community. On the other hand, the industry has been trying for some time to obtain accurate predictions of the useful life of each component, which is one of the goals of typical failure forecasts. Among the various subcomponents of the transmission system, bearing failures have been shown to be widespread and have been actively studied by industry and researchers.

2.3.1.3 Towers

Currently, the tower supporting wind turbines is generally made of steel to provide a solid and strong structure. Another material used for the construction of the tower is concrete, which also meets the requirements of structural integrity, strength, and durability. Recently, optimization techniques have been used to maximize load capacity while reducing material consumption and costs (Stratton, 2014).

During operation of a wind farm, the tower is subjected to intermittent loads due to changes in wind speed, which may cause some swaying back and forth. To reduce this movement, the frequency of the tower must be balanced with the natural frequency of the other components. Therefore, it is essential to analyze the relationship between the tower and other components of the wind turbine, such as the rotor, nacelle, and foundation. In addition, material costs, component manufacturing, assembly, and environmental impact must be taken into account when selecting the design.

2.3.2 FOUNDATIONS

Monopile, jacket, and floating foundations are now considered the three main foundation types for offshore wind turbines. Each of them, with its advantages and disadvantages, has a direct impact on the safety and maintenance of offshore structures. Figure 15 provides an overview of the different types of offshore wind power foundations.

FIGURE 15 – Types of offshore wind power foundations.

(from left to right: monopile, jacket, twisted jacket, floating platform with tension leg, semi-submersible platform, and buoy mast).

Source: Illustration by Josh Bauer – NREL, 2022.

The most common foundation type for offshore wind turbines is the monopile: a single pile with a diameter of six to eight meters and a length of 20 to 30 meters under the seabed. This type accounts for about 80% of installed foundations.

The number of jacket foundations is expected to more than quadruple in future projects, consistent with the likely decline of monopiles, whose market share is expected to decline by 28.4% (Bošnjaković et al., 2022). This is due to the trend of projects moving to deeper waters coupled with an increase in jacket foundation production capacity.

The share of floating foundations is also increasing. However, the possibility of adapting monopile foundations to deeper waters while keeping costs low is still being investigated, and thus they could remain the dominant type of foundation for some time to come. Taking into account the information about planned projects, the market share of gravity foundations will increase as they are more suitable for rocky soils where driving monopiles can be difficult.

The use of floating wind turbines is expected to increase as wind farms are moved further into the sea and deeper waters. Preliminary experience shows differences in dynamic behavior and transmission system lifetime for floating wind turbines compared to fixed base wind turbines, especially for the main bearings (Bošnjaković et al., 2022). As offshore turbines grow in size, the flexibility of these components and potential dynamic coupling effects become increasingly important in design modeling and analysis.

Floating foundation technology provides a fundamental means for advancing offshore wind power generation by opening up sites with water depths greater than 60 m and facilitating turbine installation even at intermediate depths (from 30 to 50 m), in addition to being a cost-effective alternative to fixed foundations. In general, floating foundations have environmental benefits compared to fixed foundations as they require less intervention into the seabed during installation. There are plans to install more floating wind turbines in Southeast Asia, Oceania, and Northern Europe.

Vibration control of a floating wind turbine becomes increasingly important as the size of the turbine increases. Therefore, three-branch mooring systems for floating wind turbines have been investigated (Liu et al., 2021). The sway, pitch, and yaw movements of the wind turbine in regular and irregular waves are calculated to quantify the performance of the mooring system.

The floating structures of wind turbines must be able to withstand adverse conditions. The combined effects of strong winds and high waves cause vibrations, material fatigue, and severe stress on various elements of the wind turbine. These are factors that increase the risk of failures and require more maintenance.

Thus, maintenance planning associated with the use of floating foundations can reduce costs and increase turbine availability. This includes remote monitoring, which has improved in recent years, enabling early problem detection and preventive maintenance. Subsea equipment has also been developed for inspection and repair of hard-to-reach components.

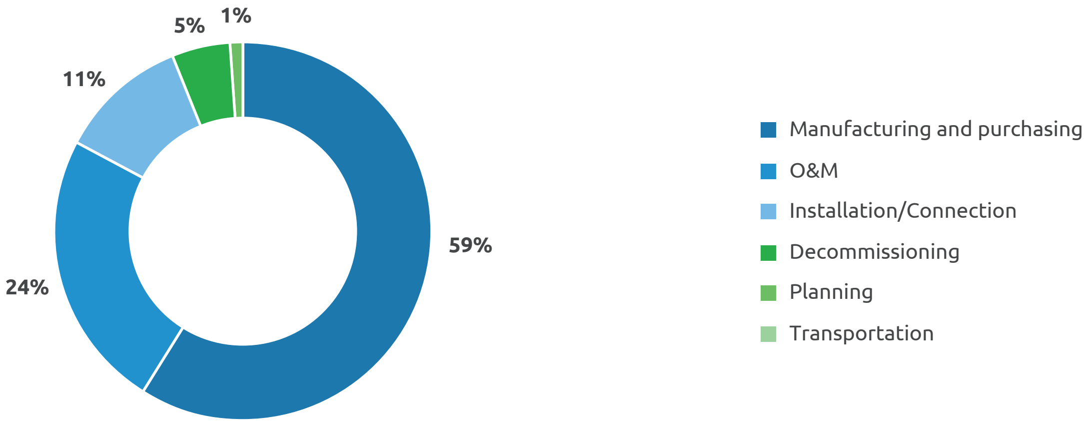
2.4 OFFSHORE WIND POWER VALUE CHAIN

Advancing renewable energy technologies as they mature and become more cost competitive can help balance economic and environmental benefits. Accelerating renewable energy and energy efficiency development can have significant socioeconomic impacts on Gross Domestic Product (GDP), social well-being, and employability (IRENA, 2018b).

In terms of employability, the wind power sector – including onshore and offshore wind power – is expected to employ around 2.2 million people by 2030 and a further 2.1 million by 2050 (IRENA, 2018b). In the offshore wind power sector in particular, the newly created jobs could come from the already consolidated offshore fossil fuel exploration industry. Given the potential economic benefits, the effectiveness of new policies to promote the offshore sector depends on knowledge of the sectors that create the most jobs along the value chain.

Figure 16, which takes the development of a 500 MW offshore wind farm as an example, shows that costs across segments of the offshore wind power value chain are not evenly distributed, with labor concentrated in manufacturing and purchasing (59%) segments, followed by operations and maintenance (24%) and grid installation/connection (11%). Such a distribution allows countries that do not focus on manufacturing activities to still benefit from the relative relevance of other activities that make up an important part of the offshore wind power value chain (IRENA, 2018b).

FIGURE 16 – Distribution of human resources in the value chain for the development of a 500 MW offshore wind farm



Source: Adapted from IRENA, 2018b.

The development of the offshore wind power sector not only provides huge employment opportunities, but also adds value through related economic activities, including most notably the purchase of materials, installation of turbines, and O&M activities. Using the example of a 500 MW offshore wind farm built off the Scottish coast, the cost of the turbine (25%) and O&M (40%) account for approximately 65% of the total cost. O&M costs vary from region to region and depend heavily on local working conditions. Turbines also play an important role in the composition of costs, and their share is strongly influenced by each country's accessibility to this equipment (Rambol, 2022).

In recent years, the technology market for components for offshore wind power generation has expanded, resulting in increasing industry competitiveness (Ramires, 2019). The increased competitiveness of the sector and the increased competition that comes with it have contributed to a decrease in manufacturers' profit margins, even for some of the largest manufacturers in the world. This aspect is leading to a reduction in the selling prices of several products, which is having an impact on the spread of offshore wind power into new markets.

The top ten offshore wind turbine manufacturers accounted for 85% of the total market in 2018. The focus of these manufacturers is on Europe, indicating a considerable maturity of the value chain in the region. The main companies involved in the wind turbine supply chain are described in Table 2 (Rambol, 2022).

Realizing the potential of offshore wind power by strengthening the value chain essentially depends on the ability of the local industry to exploit existing economic activities and adapt them to develop new ones.

As the world transitions from an economy based on fossil fuels in the energy sector to one based on renewable energy sources, there are many synergies that can be exploited with some existing industry segments, the offshore oil sector being the most important .

TABLE 2 – Key players in some of the different segments of the offshore wind power value chain

Components produced/ Services	Company	Country
Main manufacturers	Vestas	Denmark
	Siemens Gamesa	Spain
	GE Renewable Energy	United States
	Envision	China
	Enercon	Germany
	A2Sea	Denmark

Components produced/ Services	Company	Country
Main installers	Van Oord/MPI	Netherlands
	Fred Olsen Wind Carrier	Norway
	Seajacks	United Kingdom
	GeoSea	Belgium
	Ørsted	Denmark
	Vattenfall	Sweden
Developers	E-on	Germany
	Iberdrola	Spain
	Innogia	Germany
	EEW	Germany
	Sif Tecade	Netherlands
Foundations	Bladt Industries	Denmark
	Smulders JV	Belgium
	Windar Renovables	Spain

Source: Adapted from Junqueira, 2020.

IRENA's latest macroeconomic analyzes show that the energy transition needed to achieve the decarbonization targets set out in the Paris Agreement would result in the loss of around 7.4 million fossil fuel jobs by 2050. These impacts would be mitigated and even reversed by the creation of 18.8 million jobs in the renewable energy sector (IRENA, 2018b). The case of the offshore wind power sector is symbolic of a possible smoother transition between these two scenarios. What is certain is that at least some skills and professional know-how from the offshore oil and gas sector will be applicable to careers in this energy source, enabling the mobility of professionals from one sector to another. In some cases, retraining and adaptation of existing skills will be smoother, while in others, the development of new and specific skills will be required. In Germany, for example, the expertise of shipyard workers has been used to support the construction of foundations and towers for offshore wind farms (Hülsen, 2012).

Synergies between the value chain of the oil and gas sector and the offshore wind power sector have been consolidated in line with both activities in different segments. Companies in the oil and gas sector provide a range of information for project planning and topographic surveys covering environmental, geophysical, and geotechnical aspects relevant to offshore wind farms. Given the similarities between the two sectors in the marine environment, there are common challenges of working in a difficult environment, with implications for health and safety. In manufacturing, there are synergies with the oil and gas sector in connection with the production of support structures. Expertise in the design of support structures for offshore oil production facilities is of great importance for offshore wind turbines, especially in difficult locations such as deep-water regions.

Traditional manufacturers in the oil and gas sector, such as Bladt, EEW, Sif, and Smulders, have made the transition to the offshore wind power sector.

There is also plenty of room for synergies in installation and grid connection related to turbine foundations, cable laying, substations, steel structures etc. Oil and gas companies are already carrying out installation work for offshore wind turbines (e.g., 3sun, Ecosse Subsea, and ROVOP), leveraging existing skills. There are also companies in the cable and connections sector that are moving from the oil and gas sector to offshore wind power, such as JDR Cables (IRENA, 2020). Although the requirements in this area vary from sector to sector, there are great similarities when considering the simplest components of the cable system, such as connectors, terminals, protective materials, and others.

Offshore wind power and oil and gas substations are another project component that also has many similarities. Substation contracts are generally outsourced, with developers looking for partners who are highly skilled in power transmission and offshore engineering. Suppliers from the oil and gas sector are proving to be ideal partners due to their extensive understanding of the prevailing contracting models for this type of structure and their strong track record in a more mature sector. Examples include Bladt, Heerema, HSM Offshore, and Sembmarine SLP.

Finally, in the O&M segment, oil and gas suppliers already have significant experience in maintaining offshore assets and there are relevant synergies in planned maintenance, fault detection, and asset repair. In addition, the safety standards and maintenance practices are highly transferable to offshore wind turbines. Performing underwater inspections, maintenance and repairs requires skills that can be transferred after progressive training. Indeed, many oil and gas suppliers have provided maintenance and inspection services for offshore wind turbines (e.g., Briggs Marine, 3Sun, and Hughes subsurface engineering) (IRENA, 2020).

The Brazilian case is exemplary in this context. As with any emerging market of this type, Brazil's supply chain needs to be extensively developed to obtain the maximum local benefit from the growth of the offshore wind power industry. **Therefore, with mature supply chains in the related onshore wind power**[4] **and oil and gas**[5] **sectors, Brazil is in an excellent starting position compared to many emerging markets.**

However, the predictability and legal certainty of the current regulatory framework in Brazil is being questioned and is a major barrier to initial investment in the country's offshore wind power supply chain (Ramboll, 2022). In any case, the speed and efficiency of

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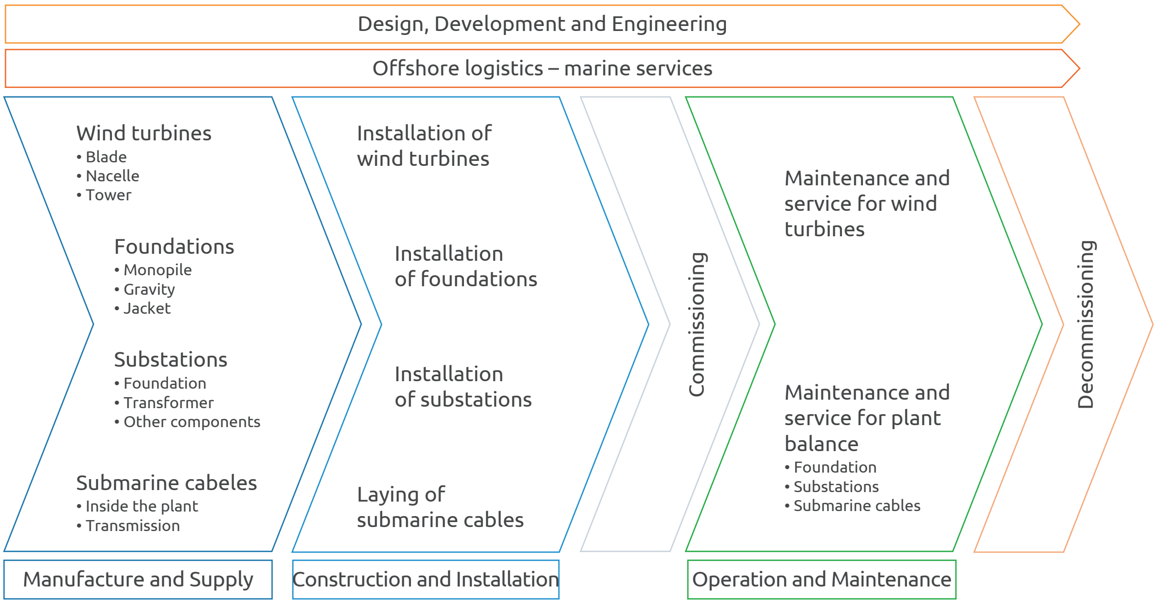
[4] More than 20 GW of onshore wind power installed by the end of 2021, expected to reach 40 GW by 2029.

[5] Forecast of 5.5 million barrels per day by 2029.

closing these gaps can be increased by working with foreign countries and governments with experience in offshore wind power.

The offshore wind power industry value chain consists of seven segments: design, development and engineering; project management; offshore logistics; manufacture and supply; construction and installation, operation and maintenance; commissioning; and decommissioning. Figure 17 illustrates the key segments of the offshore wind power industry value chain. The following sections analyze the individual phases of the chain.

FIGURE 17 – Main segments of the offshore wind power market value chain



Source: Adapted from RAMBOLL, 2022.

2.4.1 DESIGN, DEVELOPMENT AND ENGINEERING

Management during the life cycle of an offshore wind farm can vary from project to project. Some developers have their own technical teams that handle the entire cycle. Others bring in service providers who take over most of the management.

Service providers in the offshore wind power sector include project management and technical support services as well as specialized services, including engineering services, regulatory and licensing support, certification, management, commercial consulting, insurance management, environmental services, consulting, among others. These services are well established in Brazil for sectors related to offshore wind power, such as onshore wind power and oil and gas.

ABEEólica, for example, an Association that brings together more than 100 companies from the entire production chain of the wind power sector in Brazil, has 23 members classified in the category of "Engineering, Consulting and Construction" that can extend their services to the offshore wind power industry. However, the country still needs to acquire more expertise in offshore wind power through the consolidated experience of agents outside Brazil such as AECOM, Arcadis, DNV, ERM, Ramboll, and TetraTech (Ramboll, 2022).

The developers of offshore wind projects are the actors responsible for the first phases of the activities, e.g., for engineering design, financing and – in many countries – for site surveys and work permits. Many developers remain involved in the project and are responsible for the construction and operation of the offshore wind farm. Historically, developers have sought to expand their portfolio through asset development and sales, as well as through joint ventures and combinations of strategic partnerships.

Global companies such as Equinor and Shell have championed the development of offshore wind farms in Brazil. Brazilian developers such as Eólica Brasil and Neoenergia (holding company of the Iberdrola Group) have also shown interest. In the onshore wind power sector, there are already important players in Brazil such as Casa dos Ventos, Omega, Ecoenergia, Enel, and EDPR. However, it should be emphasized that the cost of a typical offshore wind farm is much higher than that of a traditional onshore wind farm. Other barriers may include the distance between sectors in terms of the complexity of the marine environment, the increased scale of components, and the size of the internal organization for management and maintenance. In addition, it appears that the largest local onshore developers are not entering the offshore market, as the potential of the Brazilian onshore wind power market still offers room for growth.

Brazilian oil and gas developers are also beginning to explore opportunities in the offshore wind power segment. Such companies are expected to face some difficulties in the transition as they struggle to adapt their usual and specialized projects with more generous profit margins to mass production and installation projects for offshore wind power with lower profit margins.

One example is Petrobras, which entered into an agreement with Equinor in 2018 to jointly develop offshore wind power in Brazil. In May 2022, Equinor and Petrobras announced that the Aracatu 1 and 2 offshore wind farms, with a total capacity of more than 4 GW, would start environmental impact assessment.

With regards to the materials supply chain, while the relevant sectors can facilitate the transition to the supply of offshore wind power components, developing consistent delivery capacity requires adequate facilities and equipment, a trained workforce, and access to raw materials. Although it is challenging to develop a supply chain for offshore wind farms, most of the jobs created over the lifecycle of a project are in the supply chain. An important aspect of developing a strong supply chain is project continuity. Manufacturers need a complete and continuous pipeline of offshore wind projects to ensure that their often-large investments pay off.

2.4.2 MANUFACTURE AND SUPPLY

2.4.2.1 Turbines

Offshore wind turbines share the same operating principles as onshore wind turbines, with differences in size and robustness, with the former being far superior, as well as anti-corrosion treatment of its components, especially the nacelle, blades, tower, and foundations. The latter will be discussed later in a separate section, as they cover a very wide range.

First, the nacelles and hubs of an offshore wind turbine house the key elements of power generation (gearbox, generator, braking system, and control unit), which are responsible for converting the kinetic energy of the wind into electrical energy.

The main manufacturers of offshore wind turbines are also the same as those of offshore wind turbines: Vestas, Siemens Gamesa Renewable Energy (SGRE), and GE Energia Renovável (GE). Each of these players has already established production capacity for the onshore segment in Brazil (ABDI, 2022). Vestas manufactures and assembles nacelles and poles in the state of Ceará (Governo do Ceará, 2019). SGRE produces nacelles in the state of Bahia (Panorama Offshore, 2019). Finally, GE assembles turbines, also in Bahia, and supplies more than 60% of its components.

While the onshore wind power industry supply chain has the capacity to serve the domestic market, offshore applications are significantly increasing the size of nacelle and hub components, meaning current production facilities cannot be used for offshore wind power. Land transportation of components is neither economically nor technically viable due to their large dimensions and heavy weight. Large investments must be made in new production centers close to the destination. Therefore, it is necessary to establish a local production capacity for specific nacelles and hubs for offshore applications. However, this reality seems to be still far away, as it requires a large demand.

The rotor blade supply sector is considered a strategic factor in the wind power value chain. The manufacturing of rotor blades for offshore wind turbines is largely done through already established relationships between suppliers and consolidated players in the manufacturing industry, with little room for the introduction of new agents due to high technological barriers, as well as the value of intellectual property associated with blade design and manufacturing (Ramboll, 2022).

Unlike the offshore wind power sector, many of Brazil's onshore wind turbine blades are contracted out to Brazil's Aeris Energy, the largest wind turbine blade manufacturer in Latin America. Aeris Energy currently supplies wind turbine blades to Vestas, Nordex-Acciona, WEG, GE, and SGRE. In 2021, Aeris manufactured blades over 80 meters long for Nordex-Acciona, which were shipped directly from the Pecém-CE Port Complex, where the Aeris Energy plant has an annual production capacity of 9 GW (Ramboll, 2022).

Despite a robust onshore wind power industry and experienced blade production workforce in Brazil, there is still a need for investment in the manufacture of new port areas and additional equipment to produce larger offshore wind blades. Another challenge that Brazil will face in localizing blade production is market fragmentation. Offshore wind turbine blades are specific to a turbine model, meaning that their manufacturers make their market entry decisions based not on the total installed capacity, but on the total installed capacity of a particular wind turbine model. It is unclear to what extent the manufacturing industry would be willing to redirect their existing supply chains to use a local, shared supplier such as Aeris Energy.

The towers have the task of supporting the nacelle and transferring the loads of the rotor-nacelle assembly to the foundation. For offshore wind turbines, the towers are typically manufactured in three or four pieces, which are then transported to the project's sorting area before being pre-assembled and loaded for installation. In contrast to onshore wind turbines, which can also use concrete towers, the towers of offshore wind turbines are made of steel. As with all other components, the impossibility of transport requires plants to be built in coastal regions.

The Brazilian onshore wind power sector has expertise in manufacturing steel towers, but in smaller dimensions than required for offshore wind power. However, the production of towers for offshore wind power, which can be up to 8.5 meters high, requires steel structures that are significantly larger than those currently being manufactured in Brazil. Plant and equipment upgrades, as well as the logistical needs to transport the large components, can slow the consolidation of an offshore wind tower supply network (Ramboll, 2022).

Torres Eólicas do Nordeste S.A. (TEN) is a Brazilian company that manufactures the structure, coating, and internal components of steel towers. The company has a plant in inland Bahia, in the city of Jacobina, a region with a high concentration of onshore wind farms. TEN's inland location is unlikely to be suitable for meeting demand for offshore components. Torrebras is another company in the onshore wind power sector that has been operating in the energy steel tower manufacturing market since 2013, also in Bahia, about 20 kilometers inland. Finally, GRI Renewable Industries, based in Madrid (Spain), has 16 wind power component plants in eight countries, including GRI Towers Brasil. The company announced in 2021 that it would build a plant at a new location in the United Kingdom (Ramboll, 2022).

It can be said that the Brazilian workforce is relatively well positioned due to its experience in the field of onshore wind power and a solid national steel industry of recognized quality that produces high quality semi-finished carbon steel slabs. Companies such as CSP, based in the Porto do Pecém complex, and Usiminas and Grupo Aço from Ceará, are good examples of potential suppliers of raw materials for towers.

2.4.2.2 Foundations

There is also a need for a strong market in the production sector for foundations for the offshore wind power industry. Turbine foundations are sold in a wide variety of designs, such as monopile, jacket foundations, gravity foundations, floating foundations, among others.

Although there is no monopile industry in Brazil, rolled tube suppliers can enter the offshore wind power market with relatively low barriers. However, new dedicated seaside facilities are expected to provide the necessary offshore wind power dimensions and transport the foundations. The biggest technical challenge in this transition is the lamination of the slabs with significantly larger diameters and wall thicknesses.

In particular, the base diameters and overall wall thicknesses far exceed those of classic onshore turbine towers. Another challenge is the logistics and storage of the larger components. Since transport by road and rail is not possible, the transport of the monopiles requires extensive investments in facilities on the shore, which requires self-propelled modular transporters (SPMT) with the appropriate classification, access by ship, and adaptation of storage areas to ensure supply to this market.

2.4.2.3 Substations

There is also a market for substations, which can be considered the “heart” of an offshore wind power facility. This component houses the electrical infrastructure required to convert the voltage from the turbines/cables between arrays to the export cables and the shore system. The substation consists of two main structures: the substructure and the topside. The substructure is usually a pinned-jacket foundation, sometimes a monopile foundation. The topside take a variety of forms, but most often it is a custom, multi-level platform that houses electrical equipment and auxiliary systems such as transformers and switchgear.

Often, the manufacturing locations for the topside platform and primary electrical components are not near the offshore wind farm site. For example, topside structures of European offshore wind farms are often manufactured in Asia. Although Brazil has no experience in manufacturing offshore wind power substations, there is considerable experience in manufacturing and integrating offshore O&G substations and floating production and offloading units (FPSO). When it comes to offshore platforms, many synergies can be found between the O&G and offshore wind power industries, although the former is generally smaller than the latter. SBM Offshore is one such company that designs, supplies, and integrates systems into an FPSO vessel. Other global OSS manufacturers such as Keppel Offshore and Marine also have onshore facilities in Brazil that can be adapted for the offshore wind power business with the help of their international headquarters. Designers like Ramboll also already have offices in Brazil (Ramboll, 2022).

Brazil is also home to companies such as ABB, GE, and Siemens that manufacture certain components for electrical substations. However, it is unclear whether the electrical components required for an offshore wind power substation are currently available in Brazil.

In summary, Brazil does not yet have experience in manufacturing topsides for offshore wind power substations, but parallel industries, primarily oil and gas, are undertaking similar projects on a smaller scale. Based on this experience, it is likely that certain manufacturing areas for offshore substations could be the initial location for the supply chain, although high investment barriers still need to be overcome.

Finally, the onshore electrical infrastructure of an offshore wind farm receives power from offshore export cables, ensuring that it can be fed into the grid or transmission system onshore. These onshore substations are very similar to other power generation plants already existing in Brazil. Electrical equipment includes switchgear and transformers, which are easy to find on the market and are not considered potential bottlenecks for the development of the offshore wind power industry in Brazil. Due to the capabilities of the Brazilian onshore wind power industry, power generation from other renewable sources, and the power transmission and distribution sector (grid integrators), the know-how to manufacture onshore substations and the necessary electrical infrastructure already exists in Brazil. Some of the companies offering these services in the country are ABB, GE, Siemens, WEG, and Schneider (Ramboll, 2022).

2.4.2.4 Submarine cables

In the case of submarine cables, there are currently a limited number of global suppliers and high barriers to market entry, such as high initial investment costs coupled with high technical complexity. Therefore, the global supply market is not expected to grow at the rate needed to meet future demand. Related sectors such as transmission and distribution or oil and gas can respond to high demand and alleviate some of the market pressure for high-voltage cables. If Brazil experiences high growth in the offshore wind power market, the local submarine cable supply industry could emerge from these very sectors. For example, Oceaneering has been present in Brazil since the 1970s and has an umbilical cable factory in Niterói, Rio de Janeiro. Oceaneering's supply capabilities in the O&G and renewable energy sectors, both for submarine cables and cable accessories such as cable protection systems (CPS), are known worldwide. Another example is MFX, a pioneering company in Brazil that produces submarine umbilical cables in Salvador, Bahia, for companies such as Schlumberger and Petrobras. Umbilical cables are designed for a more dynamic environment compared to classic offshore wind power cables and contain more armored cables as well as low voltage cables, control cables, and hydraulic lines. However, with some adjustments, both companies could be able to supply submarine cables to the Brazilian offshore wind power market (Ramboll, 2022).

2.4.3 CONSTRUCTION AND INSTALLATION

Installing an offshore wind farm is perhaps the most delicate part of the sector. After manufacturing and pre-assembly, specialized industrial vessels are responsible for transporting the components to the offshore site and completing the installation process. The main points of attention in terms of installations are: generators, substations, submarine cables, and foundations.

First, the generators are installed in the turbine nacelle with the help of a special vessel, also called a wind turbine installation vessel. Global demand for these vessels is quite high, considering that only about 10 to 15 units are in operation and even then, not all of them are designed to handle increasingly large turbine components. Brazil does not yet have local experience with turbine installation (vessels or trained labor), as none of the installation companies operate in the country. Currently, the global fleet of specialized vessels is also expected to operate in the Brazilian offshore wind power market to install turbines, further increasing the demand for these assets (Bošnjaković et al., 2022).

Other options would include locally built new ships or perhaps modernizing existing Brazilian ships in related sectors such as oil and gas. Building new ships is usually very expensive and requires special shipbuilding capacities. Almost all ships of this type are built in Asia, and in general the requirements of local legislation and/or the volume of demand do not justify the level of effort in other countries.

Oil and gas markets generally rely on smaller vessels, but these do not meet the needs of offshore wind power and are difficult to adapt. Recently, there has been an attempt by the Brazilian Association of Offshore Support Companies to promote the development of the existing fleet to meet the needs of the emerging offshore wind power industry.

Singapore-based Keppel has two coastal shipyards in Brazil and experience in developing some structures for these specialized vessels (Aborgela et al., 2022).

Regarding the installation of foundations, the process depends greatly on the type of foundation. The simpler monopile is usually loaded directly onto the installation vessel at the sorting port. The vessel may be of the self-elevating type (Jack-Up Vessels or JUV), similar to the way turbines are installed. However, this depends on the water depth and in recent years the offshore market has shifted to installing floating foundations using Heavy Lift Vessels (HLV).

Therefore, as with the installation of turbines, JUV and HLV vessels are also a highly sought-after resource when installing foundations. Currently, none of the owners or manufacturers of this type of asset operate in Brazil, which means that there is no experience in the installation of foundations in the country (vessels or trained labor). It is expected that the international fleet of JUVs or HLVs will be able to meet the needs of the Brazilian offshore wind power industry in terms of foundation installation, thereby increasing the demand for these assets (Ramboll, 2022).

As the size of the turbine increases, the size of the foundations also increases. As an example of the Brazilian situation, the projects expected for the Port of Pecém in Ceará can be mentioned. The relatively shallow coastal waters of Ceará (compared to Europe) should contribute to the use of less robust monopiles. Smaller monopiles may offer the advantage of relying on installation vessels from other markets that are designed to install heavier foundations, but which can no longer be used for the same needs. (GWEC, 2022).

Opportunities for new vessels or possibly upgrading existing Brazilian vessels in related sectors such as oil and gas, however, would require high demand and extensive investment in construction.

Regarding submarine cables, it is well known that established offshore wind power markets use dedicated cable installation vessels (Cable Lay Vessels or CLV) to install their export and inter-array submarine cables. Depending on a number of factors such as water depth, cable diameter, and installation method, projects often use multiple vessels to complete the process.

Although specialized CLV vessels are the offshore sector’s preferred means of laying submarine cables, the barrier to entry into the cable market is significantly lower compared to the installation of turbines or foundations. Although no offshore wind power cables have been installed in Brazil or by a Brazilian company to date, a similar methodology is used in related sectors such as oil and gas pipelines and submarine transmission lines. An example is the landing of cables and pipelines on land, which is similar.

The installation of an Offshore Substation (OSS) (without commissioning) is usually a short part of the wind farm installation plan, which includes only two main components – topside and substructure. The installation process starts with the substructure, which is transported to the installation site offshore on the installation vessel or by barge. Typically, a HLV with sufficient lifting capacity (crane) is used as the installation vessel. The second phase is the installation of the topside. Since these platforms typically weigh about 2,000 Mt, they are usually transported by barge to the offshore site, where an HLV lifts the topside into the substructure (Aborgela et al., 2022).

The HLV used for offshore substation installation worldwide is often chartered by owners active in both the oil and gas sector and the offshore wind power sector. Equivalent systems in the oil and gas industry that are fixed to the seabed use similar methods to offshore wind turbines. Brazil is known for its deepwater oil platforms, many of which are floating production, storage and offloading (FPSO) structures. Sheerleg crane vessels used in the assembly of these units could be used for the installation of offshore wind turbines, although the suitability of these vessels to operate at greater distances from the coast needs to be analyzed (Aborgela et al., 2022).

2.4.4 OFFSHORE LOGISTICS

Just as important as the technologies to be installed or even the design of these technologies is the operational logistics of these systems carried out by the vessels. They provide a wide range of offshore services including, among others, crew transfer, supply logistics and storage of certain components and materials, overnight accommodation for work teams, and security vessels for the offshore site. Vessels are divided into two main categories: service vessels and installation support vessels.

Service vessels are used during the installation and operation phases, or both. A wide variety of vessels could fall under this category alone. Three common types of service vessels are summarized in Figure 18. Crew Transfer Vessels or CTVs are used to transport personnel and occasionally equipment such as spare parts and smaller tools from the onshore base to the offshore site. Service Operation Vessels or SOVs are designed for long-term accommodation of offshore personnel, often for up to two weeks.

SOVs are used both during the installation phase and during larger operational campaigns. Finally, the so-called Guard Vessels or GVs are known for monitoring and securing the offshore site during installation, both by the project developer to prevent accidental damage to offshore facilities or work interruptions by other maritime users and to ensure these users are aware that construction is underway.

FIGURE 18 – Service vessels: (a) Crew transfer vessel, (b) Service operation vessel, and (c) Guard vessel (Ramboll, 2022).


(a) (b) (c)

Over the past decade, the Brazilian oil and gas industry has launched a campaign to increase the number of service vessels built in Brazil for use in the O&G industry, including as part of the 2029 Ten-Year Energy Expansion Plan. The campaign can be considered successful, as it enabled the availability of 367 support vessels in 2019, 328 of which were built in Brazil. Although many of these support vessels do not exactly fit the characteristics of a service vessel, an estimated 94 of them are classified as small supply/support vessels or fast supply vessels (Offshore Engineering Digital, 2019).

The existing fleet of Brazilian offshore service vessels is operated by several companies, including Wilson Sons, BRAM Offshore, Grupo CBO (Companhia Brasileira de Offshore), and STARNAV. Although these vessels do not have certain features for offshore wind power applications, they can support the local market for offshore service vessels. Shipyards in Brazil are also able to modernize existing ships, e.g., by modernizing supply ships or building new CTVs dedicated to offshore wind power. For the operational phase, SOVs can also be built from scratch, as a purpose-built project is generally more effective and efficient (Offshore Engineering Digital, 2019).

Figure 19 shows the three main types of installation support vessels designed to transport the assets to larger vessels to supply them with the components, materials, and equipment required for the continued operation of the offshore systems (Ramboll, 2022).

FIGURE 19 – Service vessels: (a) Platform supply vessel, (b) Anchor handling vessel, and (c) Heavy transport vessel (Ramboll, 2021).


(a) (b) (c)

It can be said that the basic characteristics of O&G vessels resulting from the above-mentioned campaign to promote the production of support vessels for the sector are suitable for the wind power sector. In 2019, an estimated 178 vessels met the parameters required for installation support vessels. Therefore, the conversion and redeployment of these vessels can be considered a viable project as the offshore wind power market grows and demand increases. Shipyards in Brazil are able to advance retrofit projects or installations specialized in offshore wind power for support vessels.

2.4.5 OPERATION AND MAINTENANCE

Maintenance of wind turbines is extremely important throughout their lifespan as it ensures reliable operation. The most successful wind farms use reliable wind turbines and have good operations and maintenance programs.

O&M practices are typically managed by onshore units, which typically include planning offices for inspections, maintenance and repair of components, maritime coordination activities, and storage of spare parts and consumables. Due to the frequent travel of technicians to the offshore site, these onshore bases are typically located in a port close to the offshore wind farm. Occasionally larger maintenance campaigns are required, such as for replacing rotor blades. These campaigns require larger vessels that may require a different port.

Maintenance and servicing of offshore wind turbine generators is usually carried out by the original equipment manufacturer for at least the first five years of operation. Onshore wind power technicians in Brazil already have the expertise to maintain offshore turbines but are not accustomed to the challenges presented by the marine environment.

In recent years, O&M for submarine cables, as well as their cable protection systems, have received increasing attention in the European offshore wind power industry. Costly losses due to cable damage, including cable O&M, regular monitoring, and subsurface inspections, are a critical factor. Balance of Plant[6] (BoP) maintenance and service in the Brazilian case are expected to be areas with a faster learning curve than turbine maintenance and service. However, certain skills and methods already exist in the local market, such as subsea inspections and ROV operations in the oil and gas industry. These skills can be relatively easily transferred to the offshore wind power industry (Veers et al., 2020).

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[6] Balance of Plant is a term generally used in the context of energy engineering and refers to all the supporting components and auxiliary systems of a plant required for energy supply, in addition to the generating unit itself.

2.5 COSTS OF OFFSHORE WIND POWER

Offshore wind power has maintained a cost reduction trend that has been ongoing for eight years and has seen gradual cost reductions worldwide in 2021. Despite supply chain constraints and inflation, the scenario is positive and points to the consolidation of an increasingly competitive market as part of the energy transition. In fact, offshore wind power technology has evolved rapidly since 2010. Cumulative installed capacity increased 18-fold between 2010 and 2021, from 3.1 GW to 55.7 GW (IRENA, 2022a). Plans and goals for future implementation are becoming more numerous as costs fall and technology matures. For example, in 2021, Belgium, Denmark, Germany, and the Netherlands announced a goal of adding enough new capacity to reach a total of 150 GW of offshore wind power by 2050. According to a Department of Energy report (DOE, 2022), the deployment and consolidation of the technology paves the way for even greater cost reductions in the coming decades.

The levelized cost of electricity (LCOE) for projects commissioned in 2020 decreased to levels just below $95/MWh, with a range of $78/MWh to $125/MWh globally. This decrease represents an average reduction of 16% compared to 2019 (Musial et al., 2020). According to data from IRENA, which accounts for the reduction over a longer period, between 2010 and 2021, the levelized cost of offshore wind power decreased by 60%, from $188/kWh to $75/MWh. Between 2010 and 2021, the average total cost decreased by 41%, from $4,876/kW to $2,858/kW. At its peak in 2011, the LCOE was $5,584/kW, twice as much as in 2021 (IRENA, 2022).

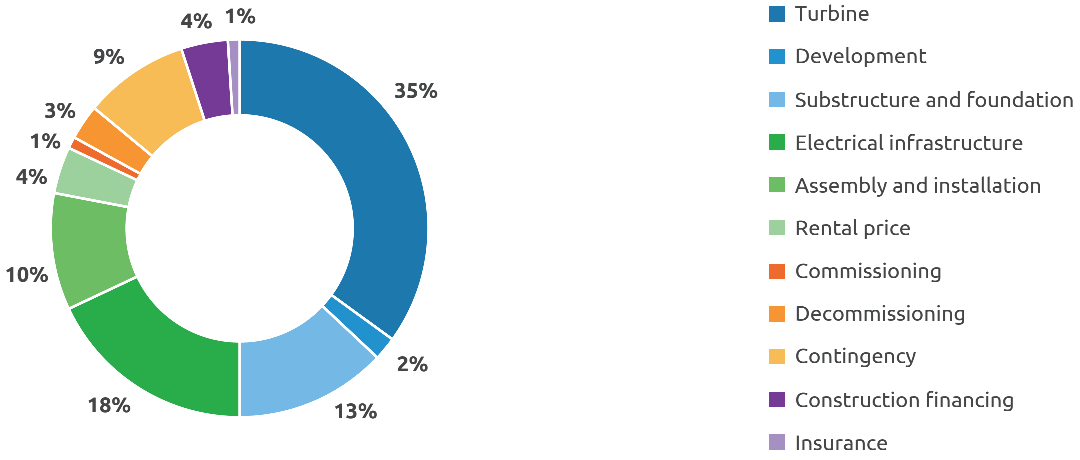
The reduction in LCOE is primarily due to technological improvements and the increasing maturity of the industry. The expertise accumulated in development, greater standardization of products, and the strengthening of regional manufacturing hubs have contributed to cost reductions (IRENA, 2022).

Capital expenditures (CAPEX) have the largest impact on the life-cycle costs of offshore wind farms and include all costs incurred before commercial operation begins. After a period of increase until 2014-2015 (Musial et al. 2017), CAPEX have declined, reaching around $3,750/kW globally in 2020.

In 2020, CAPEX were on average higher in Europe and the US than in Asia. However, there appears to be a convergence of CAPEX since 2015, with Europe and the United States reaching similar levels to Asia on average by 2027. WindEurope reported CAPEX of $4,000/kW for European projects in 2020, a substantial margin over the all-time low CAPEX of $2,900/kW in 2018.

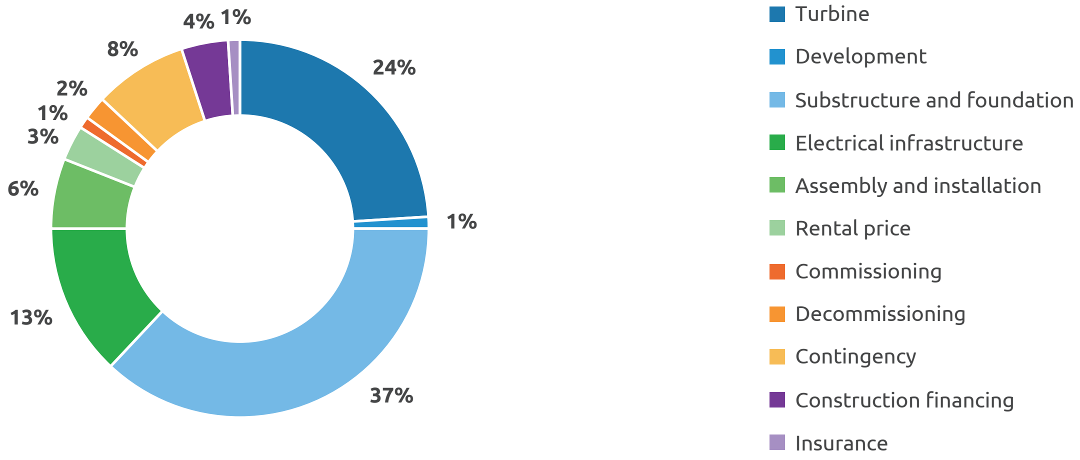
Several factors can explain variations in CAPEX in a given year and over time (Stehly, 2021), including: variations in spatial conditions (e.g., water depth, distance to port, connection point, and wave height of the sites, which influence the technical requirements for the construction and operation of a wind farm); project size; varying levels of supply chain scarcity (e.g., components, vessels, and skilled labor); changes in commodity prices; and energy, to name a few. A breakdown of CAPEX for the fixed offshore reference project and for a floating reference project is shown in Figures 20 and 21 respectively.

FIGURE 20 – Breakdown of CAPEX costs for a fixed offshore wind turbine



Source: Stehly, 2021.

FIGURE 21 – Breakdown of CAPEX costs for a floating offshore wind turbine



Source: Stehly, 2021.

As can be seen, the turbine is the component that has the greatest impact on the CAPEX of offshore wind farms, accounting for around 25 to 45% of the total CAPEX costs. Data from financial statements shows that wind turbine prices ranged from approximately $1,400/kW to $1,700/kW between 2018 and 2020. BNEF data shows a significantly lower wind turbine price of $1,000/kW, which is forecast to fall further to $850/kW in 2030.

The upward trend in the size of wind turbines is often cited as a major cost factor (Wiser et al. 2021). Using larger turbines for a given project size reduces the number of turbines that need to be installed and repaired. The tendency of project developers to choose the highest rated turbine model on the market shows that larger, more powerful wind turbines bring economic benefits. In particular, market progress in manufacturing larger turbines results in more accessible prices, so that the savings in operating and maintenance costs ($/kW/year) eventually outweigh the incremental cost of a turbine of this type ($/kW). This reduction in the overall cost of the turbine sizing system is made possible by continued innovations such as the use of lightweight materials, advanced manufacturing methods, system-wide load control, and economies of scale in production and delivery.

Another factor that makes offshore technology more expensive than onshore technology is the cost of transmitting the energy generated. For offshore wind farms, these costs can reach 15 to 30% of the total project costs (EWA, 2009). A general average estimate of the cost of transmission infrastructure and its installation is estimated at 21% of the total cost of the offshore wind project. Of this, 41% goes to the substation and its equipment, 30% to the connecting cables to the onshore grid, 18% to the installation of the grid connection, and 11% to the internal cabling of the wind farm.

The cost of these internal connections between the generators and the substation can be considered constant and represents only a small part of the investment involved.

Operating expenditures (OPEX) are higher for offshore wind farms than for onshore farms, with annual OPEX ranging from $70 to $80/kW for offshore and from $30 to $40/kW for onshore (Lazard, 2020). Maintenance personnel access to offshore sites is an important factor in this cost differential. Wind and wave conditions can limit access to these sites, resulting in longer downtime or required investment in specialized crew transfer vessels or helicopters that can operate in challenging sea conditions.

Industry analysts estimate that OPEX will decrease by 7% to 16% by 2025 and 14% to 29% by 2030.

There is also an impact of increased wind turbine capacity on maintenance costs. The cost of many O&M activities depends on the number of wind turbines rather than their capacity. For a given wind turbine capacity, OPEX tends to decrease for a smaller number of larger turbines than for a larger number of smaller turbines as the amount of maintenance work decreases. Ørsted reported a 33% reduction in OPEX/MW for 6 to 8 MW turbines compared to 3 to 4 MW turbines.

Unscheduled or corrective maintenance and spare parts account for 58% of annual OPEX (Liu and Garcia da Fonseca, 2020). Reducing the number of repairs required and improving the ability to plan maintenance in advance (allowing for schedule optimization) can reduce costs. In this context, various remote monitoring strategies are applied, including remote monitoring to detect problems early and to facilitate preventive maintenance and airborne, submarine, or blade tracking devices for inspecting and repairing hard-to-reach components.

One factor that can increase O&M costs is the tendency to install offshore wind farms farther from shore (Figure 22), resulting in longer transit times that can reduce turbine availability. Possible strategies to mitigate the effects of greater distances to shore include the use of service vessels to provide accommodation for crews for longer periods at sea. These can operate in more challenging sea conditions than typical crew transfer vessels and can maintain operations in clusters of wind farms to optimize logistics and vessel utilization.

3 REGULATORY ASPECTS OF OFFSHORE WIND POWER

In 2022, there was significant progress in the regulation of offshore wind farms in Brazil with the aim of boosting their development. This progress has been achieved in particular with regard to the assignment of use of physical spaces and the exploitation of natural resources in inland waters under the control of the Federal Government, in the territorial sea, in the exclusive economic zone (EEZ), and on the continental shelf. In addition, Ibama published a Term of Reference (TR) on Environmental Impact Studies and their Environmental Impact Report (EIA-RIMA) for offshore wind farms in 2020.

This chapter assesses the regulation of offshore wind power. Section 3.1 presents the evolution of the sector's regulatory framework. Issues related to the assignment of use of federal resources and market rules that may affect offshore wind power production were examined. Section 3.2 analyzes the regulatory barriers to the development of offshore wind projects in Brazil aimed at producing low-carbon H_2. Finally, Section 3.3 discusses regulatory issues related to environmental permits.

3.1 OFFSHORE WIND POWER REGULATION

Offshore wind power generation can benefit from an already established renewable energy market in Brazil. The first specific regulatory instrument to promote renewable energy generation in Brazil was the Program for Incentive of Alternative Power Sources (PROINFA), established by Law No. 14,380 of 2002. The program was mainly aimed at promoting solar energy, in addition to the generation of small hydroelectric plants (SHEPs), biomass thermal power plants, and wind turbines.

Regarding smaller renewable power generation plants, Normative Resolutions No. 482/2012 and 687/2015 defined the general conditions for access of micro and mini distributed generation (MMDG) to electric power distribution systems. In addition, in 2022, Law No. 14,300 created the MMDG legal framework, which aims to provide greater legal certainty to investors in this market. The sources covered by these regulations include photovoltaic solar energy, wind energy, biomass heat generation, and qualified combined heat and power. Although wind energy falls under these regulations, it has not developed as much in the MMDG market as it has in the larger market (free and regulated contracting environment – ACL and ACR, respectively).

These two energy contracting environments (ACL and ACR) were created by Law No. 10,848/2004 and Decree No. 5,163/2004, which at the time established an important regulatory framework that became known as the "new model for the electricity sector". In the ACR, the government is responsible for conducting regulated auctions to purchase energy to supply at least 100% of the electricity suppliers' markets. Due to the auctions, especially the Reserve Energy Auction in 2009 (LER No. 03/2009), dedicated to the exclusive contracting of wind energy sources, 71 projects were contracted with an installed capacity of 1,806 MW, representing a guaranteed investment of R$ 9.4 billion in this source (Gannoum, 2020). Since then, the installation of these systems on land has increased dramatically, thanks not only to the regulated auctions that continued to take place in the following years, but also to the growth of the free market (ACL).

Energy contracting was made possible in the ACR, as in the ACL, by two regulatory instruments introduced in the 1990s that defined independent power producers (IPPs): Law No. 9,074/1995 and Decree No. 2,003/1996. Also in the 1990s, Law No. 9,427/1996 established that for the production and consumption of energy from renewable sources, the so-called "incentivized sources", discounts on the tariffs for the use of the transmission and distribution systems (TUST and TUSD) should be granted. Wind energy has benefited greatly from this law, selling a significant amount of energy on the open market (ACL).

Since 2016, there has been discussion about opening the free market in Brazil, which could expand the trade of wind power (onshore or offshore). The legal instrument that opened discussions on this issue, known as "modernization of the electricity sector", was Public Consultation No. 33/2017 of the Ministry of Mines and Energy (MME). The expansion of the free market aims to create a retail energy market that is expected to increase the sector's competitiveness, benefiting the onshore wind power market, one of the country's most competitive sources of generation. A counterpoint to this discussion is that if the market were opened up completely, regulated auctions would theoretically be extinguished. These auctions can be a safe haven for contracting energy from offshore wind projects, as the risks of selling energy at auctions are much lower compared to selling energy on the open market.

Some steps have also been taken with regard to the creation of the retail energy market: Normative Resolutions No. 570/2013 and No. 654/2015 regulate retail trading; (ii) MME Ordinances No. 514/2018 and No. 465/2019 reduce the load limits (demand contracted with distributors) for concluding electricity contracts in the ACL; and (iii) GM/MME Normative Ordinance No. 50/2022 establishes that from January 2024 all high-voltage consumers are eligible for the ACL. However, opening the market to low-voltage consumers requires the adoption of Bill of Law (PL) No. 414/2021, currently being processed by the Brazilian Parliament.

As already mentioned, opening up the market creates growth opportunities for wind generation. However, Law No. 14,182/2021, whose main purpose is the privatization of Eletrobras, could limit the growth of this market, as it establishes the contracting of 8 GW of natural gas-fired thermoelectric power generation (to be supplied between 2026 and 2030) through auctions.

Offshore projects not only have an apparently favorable market regulatory framework, but also a specific regulatory structure that could help attract investment in some pilot plants in the coming years. Decree No. 10,946 of January 2022 is symbolic because, considering what was set forth in Laws No. 8,617/1993 and 9,636/1998, provides the rules for "assignment of use of physical spaces and the exploitation of natural resources in inland waters under the control of the Federal Government, in the territorial sea, in the exclusive economic zone, and on the continental shelf for the generation of electricity from offshore projects", which includes wind power generation. It should be emphasized that the Decree is in line with Bill of Law No. 576/2021, which deals with the same subject, having been approved by the Federal Senate and forwarded to the Chamber of Deputies.

The assignment of use referred to in Decree No. 10,946/2022 may be free of charge, when focused on research and development (R&D), or for consideration, when focused on operating a generation facility. In addition, it may be planned or independent. In the planned assignment, the Ministry of Mines and Energy (MME) will pre-determine the prisms. With independent assignment, interested parties can submit an application for assignment of a prism that has not yet been defined by the awarding authority. R&D pilot projects will provide more knowledge about this type of wind power production and could open the door to this new market.

In addition to Decree 10,946/2022, two regulations were published in the Official Gazette of the Federal Government (DOU) in October 2022: one dealing with the "assignment of use for consideration for the operation of an offshore power generation facility within the framework of independent power production or self-production of energy", GM/MME Ordinance No. 52/2022; and another that creates the Unified Portal for Managing the Use of Offshore Areas for Power Generation (called PUG-offshore), the Joint MME/MMA Ordinance No. 3/2022. PUG-offshore is considered a "one-stop-shop" for projects, through which all assignments of use applications must be processed. With the Portal, there is therefore a tendency to avoid overlapping projects in the same area, reduce information asymmetry between the private and public sectors, and thus ensure greater transparency in the market. In addition, the Brazilian National Electric Energy Agency (ANEEL), the agency responsible for its administration, can use the PUG-offshore to respond more quickly to applications from developers for assignments of use.

The decree and the two ordinances seek to prevent speculation by avoiding the creation of a market for assignment of use of areas. In addition, this non-statutory regulation may signal the offshore wind power market and provide greater legal certainty as the PL is debated in Congress. The question remains whether the law adopted based on this PL will contradict these ordinances and the decree. The hope is that this is not the case, as wind power market players have welcomed the adoption of these regulatory instruments.

Both GM/MME Normative Ordinance No. 52/2022 and Bill of Law No. 576/2021 make it clear that offshore wind power can be used to produce low-carbon hydrogen. The regulatory aspect is explained in more detail in Section 3.2.

TABLE 3 – Summary table of regulatory instruments dealing with offshore wind power

#	Regulatory instruments	Description of regulatory instruments	Brief summary
1	Law No. 8,617/1993	Maritime areas	Establishes the Brazilian territorial sea, contiguous zone, exclusive economic zone, and continental shelf.
2	Law No. 9,074/1995	Independent Power Producers (IPPs)	In addition to regulating the procedure for granting concessions and permits to produce electricity, it also offered consumers who originally had a load of at least 10 MW and a voltage of at least 69 kV the possibility of contracting their supply of electricity, in whole or in part, with independent power producers (IPPs). This law also authorizes the awarding authority to further lower the limits for classification as a free consumer.
3	Decree No. 2,003/1996	Self-producer and independent power producer	Regulates the production of electricity by self-producers and independent power producers.
4	Law No. 9,427/1996	Discount on TUST/TUSD for renewable energy sources	In addition to establishing the Brazilian National Electric Energy Agency (ANEEL), this law establishes percentage discounts on tariffs for the use of the transmission and distribution systems (TUST/TUSD) for the production and consumption of energy from renewable sources.
5	Law No. 9,636/1998	Federally-owned real estate	In the case of economic exploitation in the national interest, real estate owned by the Federal Government may be assigned to natural or legal persons, which may occur in the case of electricity generation in maritime areas.
6	Law No. 10,438/2002	Creation of PROINFA	Establishes the Program for Incentive of Alternative Power Sources (PROINFA), the first legal act to promote the introduction of renewable energy sources into the Brazilian energy mix. Wind power is included in this program.

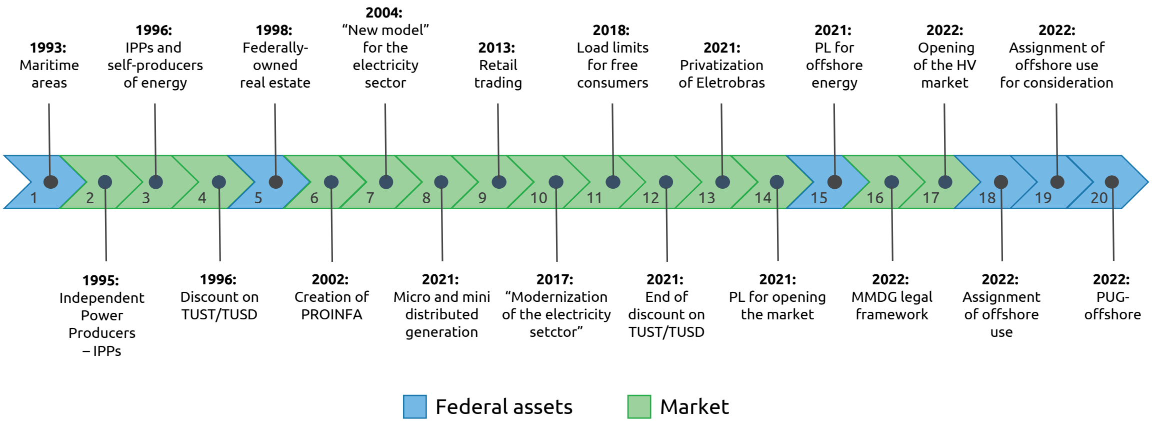
#	Regulatory instruments	Description of regulatory instruments	Brief summary
7	Law No. 10,848/2004 and Decree No. 5,163/2004.	"New model" for the Brazilian electricity sector	Creates the "new model for the electricity sector", establishing the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL). Energy Trading Contracts in the Regulated Environment (CCEAR) from existing projects may suffer cuts to compensate for the decline in their market due to the migration of potentially free consumers to the ACL. Creation of the Electric Energy Trading Chamber (CCEE) and extinction of the Wholesale Electricity Market (MAE) (Law No. 10,433/2002).
8	ANEEL Normative Resolutions No. 482/2012 and No. 687/2015.	Micro and mini distributed generation (MMDG)	Defines the general conditions for micro and mini distributed generation (MMDG) access to electric power distribution systems and establishes the rules of the electricity compensation system (SCEE).
9	ANEEL Normative Resolutions No. 570/2013 and No. 654/2015.	Retail trading	Establishes the requirements and procedures for the retail trading of electricity on the National Interconnected System (SIN). It allows natural or legal persons to participate indirectly in the CCEE (wholesale trade) through the retail trade duly authorized by the CCEE. The figure of the retailer regulated by Normative Resolution (REN) No. 570 in 2013 was modified in 2015 by REN No. 654.
10	MME Public Consultation No. 33/2017	"Modernization of the electricity sector"	The aim was to consult society in order to improve the legal framework of the electricity sector by considering key elements that lead to a model adapted to the external pressures that the Brazilian electricity sector faces and that ensures its long-term sustainability.
11	MME Ordinances No. 514/2018 and No. 465/2019	Load limits for free consumers	MME Ordinance No. 514/2018 received additional wording through MME Ordinance No. 465/2019 to regulate the provisions of Article 15 § 3 of Law No. 9,074/1995, which refers to the reduction of load limits (demand contracted with the distributors) for concluding electricity contracts in the ACL. In the migration, the following are considered free consumers: in January 2021, a minimum load of 1.5 MW; in January 2022, a minimum load of 1 MW; in January 2023, a minimum load of 0.5 MW; and in January 2024, a minimum load to be defined.
12	Law No. 14,120/2021	End of discount on TUST/TUSD for renewable energy sources	End of discount on TUST/TUSD for new projects from renewable sources (Law No. 9,427/1996). This law establishes the transition rules for the end of the discount on TUST/TUSD (concession applications by March 2, 2022, with deadline for commercial operation in 54 months). Existing projects will keep the discount until the end of their current concessions.
13	Law No. 14,182/2021	Privatization of Eletrobras	This law provides for the privatization of Eletrobras. The obligation to auction natural gas-fired thermoelectric power generation with supplied energy is: in 2026, 1 GW in the Amazon region; in 2027, 2 GW in the North and Northeast regions; in 2028, 3 GW in the Central-West region; and in 2029 and 2030, 2 GW in the Southeast region.

#	Regulatory instruments	Description of regulatory instruments	Brief summary
14	Bill of Law No. 414/2021	Business model for the electricity sector and gradual market opening	Provides for improving the regulatory and business model of the electricity sector with a view to expanding the free market and makes other provisions.
15	Bill of Law No. 576/2021	Offshore energy production	This Bill of Law provides for the use of federal assets for energy production from offshore projects.
16	Law No. 14,300/2022	MMDG legal framework	Establishes the regulatory framework for micro and mini distributed mini-generation, the Electricity Compensation System (SCEE), and the Social Renewable Energy Program (PERS). With the new legislation, distributors will be able to purchase the credits not compensated by MMDG users, which is prohibited in the current rule, provided that it is shown to be the alternative with the lowest total cost to the consumer. These rules go into effect in January 2023.
17	GM/MME Normative Ordinance No. 50/2022.	Opening the market to all high voltage consumers (Group A)	Complementary to MME Ordinances No. 514/2018 and No. 465/2019, all high-voltage consumers will be eligible for the Free Market (ACL) as of January 2024.
18	Decree No. 10,946/2022	Assignment of use of physical spaces for offshore projects.	Provides for the assignment of use of physical spaces and the exploitation of natural resources in inland waters under the control of the Federal Government, in the territorial sea, in the exclusive economic zone, and on the continental shelf for the generation of electricity from offshore projects.
19	GM/MME Normative Ordinance No. 52/2022.	Assignment of use for consideration for the operation of an offshore power generation facility	Establishes the supplementary rules and procedures for the assignment of use for consideration for the operation of an offshore power generation facility within the framework of independent power production or self-production of energy. This measure fulfills a requirement of Decree No. 10,946/2002.
20	Joint MME/MMA Ordinance No. 3/2022	Creation of the PUG-Offshore	All services related to the application and monitoring of permits to produce offshore energy will be carried out through the Unified Portal for Managing the Use of Offshore Areas for Power Generation (PUG-offshore). This measure also fulfills a requirement of Decree No. 10,946/2002.

Source: Prepared by the author

Figure 22 below shows a summary of the above regulatory instruments in chronological order. In addition, Figure 3 below shows a timeline of these regulatory instruments, identified by two colors: green, for normative instruments dealing with the assignment of use of federal assets; and blue for the regulation of the wind power market in Brazil.

FIGURE 22 – Timeline of regulatory instruments dealing with offshore wind power.



Source: Prepared by the author

It is worth noting that the regulatory instruments governing access to the transmission and distribution grids for offshore wind projects have not been examined, as the procedures are identical to those of the generation projects already connected to the Brazilian electricity grid. It is very likely that these projects are large and will therefore be connected to the Basic Grid, access to which is the responsibility of the National Electricity System Operator (ONS), whose Grid Procedures[7] must be followed. In cases where connections are made in medium and high voltage distribution systems, access opinions must follow the Electric Power Distribution Procedures in the National Electric System (PRODIST)[8].

3.2 OFFSHORE WIND POWER FOR H_2 PRODUCTION IN BRAZIL: A REGULATORY ANALYSIS

As presented in the previous section, GM/MME Normative Ordinance No. 52/2022 provides that offshore wind power can be used to produce low-carbon hydrogen. Although the creation of a market and the definition of a regulatory framework for offshore wind power are already challenging, specifying the use of this energy source for H_2 production could be even more challenging. The regulatory framework required for such a business model is much more complex as it would fall under the jurisdiction of multiple authorities, such as the Brazilian National Electric Energy Agency (ANEEL), the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP), and the National Water and Sanitation Agency

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[7] **Sub-module 7.1 - Access to transmission facilities:** In short, it establishes the products, responsibilities, deadlines, and phases of the processes associated with requesting access to facilities under the responsibility of the transmitting agency. This includes connection to the Basic Grid, to Other Transmission Facilities (DIT), to transmission facilities of Exclusive Interest to Generation Plants for Shared Connection (ICG), or to facilities for the transmission of electricity intended for international connections and connected to the Basic Grid.

[8] **Module 3 - Access to the distribution system:** It establishes detailed instructions and complementary requirements for the regulation of connections to the electricity distribution system, established in the Rules for the Provision of Public Electricity Distribution Service.

(ANA). Not to mention the Brazilian National Agency for Waterway Transportation (ANTAQ), since the port infrastructure must be used to make this business model profitable. It is therefore of utmost importance to create institutional and legal governance.

In the case of hydrogen, there is no appropriate institutional, legal, and regulatory framework in Brazil (EPE, 2021), a problem that must be overcome for the production of this fuel from offshore wind power sources. It is believed that designing appropriate market regulation could increase not only the competitiveness of offshore wind power, but also the competitiveness of low-carbon hydrogen in the domestic and international markets. Many regions near ports could become hydrogen hubs through offshore wind power generation (CNI, 2021).

The hydrogen produced from the energy of offshore wind farms can be used mainly in three markets (CNI, 2021; EPE, 2021): (i) in the transport sector, where it is used in fuel cells; (ii) in industry, e.g., in the chemical and steel industries; and (iii) in export through the production of green ammonia[9].

In the transport sector, low-carbon hydrogen could be used for heavy road, sea, and air transport, following the example of the European Union (EU) (CNI, 2021). Brazil, due to its continental size, could adopt a specific policy for the use of hydrogen in this sector to reduce dependence on diesel-powered road freight transport.

Specific guidelines could be created to stimulate the chemical and steel industries using low-carbon hydrogen. In addition, low-carbon hydrogen hubs should be promoted in partnership between industries and strategic ports. Policies along these lines could make Brazil a center for hydrogen production and even enable its export.

Although the cost of producing low-carbon hydrogen through electrolysis is about two to three times higher than gray hydrogen (IRENA, 2019), Brazil has the lowest levelized cost of renewable energy production in the world (IRENA, 2021). Therefore, the country would be a strong candidate for producing low-carbon hydrogen for export to other countries at very competitive prices (CNI, 2021). This hydrogen could be transported in the form of green ammonia produced near ports. Therefore, a specific policy to create hydrogen hubs connecting the clean energy production industry (including offshore wind power) with the chemical industry and port segments would be essential to make hydrogen viable for export, further highlighting the country's strength in the commodities market.

In the case of hydrogen hubs, where this energy source is generated from offshore wind power, the wind turbine must be connected to the power grid as the hydrogen production

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[9] **Green ammonia** is a term used to characterize ammonia produced from low-carbon hydrogen (CNI, 2021).

process requires a stable power supply. Therefore, transmission lines could be licensed for hydrogen hubs.

3.3 ENVIRONMENTAL PERMITS FOR OFFSHORE WIND TURBINES

With regard to environmental permits for offshore wind turbines, the experience from the oil and gas sector can be used as a basis for the EIA-RIMA. Many of the impacts are similar, for example in terms of structure and logistics, but others are very sector-specific. In the oil and gas sector, there is great concern about possible leaks. In the offshore wind power sector, for example, the focus is on migration processes of birds and marine animals.

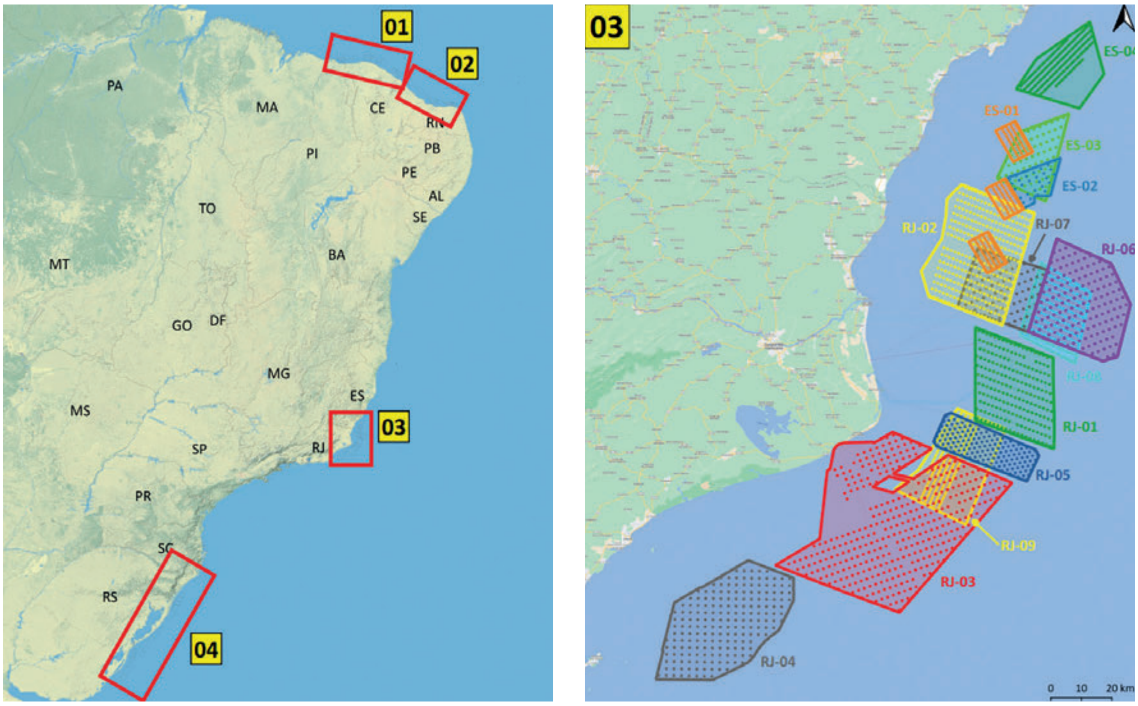
In November 2020, Ibama published a TR that aims to define the guidelines and general technical criteria that will support the preparation of the EIA and the respective RIMA for offshore wind farms (IBAMA, 2020). The scope of this TR includes: wind power generation units; the submarine connection network; the offshore substation; the power transmission network, including its subsea section and its underground land section, as well as the overhead line up to the connection with the National Interconnected System (SIN); the onshore substation; and exclusive work support areas.

Regarding environmental legislation, Law No. 13,123/2015, known as the “Biodiversity Law”, provides for access to components of the genetic heritage, protection and access to associated traditional knowledge, and the fair and equitable sharing of benefits for the conservation and sustainable use of Brazilian biodiversity. In addition, at the non-statutory level, as outlined by EPE (2021), the following regulatory instruments can be mentioned that may impact the approval of offshore projects: (i) Brazilian National Environment Council (Conama) Resolution No. 237/1997, which establishes Ibama’s jurisdiction to issue permits with significant environmental impacts in the territorial sea, on the continental shelf, and in the EEZ; (ii) Conama Resolution No. 279/2001, which provides for a simplified environmental permit; (iii) Decree No. 4,339/2002, which regulates the National Biodiversity Policy; (iv) Conama Resolution No. 462/2014, which specifically addresses onshore wind power; and (v) Joint Ordinance No. 60/2015, which establishes the administrative procedures governing the actions of federal public administrative bodies and entities in environmental permit procedures within the jurisdiction of Ibama.

According to EPE (2021), when installing offshore wind farms, it is important to highlight concerns about the multiple uses of marine space in addition to environmental impacts, namely: artisanal and commercial fishing; navigation; recreation; sand and gravel extraction; tourism; military activities; the Coast Guard; and oil and gas extraction.

As of March 24, 2023, Ibama had 74 offshore wind projects pending environmental permitting procedures, totaling 183 GW of installed capacity (IBAMA, 2023). As shown in Figure 3.2 (a), such projects are found in the Northeast region of Brazil in the states of Ceará (region 01) and Rio Grande do Norte (region 02). In the Southeast region, there are projects in the states of Rio de Janeiro and Espírito Santo (region 03). And in the South region, these projects are mainly concentrated in Rio Grande do Sul (region 04).

FIGURE 23 – Offshore wind projects with pending permitting processes at Ibama



(a) (b)

Source: Ibama, 2022.

The magnification of region 03 results in the map in Figure 23 (b), which shows several overlapping areas. For example, the prism of the RJ-07 project, the permitting process for which was requested on January 21, 2022, overlaps with the RJ-02 project, which began this process on August 20, 2020. This is a regulatory issue that needs to be solved. For example, who is entitled to the permit? Who submitted the application first, or who meets certain requirements, such as lower environmental impact, greater socio-economic viability, higher electricity production etc.?

It should also be emphasized that Ibama has limited and insufficient resources to evaluate all projects simultaneously. However, it may be that only projects for which there is a term for the assignment of use in accordance with Decree No. 10,946/2022 and which are published in the PUG-Offshore (GM/MME Normative Ordinance No. 52/2022) will be evaluated. This matter should be better discussed with interested investors and the society.

The overlapping of prisms is an experience that other countries are already facing and that needs to be resolved in Brazil.

In 2023, the Swedish government issued two overlapping environmental permits for offshore wind farms, Vattenfall Vindkraft and Galatea-Galene Vindpark. Currently, there is no legal framework in Sweden that defines how to deal with overlapping permit applications. However, the government is considering two possible ways to deal with overlapping projects:

- to decide on permit applications in the order in which they are received, i.e. to grant the exclusive right to whoever submitted the application first;
- to decide that overlapping permit applications will be processed together. Such an approach would mean that the most appropriate application from a public interest perspective receives the permit or that the overlapping area is divided between the applicants (Setterwalls, 2023).

Australia already has a legal framework for permit applications with overlapping areas. In these cases, the government may simply order that a permit be awarded to an applicant deemed to be of greater merit. However, if the government is satisfied that the applications are of equal merit and that, without the overlap, a viable permit could be offered for each of the applications, the applications may be determined to form a “group of overlapping applications”. Applicants from this group will be asked to review and resubmit their applications in order to eliminate overlap and reach an agreement between the parties. If the overlap is not resolved and the resubmitted applications are still considered to be of equal merit, the government may determine that the applications constitute a “financial offer group”. Applicants from this group will be invited to submit financial offers, initiating a competitive bidding process among the applicants (Australian Government, 2022).

This problem can be further complicated when applications to explore offshore areas overlap for projects with different purposes. In England, this happened in the dispute between BP and Orsted. The first with a carbon capture and storage (CCS) project and the second with an offshore wind farm. At the heart of the problem is the risk of vessels used to monitor carbon leaks colliding with wind turbines attached to the seabed. After years of dispute, in July 2023 the two companies found a way to advance both the offshore wind project and the CCS project through a commercial agreement (Offshorewind.biz, 2023).


H2 HYDROGEN POWER
CLEAN ENERGY OF THE FUTURE

4 OFFSHORE WIND POWER FOR LOW-CARBON HYDROGEN PRODUCTION

As mentioned in the previous chapter, there are a total of 74 offshore wind projects with permit applications at IBAMA (IBAMA, 2022). In addition to offshore wind power, there is a queue of around 200 GW of onshore wind and solar power projects with permit applications (MEGAWHAT, 2022). The key question is how the electricity sector will absorb all these expected developments and expansions in electricity generation. Low-carbon hydrogen produced from renewable energy sources seems to be one way to make such projects feasible.

The hydrogen molecule (H_2) is a very versatile energy carrier with great potential to decarbonize hard-to-abate sectors, i.e. sectors that have difficulty reducing greenhouse gas emissions in the energy transition. Among these, the petrochemical, iron and steel, and cement sectors stand out. Hydrogen can be used both to generate heat in boilers and energy in gas turbines with its combustion, and as an input to the composition of products that already use gray hydrogen produced by steam methane reforming. Currently, agriculture is one of the largest consumers of hydrogen, as it is essential for the production of nitrogen fertilizer, the raw material of which is ammonia (NH_3).

However, hydrogen is also a form of energy storage. The energy generated and stored can be used in a fuel cell to generate energy. There are already commercial solutions for the use of fuel cells in transport, but their global spread is still tentative. Storing hydrogen would also help mitigate fluctuations in renewable energy sources such as solar and wind power. Hydrogen can be obtained at times of overproduction of these renewable energy sources (peak shaving[10]), thereby avoiding curtailment[11], and it can be used via fuel cells to inject energy into the grid at times when the grid needs it most.

This chapter aims to present business opportunities and project configurations for hydrogen production in Brazil from offshore wind power, taking into account international and national experiences already available or expected in the short and medium term. Finally, project proposals for the consolidation of a hydrogen economy in Brazil with the development of its value chain will be presented.

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[10] Using energy during periods of high generation to store it.

[11] Reducing plant resources due to excess resources relative to transmission line utilization and/or congestion.

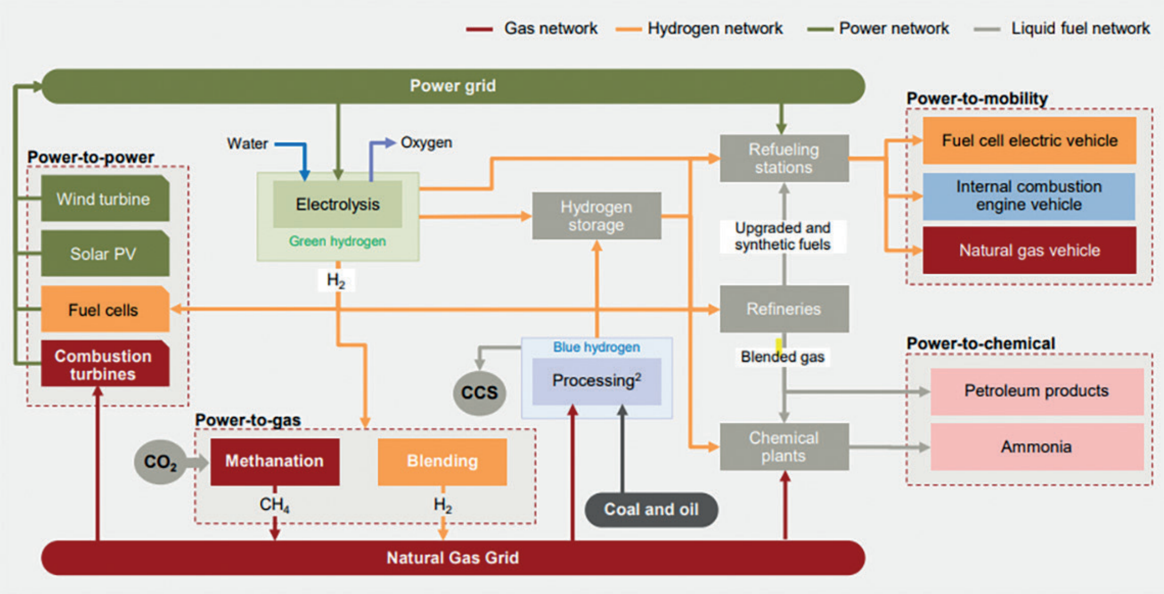
4.1 THE LOW-CARBON HYDROGEN ECONOMY

Although the hydrogen gas molecule was discovered in the 17th century, the term "hydrogen economy" was not introduced until the 20th century. The hydrogen economy corresponds to a proposed future economy based on the use of hydrogen as an energy source. Indeed, there are several applications as an energy source, but the possibility of creating a low-carbon hydrogen economy has become even more real with the need to reduce the use of fossil fuels.

Hydrogen can be produced in various ways. Today it is largely produced using fossil fuels, with around 71% coming from natural gas reforming and 27% from coal gasification[12] (IEA, 2019). However, with regard to the energy transition, low-carbon production must be given priority.

Hydrogen produced through electrolysis using renewable power sources is an avenue with great growth expectations for the near future. Offshore wind power could play an important role in the production of low-carbon hydrogen. Figure 24 shows the versatility of hydrogen produced by electrolysis.

FIGURE 24 – Versatility of low-carbon hydrogen as an energy carrier



Source: Kearney, 2020.

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[12] Energy use for direct production in Mtoe.

Power-to-X is the process of converting electrical energy into another form of energy. Table 4 presents the terms used to briefly explain Power-to-X technologies with the use of hydrogen Therefore, the versatility of hydrogen can be noted.

TABLE 4 – Power-to-X technologies with the use of hydrogen

Technology	Definition	Relevance
Power-to-Power	Conversion of low-carbon hydrogen back into the electricity grid via fuel cells, turbines, or hydrogen generators.	Integration of (intermittent) renewable energies and support in reducing the imbalance between energy production and demand. The energy surplus generated can be converted into low-carbon hydrogen through electrolysis. When demand exceeds production, the stored energy can be converted back into electricity.
Power-to-Gas	Low-carbon hydrogen for the production of gases such as synthetic methane from the combination of H_2 and CO_2 or for direct feeding into the natural gas grid.	Reduction of CO_2 emissions from synthetic methane: use of CO_2 for the reaction[13]. Feeding of low-carbon H_2 into the natural gas grid (currently limited to 20%): reducing the use of fossil natural gas.
Power-to-Mobility	Use of electrical energy to directly power electric cars by charging batteries or use of low-carbon hydrogen for fuel cell-powered electric vehicles. To generate electricity and water, the vehicle requires hydrogen and oxygen.	Exhaust gases eliminate only water vapor, resulting in no CO_2 emissions. Broad synergy of systems and components for hydrogen electric vehicles and all-electric vehicles is important to promote cost reduction in mass production of these components.
Power-to-Fuel (also referred to as Power-to-Chemical).	Low-CO_2 hydrogen used to produce synthetic liquid fuels (e-fuels). Hydrogen, together with CO_2, goes through a series of processes in the production of so-called synthetic oil (Syncrude) and subsequent refining into fuels such as synthetic diesel, synthetic gasoline, or even synthetic aviation kerosene (jet fuel).	Biomass can be used as both a hydrogen and carbon source, replacing CO_2, and can be referred to as Bio-to-Fuel. New biofuels such as hydrotreated vegetable oil (HVO) have a promising market due to available bio-oil hydrogenation technologies. These technologies are currently being tested and demonstrated in practice in Brazil.
Power-to-Ammonia (also referred to as Power-to-Chemical)	Low-carbon hydrogen for the chemical production of ammonia (NH_3).	Replaces natural gas, naphtha, or coal with low-carbon hydrogen, which in turn is synthesized with nitrogen into e-ammonia without emitting CO_2.

Source: GIZ, 2021.

4.1.1 HYDROGEN PROJECTS IN BRAZIL

Brazil has the potential to become the world leader in hydrogen production from renewable sources: it has enormous potential for renewable energy production, an extensive coastline, access to the sea, and a privileged location for accessing markets with the greatest demand for hydrogen imports. On June 23, 2022, the Brazilian National Council for Energy Policy (CNPE) published Resolution No. 6, which created the National Hydrogen Program (PNH2) and established the leadership structure of the initiative. On August 17 of the same year, GM/MME Ordinance No.164 was published, which established the composition of the

Management Committee for the National Hydrogen Program (Coges-PNH2). This will be crucial for the development of the market in Brazil.

Although there is still no fixed roadmap in Brazil, the market has already evolved. A consumer market for low-carbon hydrogen is unlikely to emerge for another 2-3 years, but negotiations must begin, which have been realized through the signing of Memorandums of Understanding (MoU), partnership agreements, and the development of infrastructure to position itself in the market. Several projects have already been announced in the last two years, which are summarized in Table 5.

TABLE 5 – Announced hydrogen production projects in Brazil

No.	Name of the project	D / O*	Application
1	Fuel cell-driven bus project for urban transport in Brazil	O	Feeding into the natural gas grid, mobility, power generation
2	FURNAS/Base Energia Sustentável	O	Power generation
3	CESP/Base Energia Sustentável	O	Feeding into the natural gas grid, power generation
4	Itaipu Binacional - Production of H_2 by alkaline electrolysis	D	E-fuels, industrial feedstock, feeding into the natural gas grid, mobility, power generation, industrial heat
5	CEMIG	D	Electronic fuels, industrial feedstock, mobility
6	Vale Powership	D	Feeding into the natural gas grid, mobility, power generation
7	Biokerosene for aviation	D	Feeding into the natural gas grid, mobility, power generation
8	COPPE UFRJ - Fuel cell hybrid bus	D	Mobility, power generation
9	COPPE UFRJ – PACOS – BNDES	D	Marine
10	Green Hydrogen Hub Pécem - Ceará	D	Industrial feedstock, feeding into the natural gas grid, mobility, power generation
11	Green Hydrogen Hub Ceará - Fortescue	D	Export
12	Green Hydrogen Hub Ceará - Qair	D	Export
13	Green Hydrogen Hub Ceará - Enegix	D	Export
14	Green Hydrogen Pilot Ceará - EDP	D	Industrial feedstock
15	Green Hydrogen Hub Ceará - Engie	D	Steel production, industrial feedstock, feeding into the natural gas grid, mobility, export
16	Green Hydrogen Hub Rio Grande do Norte - Enterprise Energy	D	Export
17	Quair Green Hydrogen Plant in Pernambuco	D	Export
18	Green Hydrogen Hub Ceará - Transhidrogênio	D	Industrial feedstock
19	Nexway and Casa dos Ventos in Piauí	D	Industrial feedstock, mobility, export
20	Raízen and Yara Biometano for H_2 as fertilizer	D	Industrial feedstock
21	Green Hydrogen Hub Ceará - AES Brasil	D	Export
22	Green Hydrogen Hub Ceará - Total EREN	D	Power generation

Key: D = Under development; and O = In operation
Source: Hinicio, 2022.

4.2 POSSIBLE CONFIGURATIONS

When it comes specifically to the use of offshore wind power for the production of low carbon hydrogen, several configurations can be found in the literature. Table 5 summarizes the most current models found with their respective concepts and references.

TABLE 5 – Models found in the literature for hydrogen production through electrolysis using offshore wind power

Reference	Year	Country	Model examined	Concept
Jang *et al.*	2022	Korea	Distributed hydrogen production	An electrolysis system is installed for each wind turbine and hydrogen is produced using the electricity generated directly in the floating structures. The hydrogen produced in each turbine is collected via risers and manifolds and transported to shore via a gas pipeline.
			Centralized hydrogen production	An offshore platform is installed near the wind farm for a large-scale electrolysis system that collects the energy generated for hydrogen production and transports it to shore via a gas pipeline.
			Hydrogen production on shore	An offshore substation is installed near the wind farm and the voltage is increased to the point where currents can reach the shore and be transmitted through high-voltage cables.
Luo *et al.*	2022	China	Hydrogen production on shore	Offshore wind farm generates power and transmits it by cable. Hydrogen is produced on shore.
			Partial hydrogen production offshore.	Offshore wind farm generates energy and is connected to the onshore power grid via submarine cables. Some of the energy can also be used to produce hydrogen, with an offshore plant installed next to the wind farm.
			Direct off-grid hydrogen production	The wind farm and hydrogen production are built offshore and are not connected to the onshore grid.
Hunt & Nascimento	2021	Brazil	Hydrogen Electrolysis Ship	The author proposes a concept for a ship containing a water desalination plant, an electrolyzer, and a hydrogen liquefaction plant. Depending on the availability of renewable energy, demand, and the price of electricity, this can be produced or transported to other locations to optimize its use.
Scolaro & Kittner	2021	Germany	Hybrid offshore wind farm with power-to-hydrogen	The main components are the offshore wind farm, an electrolyser, a hydrogen storage system, and a fuel cell. The electrolyzer uses electricity from the wind farm to produce hydrogen and oxygen. The hydrogen can then be stored or used for industrial or transportation applications. Alternatively, the stored hydrogen can be used in a fuel cell and converted back into electricity there. The system considered does not include the transport of hydrogen to users.
Settino *et al.*	2021	Malta	Offshore wind-to-hydrogen production plant with FLASC storage.	The paper proposes an offshore wind farm coupled to a Floating Hydrogen Production Unit (FHPU), which is then coupled to an innovative pneumatic system for energy storage called FLASC.

Reference	Year	Country	Model examined	Concept
Dinh *et al.*	2021	Ireland	Dedicated offshore wind farm with underground hydrogen storage.	The author proposes a special offshore wind farm coupled to a platform consisting of an electrolyzer, a water purifier, and electrical components. The hydrogen produced is stored underground and regularly transported by tankers.
Groenemans *et al.*	2022	USA	Offshore wind turbines with their own decentralized electrolyzer	The paper examines an offshore wind farm model in which each turbine works in a decentralized manner with its own electrolyzer. The hydrogen produced is then transported via pipelines to be stored by compression on shore to supply tanker trucks.

Source: Prepared by the author.

4.3 INTERNATIONAL EXPERIENCE

Both the production of hydrogen from renewable sources and the production of energy from offshore wind power are technologies that are not yet widespread and are still at a very early stage of development in terms of the technological diffusion curve. There are currently only a few announced projects for hydrogen production from offshore wind power worldwide, which are listed in Table 6.

TABLE 6 – Announced projects for hydrogen production from offshore wind power.

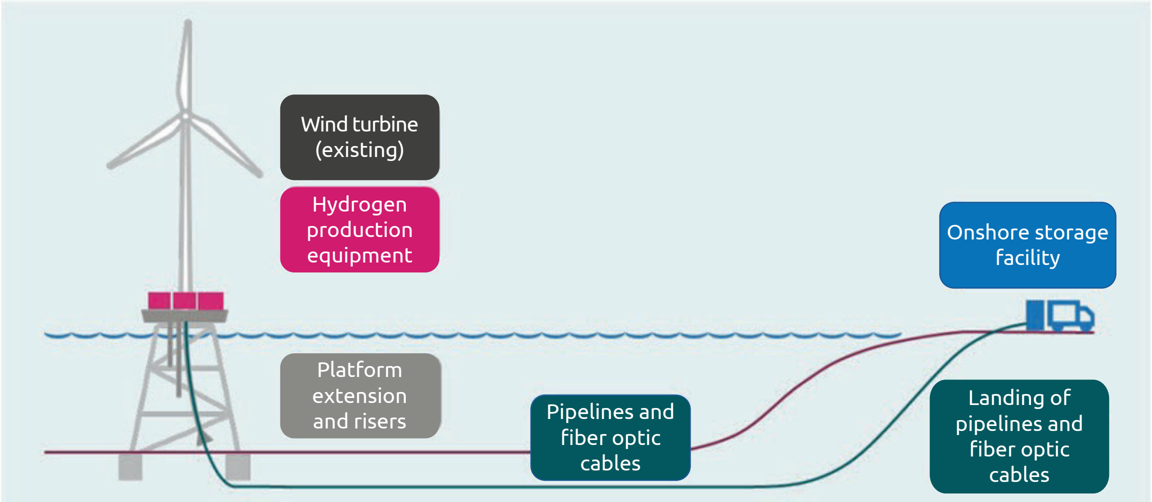
Name of the project	Site	Companies involved	Power	Expected year of completion
Sealhyfe	Saint-Nazaire, France	Lhyfe	1 MW	2022
AquaPrimus (AquaVentus Initiative)	North Sea, Germany	RWE	28 MW	2024
OYSTER	Grimsby, England	ITM Power, Ørsted, Element Energy and Siemens Gamesa	1 MW-scale	2024
H2Mare	Germany	Siemens Gamesa and Siemens Energy	-	2025
Hydrogen Turbine 1	Aberdeen, Scotland	Vattenfall	8.8 MW	2025
The Salamander Project	Peterhead, Scotland	Ørsted, Simply Blue Group and Subsea7	100 MW	2026
HØST PtX Esbjerg	Esbjerg, Denmark	DLG, Danish Crown, Arla, DFDS and Maersk	10 GW	2026
Bantry Bay green energy facility	Ireland	EI-H2 and Zenith Energy	3.2 GW	2028
Dolphyn	United Kingdom	ERM	4 GW	2030
PosHYdon	North Sea, Netherlands	Neptune Energy, Nextstep and TNO	1 MW	-
Deep Purple	Kongsberg, Norway	TechnipFMC, Vattenfall, Repsol, NEL, UMOE, DNV and Slåttland	-	-
OCEANH2	Spain	ACCIONA, Redexis, Ariema, TSI, Wunder Hexicon and BlueNewables	-	-

Source: Prepared by the author.

On September 22, 2022, Lhyfe inaugurated its first platform to produce hydrogen from offshore wind power. Sealhyfe is a 1 MW pilot project capable of producing up to 400 kg of hydrogen per day, located at the port of Saint-Nazaire in France. Despite the inauguration, the system will undergo six months of testing. It will then be deployed to the Atlantic coast for 12 months to collect data and then manufactured at scale for various locations.

The Hydrogen Turbine 1 (HT1) project will install an electrolyser directly on an already operational turbine at Vattenfall's 97 MW offshore wind farm in Aberdeen, Scotland (also known as the European Offshore Wind Deployment Centre). The hydrogen produced offshore will be piped to the shore via the port of Aberdeen. The pilot project will have a capacity of 8.8 MW and is expected to be operational by 2025 (Vattenfall, 2022). Figure 25 shows its main components. It will be necessary to extend the platform of one of the existing wind turbines and add risers (vertical pipes) to the foundation, including to collect seawater. The same platform will also house the electrolyzer for hydrogen production. A gas pipeline about 12 km long is planned to be laid under the seabed to transport hydrogen to the shore. In addition, an onshore facility, including compression and storage, need to be constructed for local use of hydrogen to fuel transportation vehicles.

FIGURE 25 – Schematic diagram of Vattenfall's Hydrogen Turbine 1 project in Scotland



Source: Adapted from RWE, 2022.

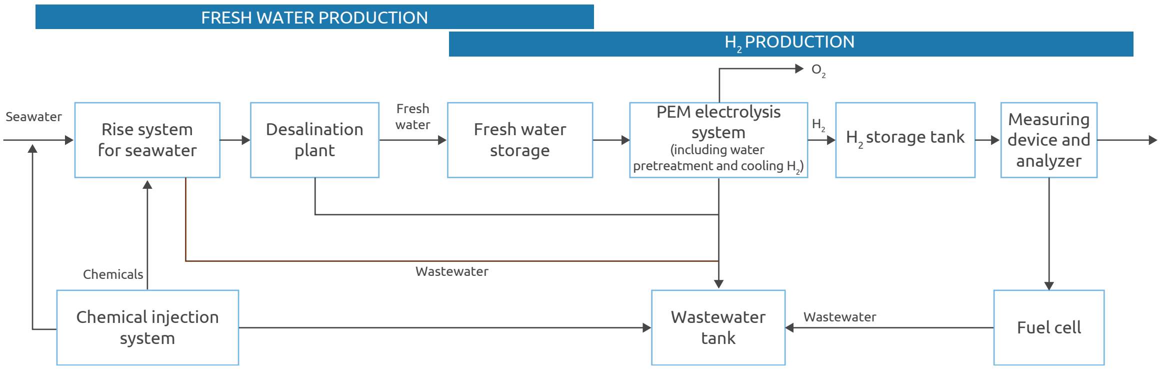
A project called AquaVentus is planned off the German North Sea coast by 2035, the overall goal of which is to install 10 GW of low-carbon hydrogen production capacity from offshore wind power and to build corresponding transport infrastructure. As part of this major project there are a number of sub-projects: the development of offshore wind turbines with integrated hydrogen production (AquaPrimus), a large-scale offshore hydrogen park (AquaSector), a central gas pipeline (AquaDuctus), and a research platform (AquaCampus).

RWE, the company responsible for the project, announced that the AquaPrimus pilot plant with a potential of 28 MW will be implemented in 2024. AquaSector (SEN-1) was put up for investment auction by the German Federal Maritime and Hydrographic Agency (BSH) in 2022, with implementation starting in 2023. With an installed capacity of 300 MW, it will produce large quantities of low-carbon hydrogen on a central electrolysis platform at the wind farm. Up to 22,000 metric tons of hydrogen will be delivered onshore via the AquaDuctus central gathering gas pipeline (RWE, 2022).

Also in the North Sea, but off the coast of the Netherlands, a pilot project called PosHYdon aims to use an existing oil and gas platform to produce hydrogen with offshore wind power. The project involves the installation of a 1 MW electrolyser on the Q13a-A platform operated by Neptune Energy, which is expected to produce a maximum of 400 kg H_2/day. The Luchterduinen wind farm is located approximately 23 Km off the coast of Zandvoort/ Noordwijk and around 25 Km north of platform Q13a-A. As part of the pilot project, there will be no direct connection between the wind turbines and the platform. However, Eneco, which is responsible for the wind farm, will provide simulated wind generation data that will be used for accurate modeling of the electrolyser's electricity consumption (Poshydon, 2022).

Another project due to be operational in the UK by 2030 is Dolphyn (Deepwater Offshore Local Production of HYdrogeN), by ERM. The plan is to install 400 wind turbines with an output of 10 MW, with the structure of hydrogen production shown in Figure 26. The project consists of a floating base on which the wind turbine, the electrolyzer with hydrogen storage system, photovoltaic modules, and the desalination plant will be installed. The energy generated by the wind turbine and photovoltaic modules, as well as the desalinated water, will pass through the electrolyzer to produce hydrogen. Hydrogen can be stored beforehand to be transferred via pipelines for use on shore.

FIGURE 26 – Schematic diagram of the Dolphyn project



Source: ERM, 2021.

4.4 BUSINESS OPPORTUNITIES

This section examines the main business opportunities in both the foreign and domestic markets, highlighting the key points to consider. Since 2010, 95% of the hydrogen used in Brazil has been produced from fossil sources (CGEE, 2010). This represents a major opportunity for Brazilian industry to advance decarbonization, maintain its relevance in view of the energy transition, and play a leading role in the development of the low-carbon hydrogen market.

4.4.1 EXPORT

It is clear that many hydrogen production projects aim to distribute production to the foreign market, especially the European market, which aims to import 10 million tons of hydrogen by 2030.

It is well known that low-carbon hydrogen is even more expensive to produce than fossil fuels from natural gas reforming. However, financing mechanisms such as H2 Global can make this export profitable in the medium term. The mechanism only targets imports into Europe and aims to make up the difference between the price charged by the producer of renewable hydrogen and the price the buyer is willing to pay. The procedures for the first three tenders, which include a subsidy of 900 million euros, have been published, as well as the announcement of a fund with a further 4 billion euros for the next tenders (Hydrogen Central, 2022). The fund is dedicated exclusively to low-carbon hydrogen derivatives such as ammonia, methanol, and e-SAF.

The hubs for hydrogen production in Brazil are formed mainly in the ports, in particular the Port of Pecém, the Port of Açu, and the Port of Suape. However, as shown in Figure 27, Brazil has a large number of ports that could be used for this purpose. This would require investment in the infrastructure of these ports to adapt them to this new demand.

FIGURE 27 – Main Brazilian ports

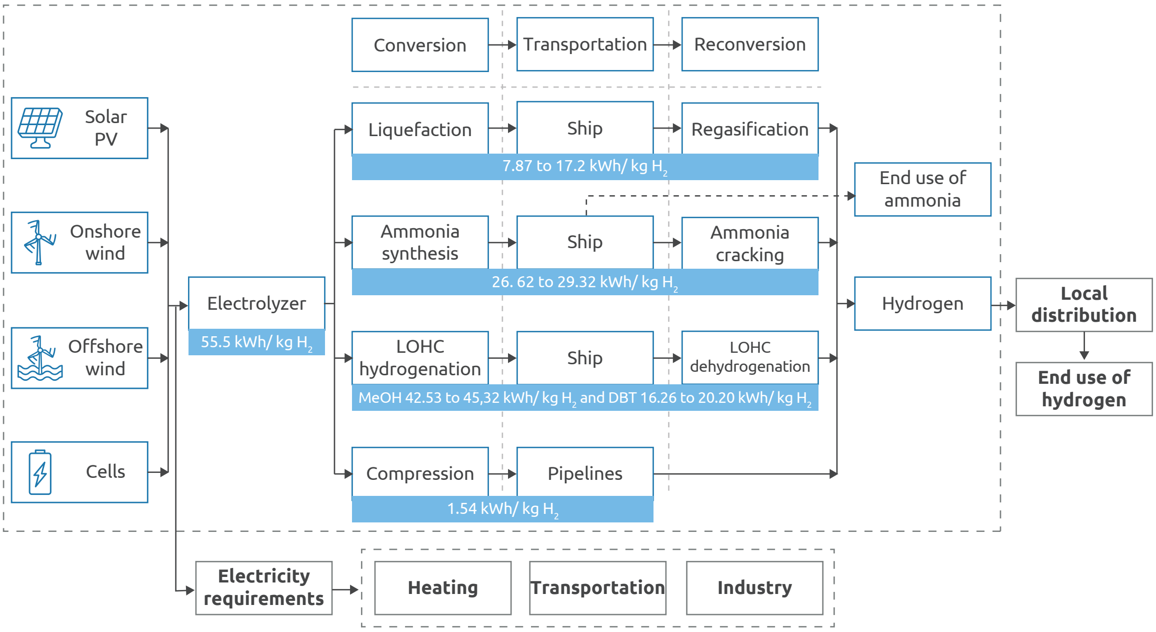
Source: Brazilian Ministry of Transport.

Transporting hydrogen over long distances is still a technological challenge that needs to be overcome. Hydrogen has a high energy density per mass (MJ/kg), but a low energy density per volume (MJ/m^3). While compression can increase the amount of energy per volume, it is not yet economical for long-distance transportation. A large ship full of compressed hydrogen would carry little energy, which would not justify export.

Another route currently being explored is the transportation of liquefied hydrogen. At atmospheric pressure, hydrogen does not reach its liquid state until -253 °C. Under these conditions, the density of hydrogen is 70.83 g/L, about 2.3 times higher than when compressed at 500 bar, which would be close to 30 g/L (Cebolla et al., 2022). However, under these conditions, the energy costs of cooling the hydrogen over long distances are quite high.

There is also the possibility of transporting hydrogen using other chemical components, the so-called carriers, such as ammonia (NH_3), methanol (MeOH), and DBT (dibenzyltoluene). However, they all have to go through a process of conversion, transport, and conversion back into hydrogen, which requires a significant amount of energy. Figure 28 shows the routes for the production and long-distance transport of low-carbon hydrogen with the respective energy requirements.

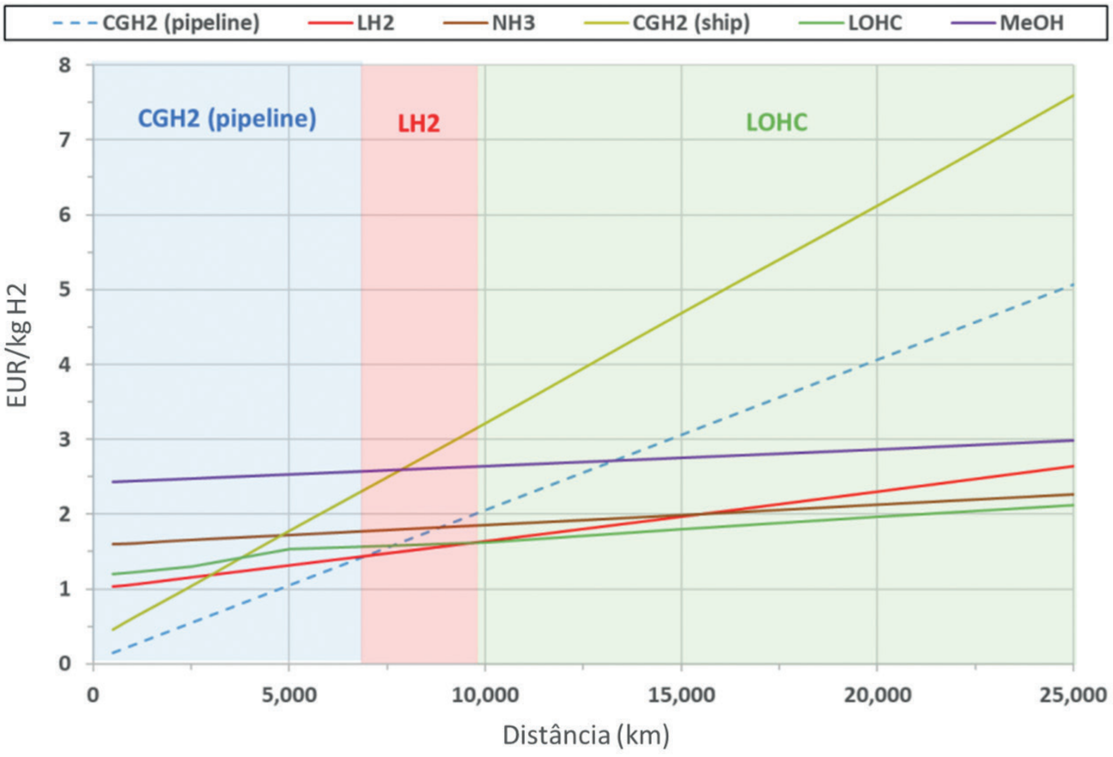
FIGURE 28 – Routes for the production and long-distance transport of low-carbon hydrogen with the respective energy requirements



Source: Adapted from IRENA (2022) with information from Cebolla et al. (2022) and ANL (2022).

Using ammonia directly, without having to convert it into hydrogen, could be a competitive advantage for long-distance transportation. About 80% of ammonia produced worldwide is used to produce fertilizers and another 10% to produce fibers for the textile industry (Patonia & Poudineh, 2022). The possibility of transporting compressed hydrogen via pipelines seems to be an interesting option given the low energy requirements, but the technical and economic feasibility of such routes for long distances needs to be analyzed. Cebolla *et al*. (2022) performed an analysis on the European continent and found that this option would be economically viable for transports up to about 6,500 km. After that, LH2 (liquefied hydrogen) would be most promising up to 10,000 km and then DBT (LOHC – Liquid Organic Hydrogen Carrier). Figure 29 shows the results of the study. This simulation assumes values of expected electricity costs for 2030.

FIGURE 29 – Cost per kilogram of hydrogen according to distance for different technologies



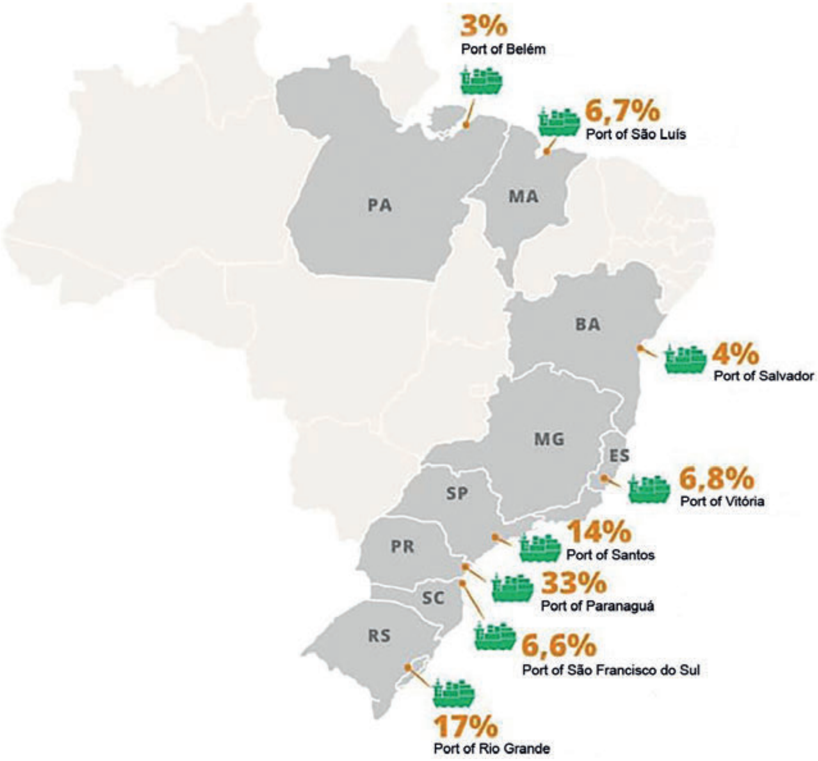
Source: Cebolla *et al.* (2022).

4.4.2 FERTILIZERS

Over the past 10 years, the fertilizer industry has consumed around $100 billion, totaling nearly 290 million net tons (MDIC, 2022). Figure 30 shows the main ports of entry for fertilizers in Brazil. In 2018, the ports of Paranaguá, Rio Grande, and Santos were responsible for 64% of the fertilizer volume imported into Brazil, equivalent to 16 million tons, with imports of 33%, 17%, and 14%, respectively (GlobalFert, 2019).

Most of these fertilizers are nitrogen-based and use ammonia as the basis for the manufacturing process. In 2021, the Ministry of Industry, Foreign Trade and Services recorded that nitrogen fertilizers such as urea, ammonium sulfate, and ammonium nitrate accounted for 31.23% of the mass of all imported fertilizers. This figure can reach 45.6% of fertilizers if nitrogen-based fertilizers are taken into account (MDIC, 2022). Therefore, there is a great opportunity to use hydrogen produced from the energy of offshore wind farms for the production of fertilizers.

FIGURE 30 – Entry of imported fertilizers into Brazilian ports in 2018.



Source: GlobalFert, 2019.

4.4.3 STEEL INDUSTRY

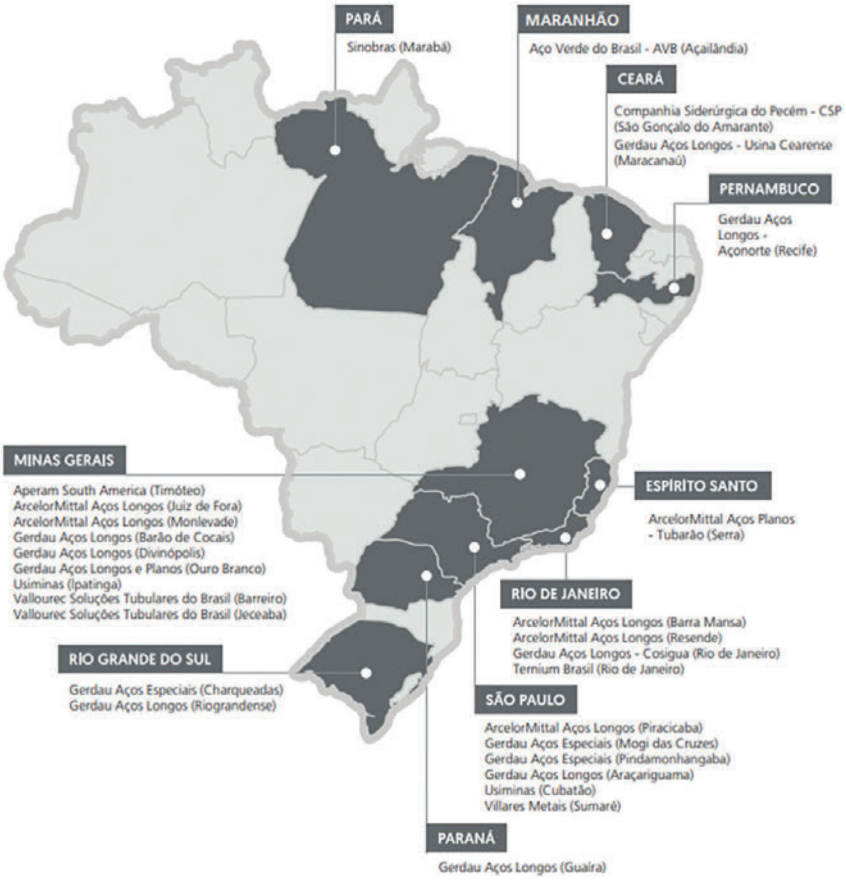
Another way to use low-carbon hydrogen would be to produce steel, the so-called green steel. This represents a major opportunity globally, as the European market, for example, will impose carbon taxes on unsustainable products.

The Carbon Border Adjustment Mechanism (CBAM) is a customs mechanism for taxing products exported to the European Union. It aims to align the carbon price for imports from outside the EU with the price that would be paid if the products were manufactured on European territory and were therefore subject to the Emissions Trading System (ETS). The CBAM will come into force from 2026, but a transition period will begin in 2023 during which EU importers will have to report the total carbon emissions contained in the products they import (WayCarbon, 2022).

The United Nations Conference on Trade and Development (UNCTAD) shows that the most at-risk product is Brazilian steel, which the agency calculates could face a carbon tax of $3.3 per ton. Considering that Brazil exported more than 600,000 tons to the European Union in 2021, the blow would not be insignificant (UDOP, 2022).

Figure 31 shows the companies in the steel industry in Brazil. A large number of them are also strategically located near the main Brazilian ports.

FIGURE 31 – Companies in the steel industry in Brazil



Source: Instituto Aço Brasil, 2022.

4.4.4 REFINING

Like the steel industry, refineries are also facing a major challenge with the tightening of environmental regulations. They is currently evaluating the options available to reduce the carbon footprint of their operations in order to continue to play an important role in the world of low or zero carbon energy.

Around 74% of the hydrogen used in the Brazilian industry goes to refineries. These refineries produce hydrogen by reforming natural gas and produce it themselves. According to GIZ (2021), Brazilian refineries produced around 4,400,000 Nm^3 of hydrogen in 2018, which corresponds to around 320,000 tonnes. Replacing this gray hydrogen with low-carbon hydrogen would require a large installed capacity of renewable energy sources.

Hydrogen is used in refineries primarily for hydrocracking of heavy crude oil to achieve higher yields of more noble (light and medium heavy) derivatives, and for hydrotreating for fuel specification (particularly to remove sulfur, oxygen, nitrogen, and metals). Through the use of bifunctional catalysts, hydrocracking is one of the most important processes in modern petroleum refining (CNI, 2022). In addition, it is valued for its pronounced versatility, with numerous process variants that help meet specific requirements in refineries or petrochemical plants.

The use of hydrogen in refineries has increased significantly in recent decades at the expense of fuel oil production due to the need to increase the production of more noble derivatives. This change in the profile of fuel demand and the decline in fuel oil consumption in the industry required refineries to increase their conversion capacity to produce more gasoline, diesel oil, and QAV (aviation kerosene). In addition, evolving environmental regulations have led to more stringent specifications for local pollutants such as SOx, NOx, and heavy metals. Changes in fuel specifications have resulted in higher hydrogen consumption for hydrotreating petroleum derivatives (CNI, 2022).

4.4.5 METHANOL

Producing methanol using low-carbon hydrogen is considered a very effective alternative to decarbonization. Methanol can be used as a practical energy storage, fuel, and raw material for the synthesis of hydrocarbons and their products. Hydrogen can be stored by converting it into methanol using carbon dioxide from industrial wastewater or the atmosphere. The required hydrogen can also be obtained through the electrolysis of water from renewable sources. Flue gases from fossil fuel power plants can be a rich source of carbon dioxide. Rather than just sequestering it, this process would convert the carbon dioxide into useful fuel and provide a source of hydrocarbons for other petrochemical products.

A major advantage of converting low-carbon hydrogen into methanol is that the process does not require the development of new, extremely expensive, and unproven infrastructure, nor does it face safety barriers like those associated with the direct use of hydrogen. On the other hand, green methanol is significantly more expensive than the traditional option because its production and use requires a combination of technologies (as well as logistics) that have not yet been able to achieve economies of scale and attractive returns (MME/EPE, 2019) .

Methanol is produced in the chemical and petrochemical industry mainly by hydrogenation of carbon monoxide. The main feedstock for its production is natural gas, from which a mixture of carbon and hydrogen is extracted, mainly by steam reforming of natural gas. Carbon monoxide and hydrogen are recombined by reaction over a catalyst to form methanol and water. Methanol is then mainly converted into formaldehyde, which is widely used in various areas, but especially in polymer production. It is also the precursor of simpler methylamines (some pharmaceutical products, pesticides, and solvents), methyl halides (which are used as precursors and as extractants in various chemical processes, e.g., in the production of silicones, local anesthetics etc.), and methyl ethers (DME, which is used for the production of the methylating agent).

The EPE (MME/EPE, 2019) points out that there has been no domestic production of methanol since 2016 and the product is entirely imported from countries such as Trinidad and Tobago, Chile, and Venezuela. Due to difficulties related to the availability and price of natural gas, international competition, and the level of investment required, no new projects are planned in this segment. As in other sectors, methanol plants are looking for the best ways to decarbonize their production, and low-carbon hydrogen is the only alternative that competes with gray hydrogen.

4.4.6 TRANSPORTATION

In the transportation sector, there is great expectation that hydrogen will play a fundamental role. A study conducted by the Climate Watch in 2020 found that 16.2% of emissions come from this sector, including 11.9% from road transportation, 1.9% from aviation, 1.7% from ships, and 0.4% from rail vehicles (Our World.) Data, 2020).

In road transport, hybrid and battery vehicles have gained ground in the passenger car class. For this mode, there are already established hydrogen solutions on the market such as Toyota Mirai, Hyundai Nexo, and Honda Clarity. There are also major efforts to develop low-emission freight and long-distance transport vehicles. In this context, hydrogen has great potential compared to conventional battery solutions. Although large quantities are required, hydrogen stores much more energy per kilo than traditional ion lithium batteries. In addition, charging times are shorter compared to battery-powered vehicles.

In rail transport, the company Alstom put the first 100% hydrogen-powered train into operation in Germany in 2022 (Alstom, 2022).

Companies such as Embraer, Airbus, and Boeing are investing in hydrogen turbine solutions for the aviation sector. There are important targets for decarbonizing the sector with the introduction of Sustainable Aviation Fuels (SAF). By 2035, hydrogen fuel cells could be used for the electrification of medium-haul flights and hydrogen combustion aircraft for long-haul flights (World Economic Forum, 2022).

4.4.7 ELECTRICITY GENERATION AND STORAGE

With the transition to the hydrogen economy, the electricity sector benefits not only from the renewable energy generation infrastructure to be built, but also from the possibility of using hydrogen to store energy. In September 2022, the cancellation of the auction to contract reserve capacity, scheduled for December, caused surprise in the market (Agência Infra, 2022). However, from a positive perspective, the MME and EPE will have enough time to allow the inclusion of storage solutions, which will open up competitive opportunities for renewable sources in the auction. This includes not only traditional battery storage, but also hydrogen itself with fuel cells. This stored energy can be used both in times of highest demand and for ancillary services for the SIN.

Hydrogen can generate electricity via a fuel cell or even through direct combustion in a turbine. Major gas turbine manufacturers such as GE, Siemens, and Mitsubishi have brought technologies to market that operate on up to 100% hydrogen (Azevedo et al., 2022b). Taamallah *et al.* (2015) point out that all gas turbines can absorb significant amounts of hydrogen mixed with natural gas through small changes to the combustion system. A publication by the gas turbine manufacturer Mitsubishi Power reports that existing turbines can now absorb up to 20% hydrogen (MITSUBISHI POWER, 2020). According to GE, the new generation of the 7HA turbine, the same turbine installed at the Porto de Sergipe Thermal Power Plant, is capable of absorbing up to 50% hydrogen by volume (Goldmeer, 2020).

4.4.8 TRANSITION OF THE OIL INDUSTRY

In addition to its geopolitical advantage, Brazil is also relying on the knowledge and infrastructure it has acquired over the past two decades, particularly in the oil and gas industry. The similarities between the two industries can be leveraged. There is also great interest from the oil and gas industry, which, in order to participate in the energy transition, is rethinking its business models. Hunt *et al*. (2022) conducted an analysis of how the oil and gas industry in Brazil can leverage the currently existing deepwater offshore exploration infrastructure for a sustainable hydrogen future. Table 7 summarizes the main points of the study.

TABLE 7 – Leveraging the hydrogen economy and the oil and gas industry

O&G activity	Related activity	Description
Exploration and production (upstream)	Natural hydrogen	It is estimated that a natural hydrogen flow of 2.54 X 1011 m^3 H_2/year emerges from the Earth's crust. Some countries are already using natural hydrogen to generate electricity. This alternative has the potential to become competitive in H_2 production.
Marine activities (upstream)	Offshore wind power	Project management and engineering experience with offshore activities can be an advantage for oil and gas companies. Offshore wind power offers synergies to improve the implementation of carbon capture and storage in offshore O&G activities.
	Subsea transmission	Subsea pipeline technology has already been consolidated in the O&G industry. This experience can be applied to electric transmission and support the development of a global power grid.
Gas industry (midstream)	Hydrogen liquefaction	Opportunity for the liquefied natural gas (LNG) industry to gradually transition to hydrogen liquefaction.
	Hydrogen storage in salt caverns	Just as natural gas is stored in salt caverns, hydrogen can be stored as well. Underground natural gas storage has been successfully implemented around the world. This can be replicated with hydrogen.
	Hydrogen gas pipeline	There are ways to adapt hydrogen transportation by upgrading the existing gas pipeline infrastructure and blending hydrogen into the natural gas system. In this way, building hydrogen pipelines for transport and distribution could become economically viable in the long term.
	Hydrogen distribution	The strategy could involve transporting hydrogen in pressurized tanks and trucks using cryogenic liquid hydrogen.
Gas industry (downstream)	Hydrogen for heating	Natural gas can be replaced with hydrogen with some upgrades to existing boilers. With the electrification of the heating sector, hydrogen tends to become an alternative to electric heating, helping the electricity sector overcome the intermittence and seasonal fluctuations of renewable energy sources.
	Hydrogen gas turbines	Replacing natural gas with hydrogen in the operation of gas turbines could be a solution to ease the transition from natural gas to a hydrogen-based economy. This plays an essential role in balancing fluctuations in power generation in a future energy system with a high share of variable renewable energy sources.
Refineries (downstream)	Biofuel	It is possible to blend some types of biofuels with petroleum derivatives. Converting an oil refinery to a biofuel refinery may be preferable to closing the facility.

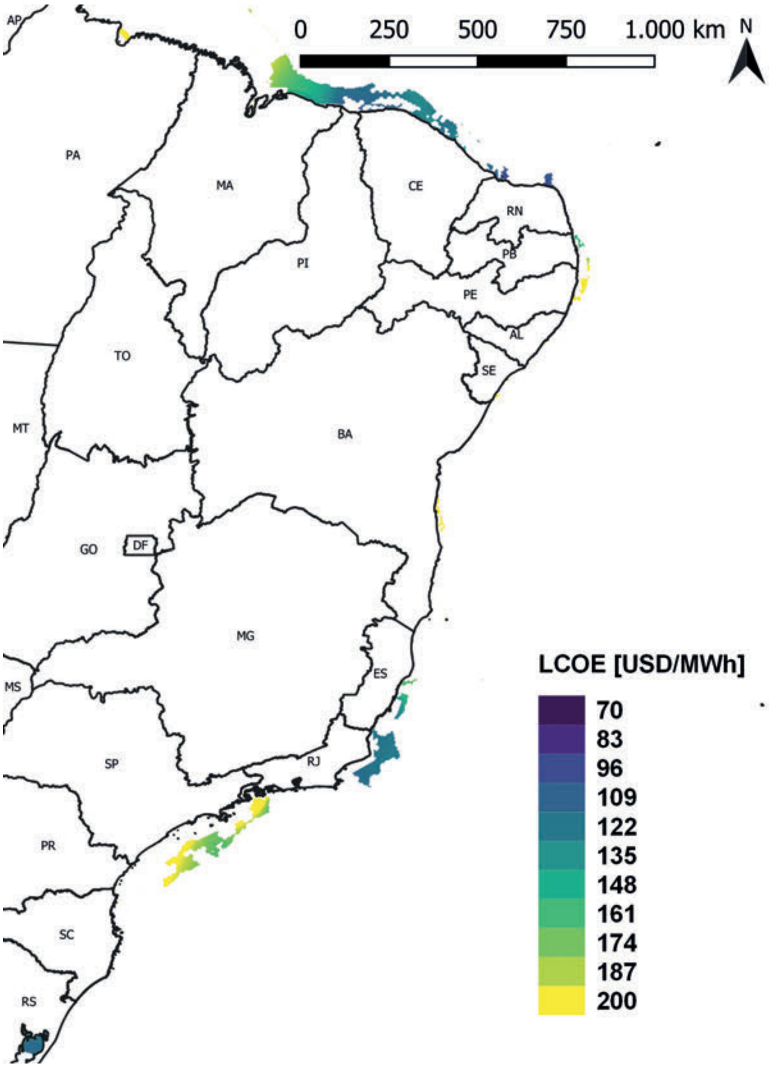
Source: Hunt *et al.* (2022).

4.5 ECONOMICAL ASPECTS

The economic aspects of hydrogen production from offshore wind power are important so that there is a basis for comparison to other production routes. For low-carbon hydrogen routes, energy costs are the parameter that most influences the price. In order to have a benchmark for other available renewable energy sources, the Levelized Cost of Electricity

(LCOE) is a suitable indicator for comparison. Figure 32 shows the LCOE for offshore wind turbines in the technical potential area shown. The calculation used a discount rate of 8% p.a., CAPEX of $ 3,137/kW and OPEX of $ 80/kW/year (EPE, 2022).

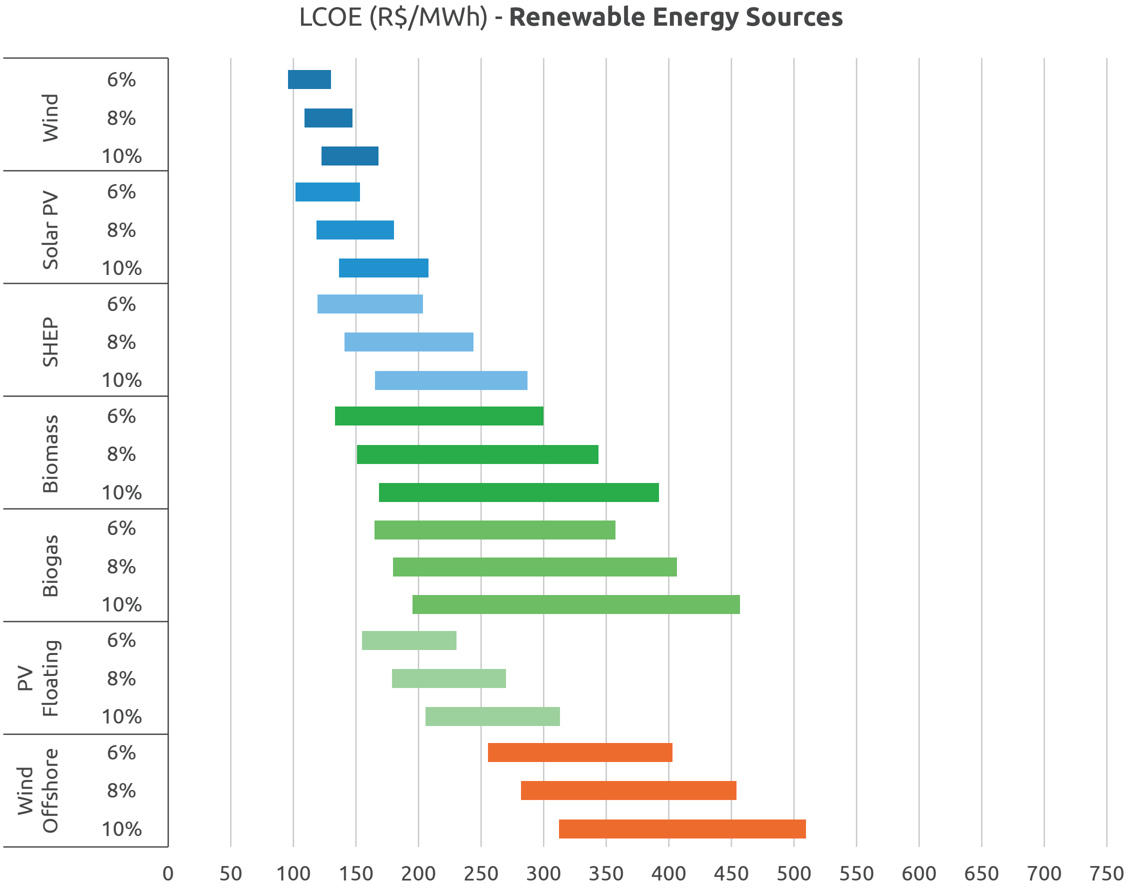
FIGURE 32 – Map of the economic potential of offshore wind power in Brazil using the LCOE



Source: Azevedo et al. (2022a)

When comparing this result with data from the literature, Figure 33 shows that the data found for offshore wind power agree. However, when comparing the data from other generation technologies, it becomes apparent that offshore wind power is not yet competitive with other technologies and requires technological improvements.

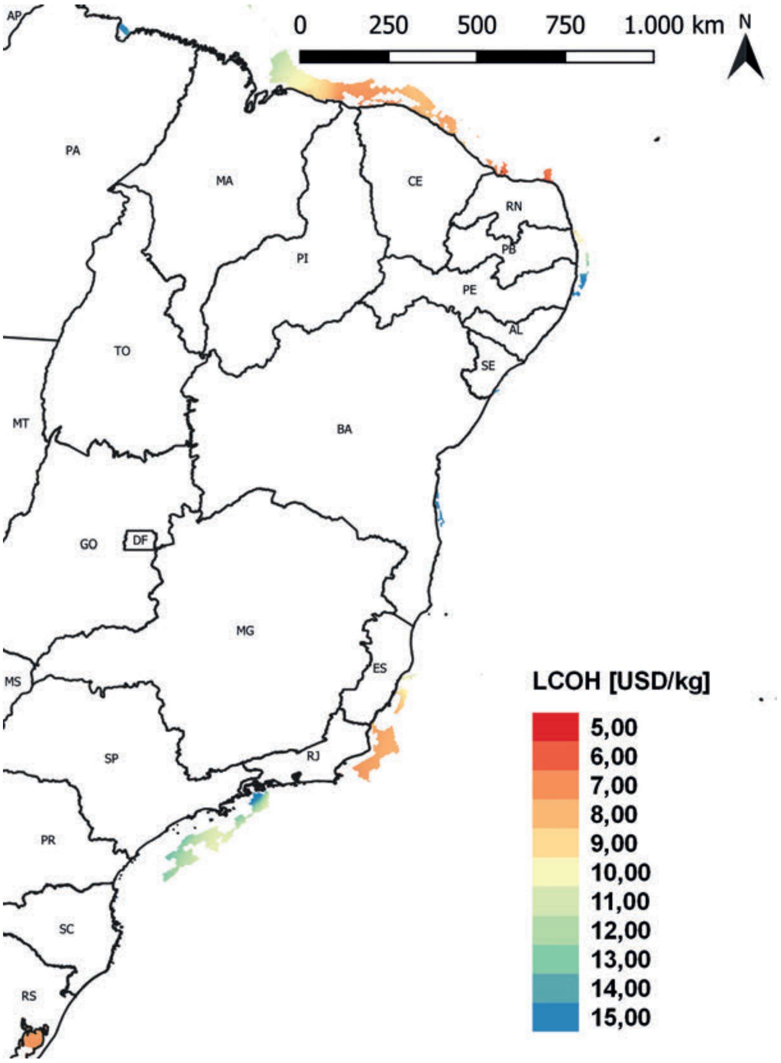
FIGURE 33 – LCOE for renewable energy sources in Brazil



Source: EPE (2021).

Based on these outlined models, it is possible to start economic modeling experiments to calculate the Levelized Cost of Hydrogen (LCOH). LCOH is the production cost of a kilogram of hydrogen, including electricity generation costs, electrolyzer CAPEX, and OPEX. However, it does not include setup costs such as transmission lines, pipelines, and storage, as well as distribution and transportation costs. Therefore, the LCOH for offshore hydrogen production from offshore wind power was plotted into the direct off-grid model shown in Figure 34.

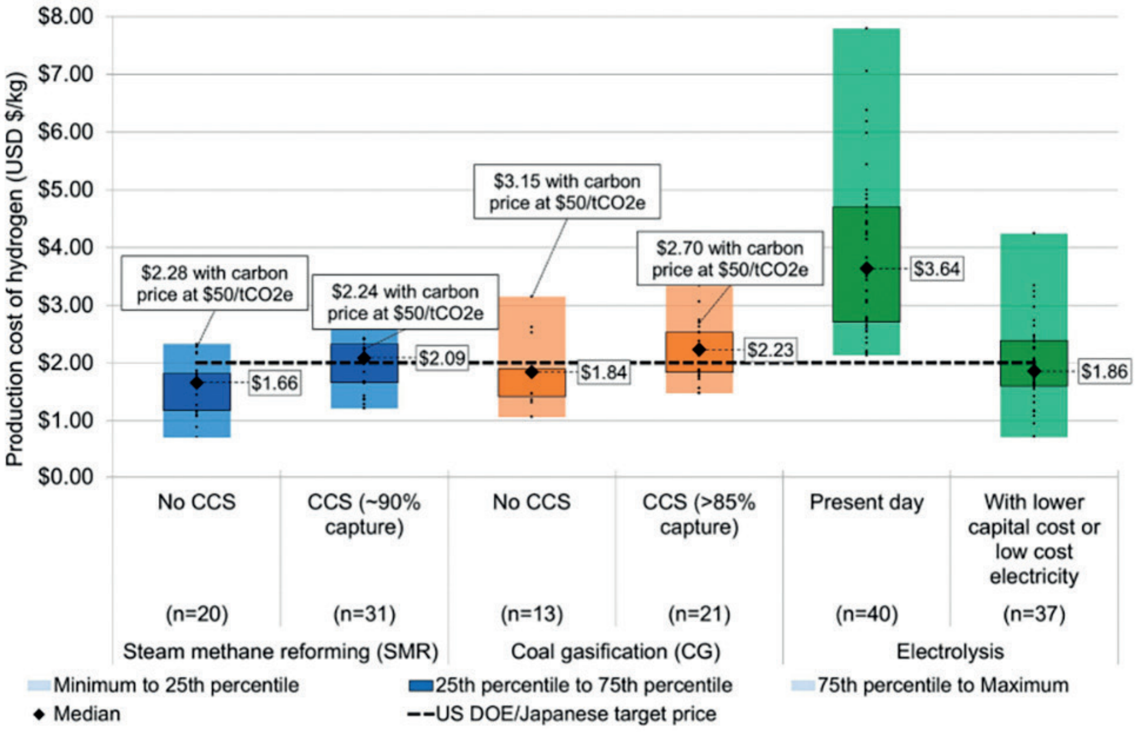
FIGURE 34 – Map of the economic potential of hydrogen production from offshore wind power in Brazil using the LCOH



Source: Azevedo et al. (2022a)

In fact, these are two evolving markets and more concrete data is still needed to make more accurate forecasts about the costs of hydrogen production. For comparison purposes, Figure 35 shows the production cost statistics for the main technologies using data from the literature. For electrolysis, for example, 40 data points were collected from the literature from 2018 to 2020. It can be seen that the LCOH determined for hydrogen production from offshore wind power in Brazil is well above average. In fact, the costs of hydrogen production are very dependent on the LCOE. Therefore, only other current technologies such as onshore wind and solar PV currently offer a viable business opportunity.

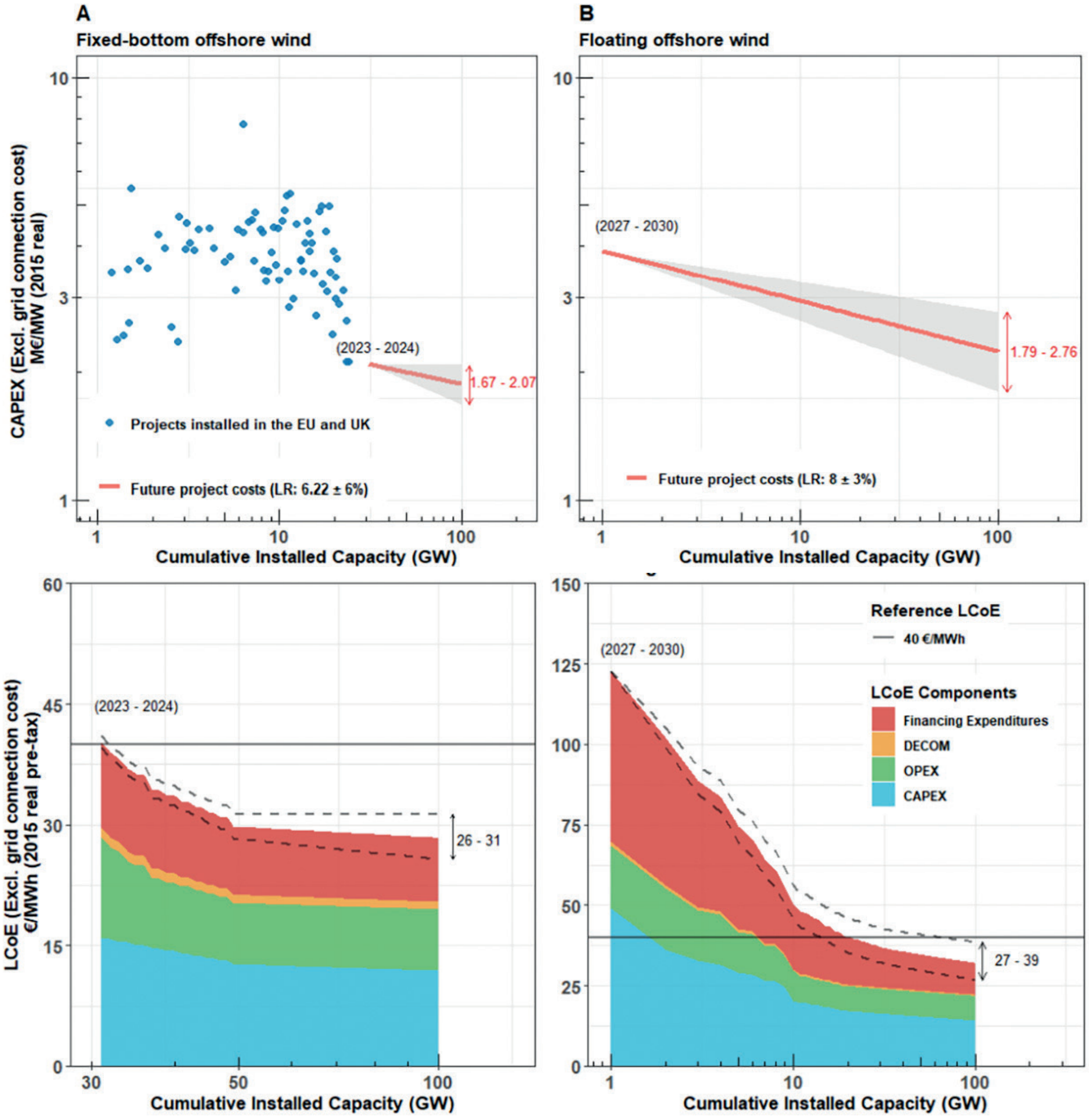
FIGURE 35 – LCOH box plot found in several literature references



Source: Longden *et al.* (2021).

For the production of hydrogen from the electrolysis using offshore wind power to become sustainable, the learning curve must evolve significantly over the next 10 years, just as it has with onshore wind and solar photovoltaic power over the last 20 years. In the work of Santhakumar et al. (2022), a study was conducted that applied bottom-up cost modeling and identified the long-term cost reduction potential of fixed and floating offshore wind turbines. Figure 36 shows the potential CAPEX developments, with reductions to €1.87 million/MW for fixed-bottom offshore wind turbines and €2.23 million/MW for floating offshore wind turbines with an installed capacity of 100 GW, which is already well below the value used in Figure 32. The LCOE would then fall to €28.4/MWh for fixed-bottom offshore wind turbines (30%) and €32.0/MWh (74%) for floating offshore wind turbines.

FIGURE 36 – CAPEX and LCOE forecasts for offshore wind. a) Fixed-bottom offshore wind turbines for an installed capacity of 31 to 100 GW. b) Floating offshore wind turbines for an installed capacity of 1 to 100 GW



Source: Santhakumar *et al.* (2022).

In fact, this cost reduction in the energy source will reduce the cost of producing hydrogen. However, Brazil must pursue a well-coordinated development and investment strategy. The USA, for example, has launched in 2022 an update to its hydrogen roadmap in the country. Called 1:1:1, the strategy promises to reduce the cost of hydrogen production to \$1/kg within a decade. To achieve this, \$9.5 billion will be invested this year alone, of which \$1 billion is for improvements to electrolysis equipment, \$0.5 billion for improvements to equipment production and recycling methods, and \$8 billion for the so-called hydrogen hubs (DOE, 2022). These are hydrogen market development hubs that will initiate and demonstrate the operation of the clean hydrogen market with producers, potential consumers, and connecting infrastructure.

These hubs will promote the production, processing, delivery, storage, and end use of clean hydrogen, enabling sustainable and equitable regional benefits and market acceptance. In addition, the Inflation Reduction Act, a federal law introduced in the United States in 2022, created an incentive program for clean hydrogen production that can pay up to a $3 subsidy per kilo of clean hydrogen produced. This financing mechanism will be crucial for the short- and medium-term development of the market.

4.6 PROJECT PROPOSALS

Based on the data presented in this study, this section highlights the areas with the greatest potential for hydrogen production projects with offshore wind power in Brazil. The first step is to look at the potential for offshore wind power and the demand for hydrogen for both foreign and domestic markets. Figure 10, which shows the map of the technical potential for offshore wind power production, analyzes the regions with the greatest potential and the projects proposed for each region, depending on the local vocations for the hydrogen economy.

4.6.1 NORTHEAST REGION

The Northeast region is the area with the greatest potential for offshore wind power generation in Brazil, especially in the states of Rio Grande do Norte, Ceará, Piauí, and part of Maranhão. It appears that there is still great potential even when taking into account the technical, economic, and environmental constraints mentioned in Table 1.

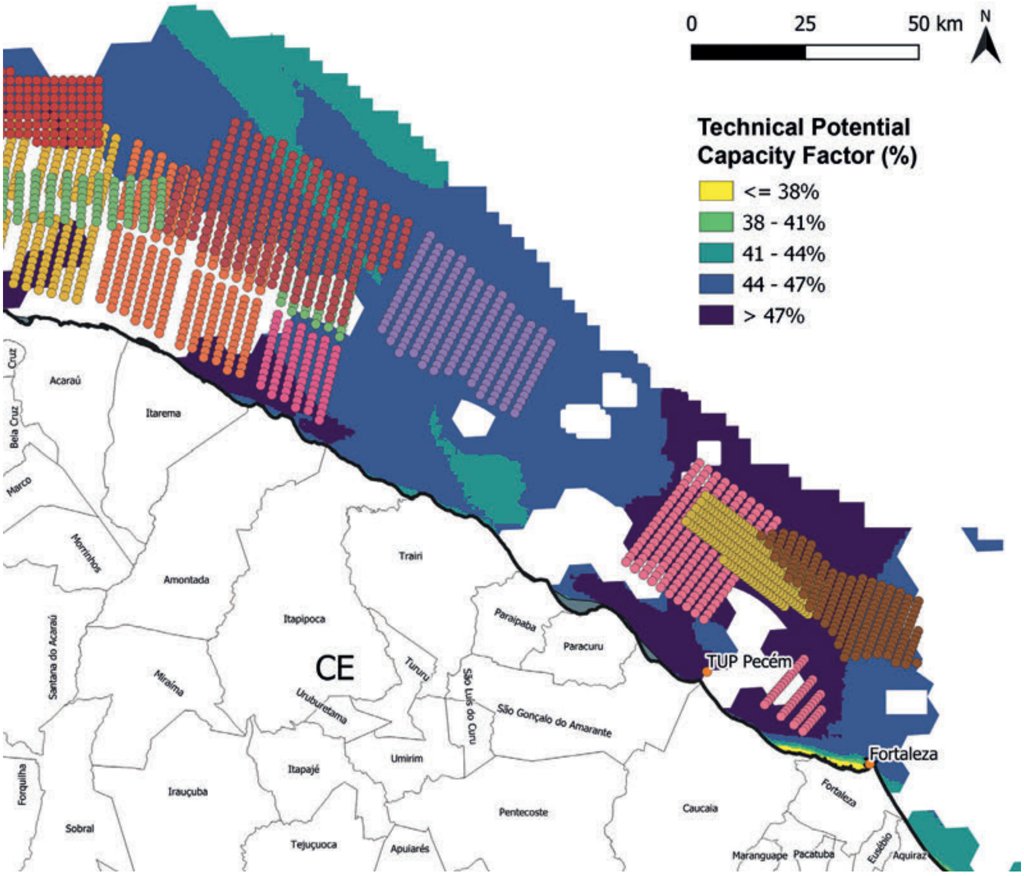
This region also has great potential for photovoltaic and onshore wind power generation, with areas yet to be explored. It is necessary for the investor to justify the investment in offshore technology and the decision is usually made on purely economic criteria, which means that there must be a return on investment in these projects. For example, the higher average annual capacity factor, better wind stability, and the possibility of reducing infrastructure and logistics costs can be points that lead to a higher profitability of the project in the long run.

The Northeast region's main vocation for the production of low-carbon hydrogen and its derivatives would be for export to the European continent. The distance between the port of Pecém (São Gonçalo do Amarante-CE) and the port of Rotterdam in the Netherlands is about 7,500 km or nine days by sea.

Financing mechanisms such as H2Global, which has tendered a long-term contract to import green ammonia, e-methanol, and e-SAF to Europe, could make such projects profitable.

There are around 35 offshore wind projects with permit applications off the coast of the Northeast region, 21 of which are concentrated on the coast of the state of Ceará. Figure 37 shows that there is a large potential area for offshore wind turbines near the Port of Pecém. Nevertheless, only two of the three projects with permit applications are expected to receive the assignment of area, as there are overlaps in three of them. However, there is still a large area without a permit application, but with great potential for offshore wind power generation.

FIGURE 37 – Map of capacity factor in the area of technical potential and offshore wind projects with a permit application at Ibama in the state of Ceará

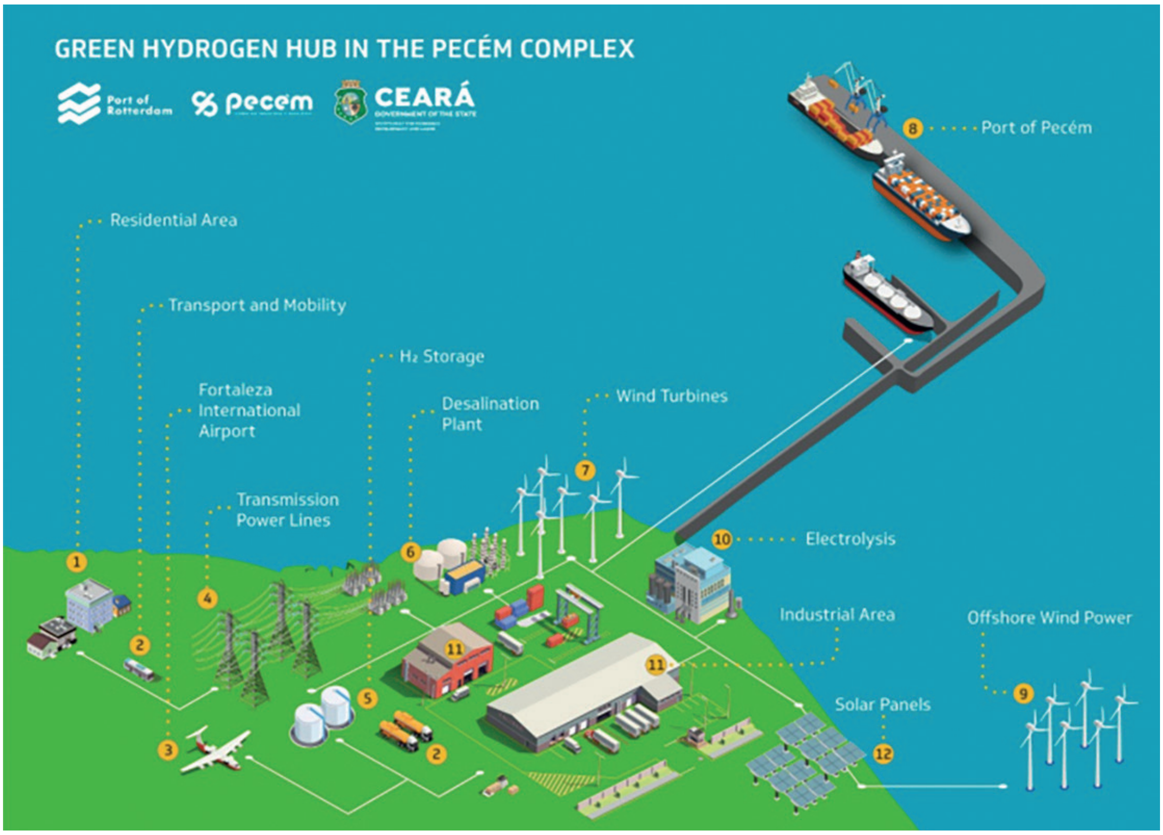


Source: Prepared by the author.

The Port of Pecém is an offshore-style port terminal on the northeast coast of Brazil, built in a geographical area called Ponta do Pecém (Pecem Cape) in the Pecem district of the municipality of São Gonçalo do Amarante. It is located on the west coast of the state of Ceará, within the Fortaleza metropolitan area, about 60 kilometers by road from the capital city of the state.

Due to its local industrial development, it is called the Pecém Industrial and Port Complex (CIPP) and has the Ceará Export Processing Zone (ZPE) with administrative, tax, and exchange rate incentives for exporting companies. Figure 38 shows the low-carbon hydrogen hub project under construction. According to the CIPP (2022), in addition to the favorable location, tax incentives and the great potential for renewable energy production are important competitive advantages for the development of an H_2 hub in Ceará.

FIGURE 38 – Low-carbon hydrogen hub in the Pecém Industrial and Port Complex



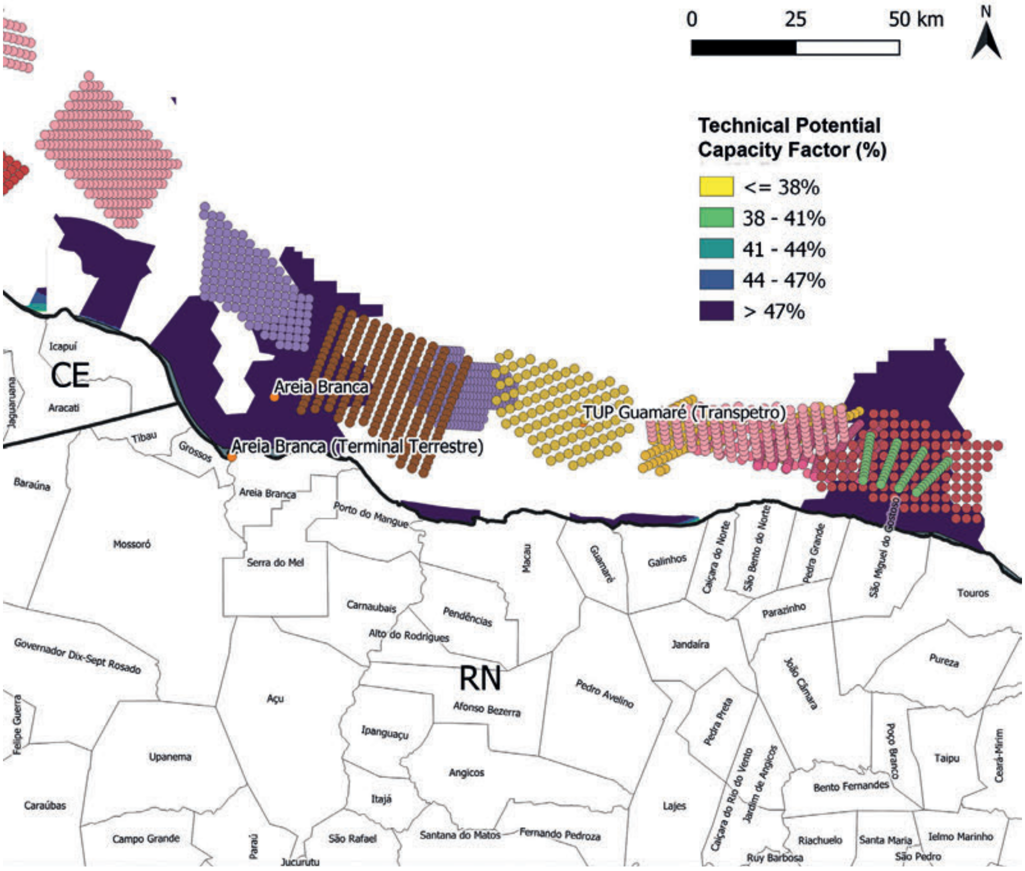
Source: CIPP, 2022.

There is also great potential for offshore wind power production off the coast of the state of Rio Grande do Norte. The state is already the largest producer of onshore wind power with 6.7 GW. Nine projects totaling 17.8 GW have applied for offshore wind power permits in the state, but as Figure 39 shows, many of them are likely to face approval barriers because they are located in conservation priority areas (Figure 9) or because they overlap with other projects. However, there is an area with potential for which there is no permit application at Ibama yet (Figure 39).

The state has two small ports, which are not sufficient to meet the needs of the sector. To the east is the Guamaré water transportation terminal, which serves primarily as a storage and transport point for petroleum production from the onshore fields and is operated by the subsidiary Transpetro, whether by cabotage or long-distance transport. Further west is the Areia Branca (Tersab) Salt Terminal, better known as Areia Branca Port-Island. In November 2022, Companhia Docas do Rio Grande do Norte (CODERN) leased this terminal to the Intersal Tenant Consortium, made up of the companies Intermarítima and Salinor.

The state is looking for investments of around R$ 6 billion to build a port-industry. For this purpose, a memorandum of understanding was signed in October 2022 with Nordex Energy Brasil, Comércio e Indústria de Equipamentos to carry out technical studies. The purpose of installing the port-industry in the state is to support onshore and offshore wind power generation projects and low-carbon hydrogen production (Energia Hoje, 2022).

FIGURE 39 – Map of capacity factor in the area of technical potential and offshore wind projects with a permit application at Ibama in the state of Rio Grande do Norte

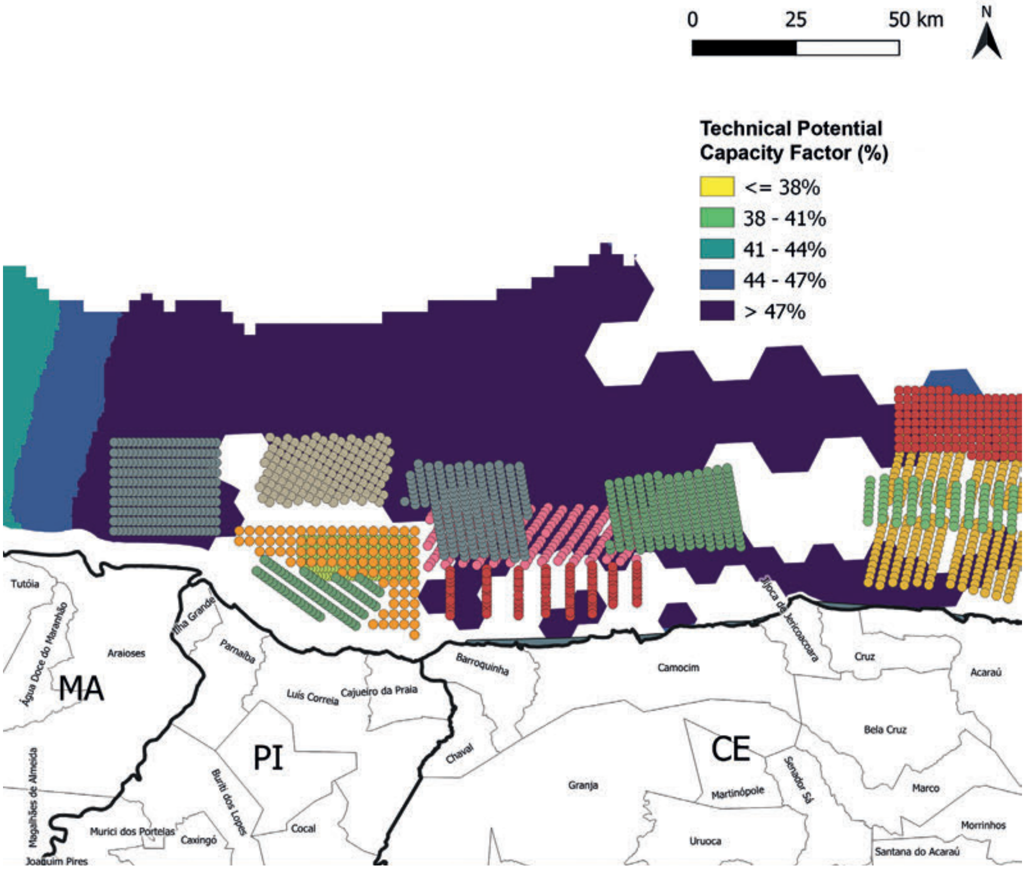


Source: Prepared by the author.

There are a total of five permit applications for offshore wind power in the state of Piauí and at the beginning of the east coast of the state of Maranhão. There are four projects in Piauí and one in Maranhão. Figure 40 shows that there is still a large area with a high capacity factor that could be explored for the construction of these projects.

Piauí lacks infrastructure for industrial development. The state has been planning to build its first port for more than 40 years. The project, which started in the 1980s, was never completed, and the state is the only one in the country without its own terminals. In 2018, feasibility studies for the project resumed (PPP Piauí, 2022). The implementation of the port in the form of a concession will open up space for the repositioning of the state in the political and economic scenario of the country, especially in the flow of local and regional production, as well as helping to boost its entire production chain. The Port of Luís Correia is expected to be built in the north of the state, in the coastal plateau region. It will be located 20 km from the Export Processing Zone (ZPE) of Parnaíba, 30 km from the coastal plateaus, and about 800 km from the Cerrado biome of Piauí.

FIGURE 40 – Map of capacity factor in the area of technical potential and offshore wind projects with a permit application at Ibama in the state of Piauí and east Maranhão

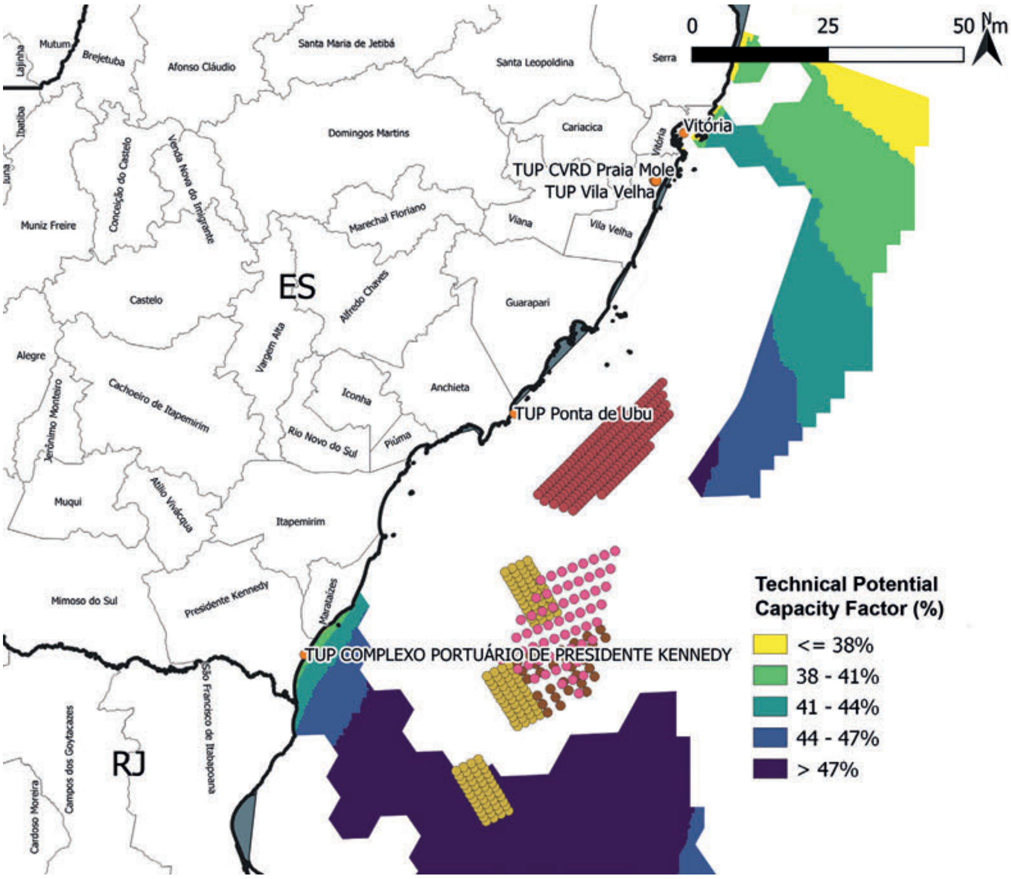


Source: Prepared by the author.

4.6.2 SOUTHEAST REGION

The Southeast region has enormous offshore wind power potential on the north coast of Rio de Janeiro and in the south of Espírito Santo. There are four permit applications in Espírito Santo and nine in Rio de Janeiro, for a total capacity of about 33.2 GW. Figure 41 shows the coast of Espírito Santo with the respective permit applications and the capacity factor in the technical potential area. Due to the overlap, only two of the four projects can be continued. They are all located in high priority conservation areas (Figure 41) and are at risk of having their permits refused.

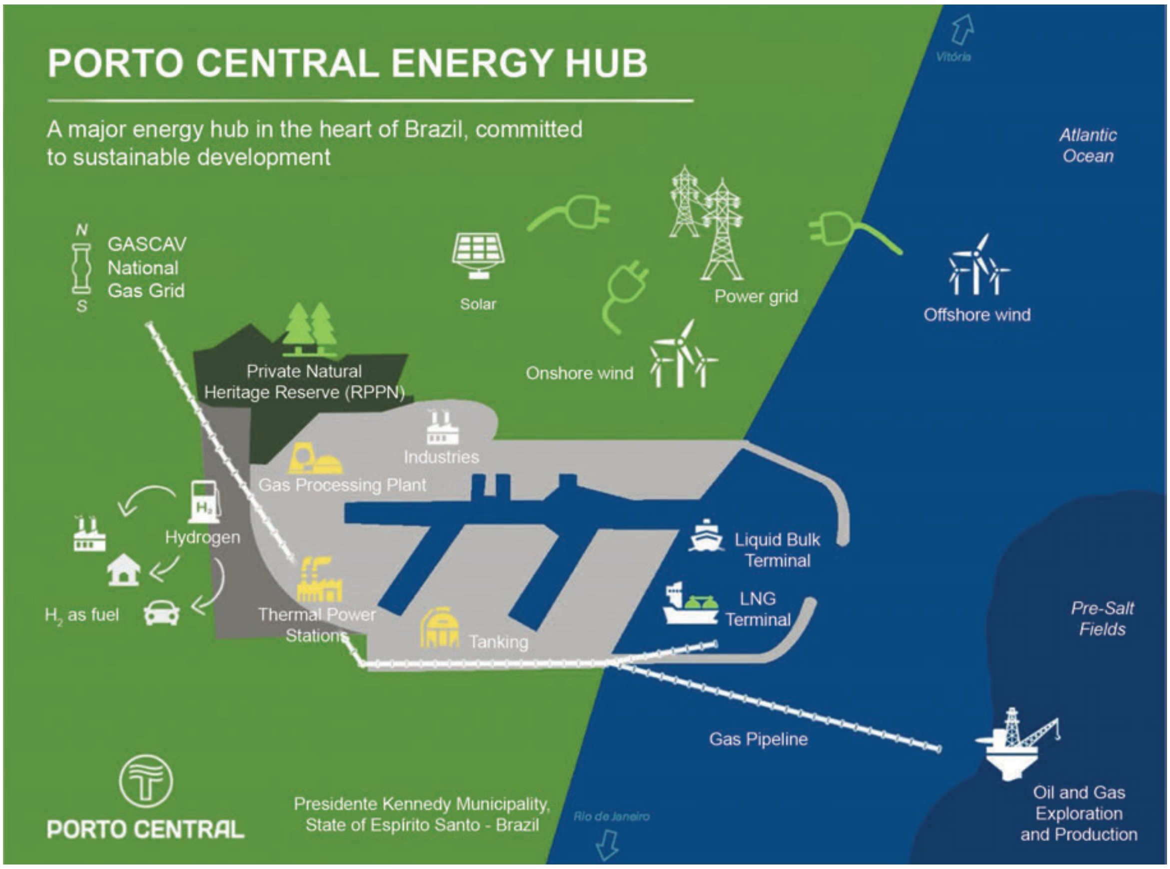
FIGURE 41 – Map of capacity factor in the area of technical potential and offshore wind projects with a permit application at Ibama in the state of Espírito Santo



Source: Prepared by the author.

Close to the areas with the greatest potential and the projects with permit applications at Ibama, there is an ongoing project to build Porto Central, which aims to become a unique industrial port complex and a global reference. It is planned to be a port for transshipment of various types of goods such as oil and gas, grains, fertilizers, minerals, containers, general cargo etc. In addition, a terminal for the offshore wind power industry is planned to attract investment in the production of low-carbon hydrogen on a large scale for both the domestic and international markets. This plant could be installed within the Export Processing Zone (ZPE) of Porto Central, already licensed.

FIGURE 42 – Schematic layout of Porto Central



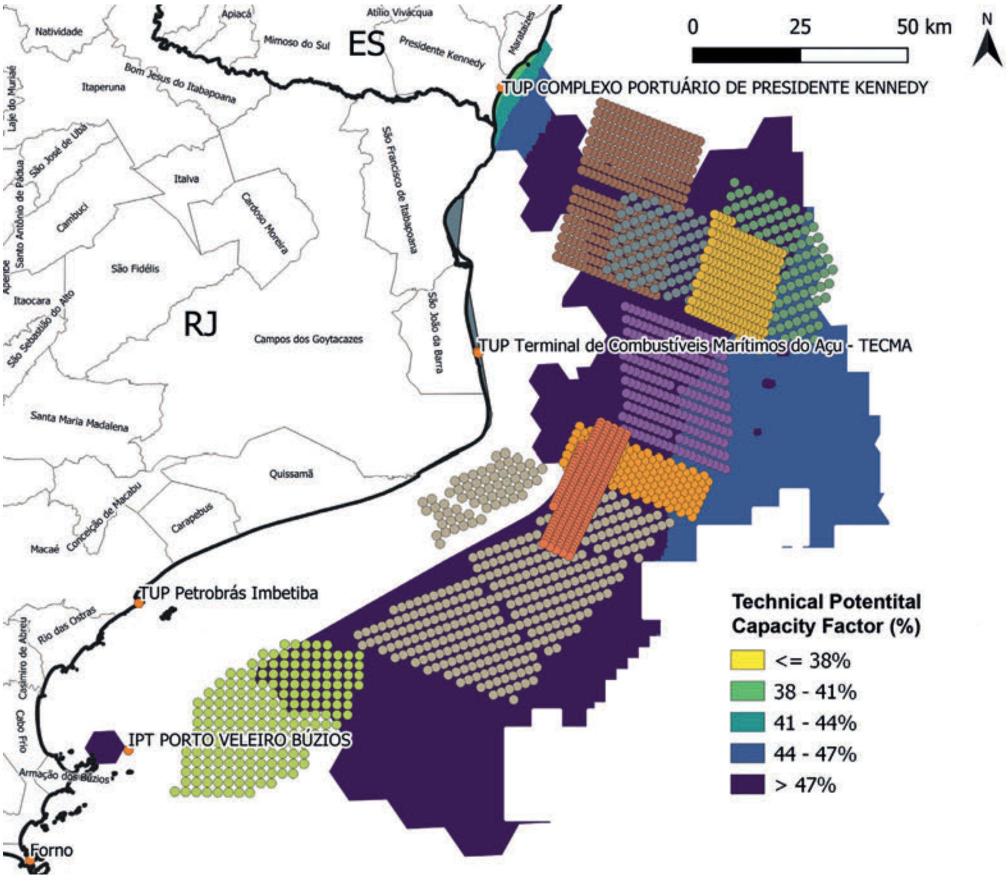
Source: Porto Central, 2022.

Most of the projects with permit applications in Rio de Janeiro are located in the area that has been mapped with technical potential. However, given the overlap, not all of them are expected to continue. Figure 43 shows that there are still projects in conservation areas with extremely high priority. Therefore, they must have the approval of Ibama and the competent authorities to proceed with the assignment of use of the area.

The state is the third smallest in the Federation but has 15% of all ports in the country and 50% of all shipyards. The five main ports are: Açu, Macaé, Rio de Janeiro, Itaguaí, and Angra dos Reis. In addition, two ports are under construction: Tepor and Maricá.

Although there are other ports with potential, Port of Açu has proven to be the most promising and is positioning itself as an energy hub. It is working on developing a hydrogen hub that attracts different sectors of the value chain: H2 producers and distributors, green ammonia and biorefinery industries, low-carbon steel industries that can use low-carbon H2 (either as an energy vector or as a raw material in their production process), as well as equipment manufacturers operating in the H2 industry.

FIGURE 43 – Map of capacity factor in the area of technical potential and offshore wind projects with a permit application at Ibama in the state of Rio de Janeiro



Source: Prepared by the author.

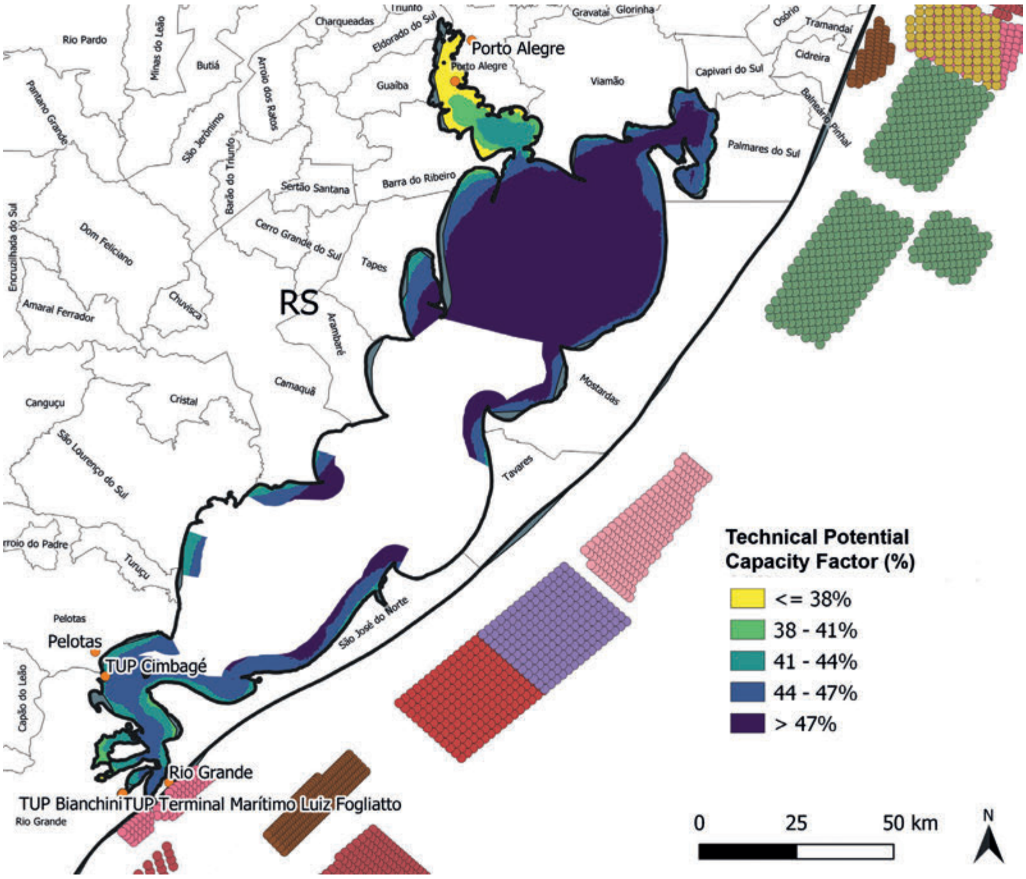
In the case of Rio de Janeiro, the energy from offshore turbines can be used for domestic consumption, not only in the state, but also near the load centers of São Paulo and Minas Gerais. The Port of Açu is the best positioned energy hub and has an area equivalent to almost two islands of Manhattan, which is important for investors.

The state's infrastructure combines various modes of transport. There are highways connecting to the main parts of the country. Recently, the construction of the EF 118 railroad was approved, connecting Port of Açu with the Anchieta Terminal in Espírito Santo. The railroad also leads to the Central-West region. This integration is important because it helps to transport the production of nitrogen fertilizers inland. And, in the opposite direction, grain production is transported for export through the Port of Açu.

4.6.3 SOUTH REGION

The South Region has the largest gross potential for offshore wind power in Brazil. However, the application of technical, environmental, and economic constraints practically reduces the exploration areas to Lagoa dos Patos lagoon in Rio Grande do Sul (RS). This is due to the extremely high priority conservation area mapped on the coast of the South region. As shown in Figure 44, the region has 21 projects in Rio Grande do Sul and one in Santa Catarina.

FIGURE 44 – Map of capacity factor in the area of technical potential and offshore wind projects with a permit application at Ibama in the state of Rio Grande do Sul



Source: Prepared by the author

Nevertheless, the Secretariat of Environment and Infrastructure (SEMA) of Rio Grande do Sul has completed a preliminary study to launch a public tender for the concession to use land (plots) in the Lagoa dos Patos lagoon, which provides for the installation of electricity-generating wind turbines (wind farms) by the private sector (SEMA-RS, 2022). There is also the possibility of exporting hydrogen and its derivatives to Argentina, Uruguay, and later Paraguay.


WINDFLOAT
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5 BARRIERS AND RECOMMENDATIONS

As we have seen, there is great potential for the exploitation of offshore wind power in Brazil, but the following is required: (i) overcoming some regulatory and institutional barriers to create a safe environment for investors; (ii) creating a new market inside and/or outside the country for the consumption of the energy produced; (iii) investing in infrastructure so that this energy generated with this technology is competitive; and (iv) improving the country's technological infrastructure so that this industry performs in a way that makes it competitive.

This potential is around 697 GW (EPE, 2020), which is three times the country's installed capacity[13]. Opportunities therefore exist to create a low-carbon hydrogen market from offshore wind power generation, but there are barriers that need to be mapped so that recommendations can be made. Therefore, this section discusses the key barriers related to (i) regulatory (Section 5.1), market (Section 5.2), (iii) infrastructure (Section 5.3), and (iv) technological (Section 5.4) aspects. Environmental aspects are considered in the discussions and addressed within the regulatory framework. To overcome the listed barriers, recommendations were made to use offshore wind power generation to produce low-carbon hydrogen. This could be absorbed by the country's industry, but there is also the possibility of supplying this commodity to the international market.

In the following subsections, the discussion of barriers and recommendations for each of the above aspects follows the same logic. First, a list of barriers is presented with their respective codes (e.g., the first regulatory barrier is BR.1 and so on – Table 8). The recommendations for overcoming one or more barriers are then presented. For example, in Table 9 the first recommendation for the first regulatory barrier listed (RRB.1) targets barriers RB.1 and RB.2.

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[13] According to the Brazilian Energy Balance, the installed capacity of the Brazilian generation park in 2021 was 181.6 GW (EPE, 2022).

In order to consolidate the lists of barriers and their respective considerations, various documents were consulted, which are listed in the bibliographical references. In addition, the perceptions of experts on the debates that took place during Brazil Wind Power 2022 were also taken into account.

At the end of this chapter, in section 5.5, an agenda of studies is proposed so that some of the barriers presented can be overcome.

5.1 REGULATORY BARRIERS AND RESPECTIVE RECOMMENDATIONS

Table 8 shows the regulatory barriers. Next, in Table 9, the recommendations for overcoming the barriers raised are also listed. Finally, considerations are given to the regulatory barriers and the corresponding recommendations.

TABLE 8 – Regulatory barriers

Regulatory barriers (RB)	Code
Large number of stakeholders involved in this market	RB.1
Unclear governance of public policy and incentive mechanisms	RB.2
Standardization and regulation processes in the offshore wind power sector	RB.3
Conflicts between maritime land use and other economic activities	RB.4
Regulatory uncertainty for offshore wind turbines, as only non-statutory regulatory mechanisms exist	RB.5
Need to resolve the issue of overlapping existing areas in Ibama permit applications	RB.6
Lack of a specific regulation on the basis for calculating the amounts payable in the case of assignment for consideration	RB.7
Delay in opening the retail electricity market	RB.8
High cost of energy generated by offshore wind turbines	RB.9
Lack of regulation that adequately compensates ancillary services[14]	RB.10

Source: Prepared by the author

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[14] Ancillary services contribute to ensuring the functionality of the SIN and, under current regulations, consist of (ONS, 2019): (i) primary and secondary frequency control of generating units; (ii) reactive support; (iii) supplemental order to maintain operating power reserve; (iv) partial and full self-restoration; and (v) Special Protection System (SEP).

TABLE 9 – Recommendations for regulatory barriers

Recommendations for Regulatory Barriers (RRB)	Barrier
RBR.1 – To define stakeholder responsibilities, map any points of conflict and alliances between them	RB.1, RB.2
RRB.2 – Involve all stakeholders in the discussion of public policies (MME, MDR, MCTI, MMA, MF, Navy, etc.) and define their responsibilities throughout the process. It is suggested that the MME be the coordinating body	RB.1, RB.2, RB.3
RRB.3 – Reduce uncertainties regarding potential socio-economic conflicts that could arise between offshore wind power activities and other activities through the implementation of Maritime Spatial Planning – MSP.	RB.3, RB.4
RRB.4 – Align the text of the Bill of Law discussed in Congress with Decree No. 10,946/2022	RB.5
RRB.5 – Establish clear criteria for dealing with the problem of overlapping areas	RB.6
RRB.6 – Accelerate the process of publishing the regulation dealing with the amounts to be paid in the case of offshore wind projects with assignment for consideration	RB.7
RRB.7 – Accelerate the opening of the retail market, defining the deadlines and the consumers eligible to participate	RB.8
RRB.8 – Conduct capacity reserve auctions in the form of power for peak supply with storage technologies	RB.8, RB.9
RRB.9 – Review the regulation of ancillary services	RB.9

Source: Prepared by the author

For a better understanding of the responsibilities that the different stakeholders must have in a future market for offshore wind power and low-carbon hydrogen (RB.1), we recommend conducting an assessment of mutual interests and their main points of conflict. This is an important and not an easy task, since according to EPE (2020) at least 17 governmental bodies are involved in environmental permits only (Appendix 1). In addition to these bodies, it is necessary to involve civil society actors such as investors, consumers, industries, associations, financing entities etc. Only with this action will it be possible to establish clear governance when setting guidelines to drive the creation of these two markets through incentive mechanisms (RB.2). It is also necessary to define the standardization and regulation processes (RB.3). For the project to be successful, we also recommend that the MME be the contact point for all public and private bodies involved.

In addition, we recommend preparing a Maritime Spatial Planning (PEM)[15] (EPE, 2020; BEP 2020) to reduce uncertainties about possible socio-economic conflicts that could arise between offshore wind power activities and other activities (RB.4). This planning aims to regulate different areas of activity (Carneiro, 2022): maritime transport, renewable energy, marine conservation/protection, mining, fishing, aquaculture, oil and gas exploration, and military defense. This can promote foreign exchange and job creation and lead to greater legal certainty that can promote economic development without neglecting strategic and national defense interests, as well as maximizing private and public interests.

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[15] Maritime Spatial Planning (MSP) can be understood as a public, multisectoral, legal, and practical instrument that organizes the common, efficient, harmonious, and sustainable use of the seas (Carneiro, 2022).

Both Bill of Law (PL) No. 576/2021 and Decree No. 10,946/2022 address the use of federal assets for energy production from offshore projects. In the case of the PL, it is important that the deliberations in the Chamber of Deputies and in the Senate do not result in drastic changes to the decree text in order to ensure legal certainty for investors in offshore wind projects. The fear of companies considering investing in this source of energy production is something similar to what happened with Law No. 14,182/2021, which provides for the privatization of Eletrobras, where parliamentary amendments were made that have no direct relation to the main text. It is important to ensure that the non-statutory mechanisms currently dealing with this issue (Decree No. 10,946/2022, GM/MME Normative Ordinance No. 52/2022, and Joint MME/MMA Ordinance No. 3/2022) not have their texts altered, so that investors are given due legal and regulatory certainty (RB.5).

With regard to the regulations on the assignment of areas, it is also important that the criteria for dealing with overlapping areas for projects that have already applied for permits at Ibama are transparently defined (BR.6). The rule established in GM/MME Normative Ordinance No. 52/2022 is not very clear and should be better specified, since out of the 70 projects submitted by December 2022, there were more than 30 with overlaps, some even with four other projects. This is an issue that needs to be addressed quickly and discussed with the parties concerned in order to avoid judicialization of this market and speculative use of water. Such criteria should be more clearly expressed in the creation of the PUG-offshore, which was established by the Joint MME/MMA Ordinance No. 3/2022. Therefore, we recommend taking into account not only economic but also social and environmental criteria in order to ensure the maximum socio-economic benefits to society.

In the specific case of assignment of an area for consideration, as regulated by GM/MME Normative Ordinance No. 52/2022, it is important that the process of publishing the regulations that will deal with the amounts to be paid (RB.7) is carried out quickly. This will allow balancing the interests of society and allow the private sector to better estimate these costs in their financial models. When determining the methodology for calculating these values, we recommend taking into account the experience of two major segments of the energy sector: large hydroelectric power plants and oil and gas exploration.

As far as the use of the energy generated by offshore wind projects in industry is concerned, two paths can be taken: (i) the direct generation of electricity demanded by industry; and (ii) the production of low-carbon hydrogen, which can also be used by industry or stored to generate electricity for the grid.

In the first case, the opening of the retail market should be accelerated by defining the deadlines and the consumers eligible to participate, in particular the industrial consumers supplied with low voltage (RB.8).

In the case of using wind power to produce hydrogen, the natural route would be the direct use in industry (e.g., production of ammonia and fertilizers, production of methanol for the chemical and petrochemical industries, use in the steel industry, ceramics and glass production, and cement production). It is also envisioned that this hydrogen will be used as stored energy to generate electricity during critical times of power grid use (e.g., peak periods) or as ancillary services. To this end, we recommend holding an auction for reserve capacity in the form of power for peak supply with storage technologies (RB.8), since this could enable hybrid projects of renewable generation and storage (e.g., offshore wind power and hydrogen storage). In addition, we recommend considering the revision of sub-module 14.3 of the National Electricity System Operator (ONS) Grid Procedures, which addresses compensation for ancillary services (RB.9). The current value is outdated as the last revision of the calculation methodology was in 2008 (ONS, 2008).

5.2 MARKET BARRIERS AND RESPECTIVE RECOMMENDATIONS

Table 10 lists the market barriers identified based on the document survey conducted by the authors. Table 11 lists the recommendations for overcoming these barriers. Then, considerations are given to the market barriers and the corresponding recommendations.

TABLE 10 – Market barriers

Market barriers (MB)	Code
High initial costs of introducing technological solutions related to offshore wind power and low-carbon hydrogen projects	MB.1
Low availability of information about the potential and costs of the opportunities	MB.2
Low availability of specific credit lines for the offshore wind power and hydrogen market	MB.3
Withdrawal of investments in ST&I with impact on the energy market	MB.4
Lack of a domestic and a foreign hydrogen market	MB.5
Limiting carbon trading systems to the European Union and the United States	MB.6
Lack of demand for green products	MB.7
Possible lack of equality among all players involved in the offshore power generation market	MB.8
Lack of experience in licensing offshore wind farms.	MB.9

Source: Prepared by the author.

TABLE 11 – Recommendations for market barriers

Recommendations for Market Barriers (RMB)	Barrier
RMB.1 – Create competitive mechanisms to expand energy supply in the country and energy planning tools to include offshore wind power and hydrogen in the mix	MB.1, MB.2, MB.3
RMB.2 – Create tendering procedures for the assignment of the planned area	MB.1, MB.2
RMB.3 – Increase the number of monitoring stations to measure the potential for offshore wind power generation more accurately	MB.2
RMB.4 – Ensure the creation of stable, reliable, and competitively priced funding lines using the experience of the onshore wind power industry	MB.2, MB.3
RMB.5 – Create programs and publish specific tenders for the offshore wind power and hydrogen sectors with the goal of strengthening the foundations of research and technological development with these specificities	MB.2, MB.4, MB.5
RMB.6 – Introduce a carbon market as a pillar to promote decarbonization of hard-to-abate[16] segments in the industry	MB.6
RMB.7 – Develop public mechanisms to create demand for green products in the country	MB.7
RMB.8 – Equality in setting the criteria for the assignment of areas for offshore wind power use	MB.8
RMB.9 – Leverage the experience with environmental permitting for large oil exploration and onshore wind projects	MB.9

Source: Prepared by the author

Competitive mechanisms must be created using regulatory tools to expand the country's energy supply by incorporating offshore wind and hydrogen into the Brazilian energy mix. These mechanisms are very important to allow the introduction of technological solutions for offshore wind projects and the production of low-carbon hydrogen (MB.1), thus laying the foundations for the development of this market. Some of these mechanisms have been mentioned in Section 5.1, as a regulatory framework is needed for this market to develop in a harmonious and orderly manner in the country.

One important measure would be the creation of tendering procedures for planned assignment of areas, as it not only provides an incentive for the inclusion of offshore wind power in the mix, but also provides further information on the potential of this energy source and the cost of opportunities (MB.2). For example, generation potential and environmental impact studies are the responsibility of the government. This would refine some available data and collect additional unavailable information, including generation potential, which can be accomplished by increasing the number of monitoring stations. This would allow this generation potential to be measured more accurately, reducing uncertainty about the suitability of sites and the risks to investors.

In addition to the regulatory mechanisms, stable, reliable, and affordable financing options should be created, leveraging the experience of the renewable energy sector. Institutions such as the Brazilian Development Bank (BNDES) and the Bank of the Northeast (BNB)

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16 Hard-to-abate emissions are those that are prohibitively costly or impossible to reduce with currently available technologies. They are found in some heavy industries such as cement, steel, and chemicals (Paltsev et al., 2021).

play an important role in granting loans for onshore wind projects. According to the BEP (2022), these two institutions are acquiring knowledge of offshore wind power and expect to finance projects in this sector (MB.3).

We also recommend that BNDES act as an accelerator body for this initiative, funding studies on bottlenecks in the production of goods and services in both the offshore wind power chain and the hydrogen chain to identify a strategy to develop these sectors in the country (MB.1 and MB.3).

Research, Development and Innovation (RD&I) play an important role in better understanding the offshore wind power and low-carbon hydrogen market in Brazil. According to the BEP (2021), the Ministry of Science, Technology and Innovation (MCTI) has supported the development of the sector through partnerships with universities and technology centers. However, due to the economic downturn caused in particular by the pandemic, there has also been a decrease in investment in ST&I in the country in recent years, with a direct impact on the energy market (MB.4). Furthermore, in Brazil there are still no specific tenders for the offshore wind power sector, nor programs to strengthen the foundations of research and technological development with this specificity (BEP, 2021).

We therefore recommend creating programs and publishing tenders for the offshore wind power and hydrogen sectors in order to reduce the low availability of information on the potential and opportunity costs (MB.2), thus enabling the creation of the foundations for the development of a domestic and foreign hydrogen market (MB.5). Brazil has one of the lowest levelized costs of renewable energy production in the world (IRENA, 2021), making it a strong candidate for producing low-carbon H_2 for export to other countries at a very competitive price (CNI, 2022) .

Another way to make hydrogen produced from offshore wind power more competitive is to introduce it into a green economy by introducing a carbon market that encourages the decarbonization of hard-to-abate segments in the industry (MB.6). This can create greater demand for green products in the country (MB.7).

In terms of setting the criteria for the assignment of areas for offshore wind power use, we advocate for equality. We recommend setting well-established rules for cases where oil exploration and wind power production might overlap. This is an important rule to ensure equality among all investors interested in exploring the country’s maritime areas (MB.8) and to ensure the smooth operation of the future offshore wind power market.

Regarding the environmental permits for offshore wind turbines in Brazil (MB.9), we recommend taking into account the experience from the oil and gas sector, as the impacts are similar. However, the specific impacts of each sector must be taken into account. In the oil and gas sector there is great concern about possible leaks, while in the offshore wind power sector the migration of birds and marine animals deserves attention. In addition, we recommend evaluating the experience of other countries that have already invested in this source, in particular the United Kingdom.

5.3 INFRASTRUCTURE BARRIERS AND RESPECTIVE RECOMMENDATIONS

Table 12 below lists the infrastructure barriers, taking into account the studies carried out. To overcome these barriers, recommendations are presented that can be evaluated in Table 13. Then considerations are given to the contents of these two tables.

TABLE 12 – Infrastructure barriers

Infrastructure barriers (IB)	Code
Global crises (COVID-19 and the Ukraine war) led to an increase in equipment prices on the world market	IB.1
Low competitiveness of the wind turbine industry compared to the international industry	IB.2
Lack of logistics infrastructure (roads and ports)	IB.3
Lack of a global hydrogen market	IB.4
Technical limitations of the offshore wind power and low-carbon hydrogen industries.	IB.5
Offshore wind projects must be large and require transmission planning studies	IB.6
Large demand from other industries for cranes	IB.7

Source: Prepared by the author

TABLE 13 – Recommendations for infrastructure barriers

Recommendations for Infrastructure Barriers (RIB)	Barrier
RIB.1 – Hedge against fluctuations in international commodity prices (industry inputs)	IB.1
RIB.2 – Identify available skills from other sectors of the economy that can be used in the offshore wind power industry	IB.1, IB.2
RIB.3 – Involve international partners to increase the quality level of components in the supply chain	IB.2
RIB.4 – Create local production hubs for components in the wind power production chain to supply the domestic market and other countries in the Americas	IB.1, IB.2, IB.3
RIB.5 – Promote the production of large wind turbine equipment (e.g., blades and towers) near ports	IB.1, IB.2, IB.3
RIB.6 – Promote public-private partnerships to improve ports and roads near tender areas	IB.3
RIB.7 – Promote cooperation to create a global hydrogen market	IB.4
RIB.8 – Conclude agreements with universities and other institutions such as SEBRAE and SENAI that can offer more qualified training	IB.5
RIB.9 – Conduct (EPE and ONS) preliminary studies on projects already registered with Ibama.	IB.6
RIB.10 – Map companies in Brazil that provide lifting and crane services in strategic sectors such as civil construction, ports, and energy (wind power and O&G)	IB.7

Source: Prepared by the author

Due to global crises, especially the pandemic and the war between Russia and Ukraine, there was an increase in the prices of commodities and electronic components manufactured in China (in dollars), which ultimately led to an increase in equipment prices in the global market. It was no different in the wind power sector, especially because it is a sector completely dependent on commodities (IB.1). It is necessary to create a hedging culture in the country so that the industry is not exposed to fluctuations in commodity prices and exchange rates. For example, a guarantee fund created by BNDES could bring more security to a future offshore wind power market.

To increase the competitiveness of the wind power industry in the country (IB.2), we recommend identifying the skills existing in other sectors of the economy that can be used in the offshore wind power industry, such as the expertise of the oil and gas industry. In addition, this competitiveness can be increased through partnerships between domestic industries and international partners to increase the quality level of supply chain components in the country.

Another recommendation to increase the competitiveness of the wind power sector (IB.2) would be the creation of local production centers for components of the production chain to supply the domestic market and other countries in the Americas (IB.1, IB.2, IB.3). Of course, the creation of these centers would require a lot of time and large investments, but it could mitigate the impact of the country's dependence on Chinese-made products and strengthen our industry in this sector. In addition, it could support the strengthening of port and road infrastructure in the country (IB.3), since the production of large equipment that make up wind turbines (e.g., blades, towers, and structures) would take place near ports to facilitate the logistics of offshore wind projects.

The investments required to create local hubs could be made through a public-private partnership, with investments in infrastructure, ports, and roads (IB.3) that could be carried out on a concession basis, for example, similar to what happens today with the concession of roads, airports etc. We therefore recommend carrying out a detailed study of the current Brazilian port infrastructure in order to identify possible improvements and necessary adjustments.

In order for the offshore wind power and low-carbon hydrogen industries to develop rapidly in the country, we recommend seeking international cooperation to create a global hydrogen market (IB.4). Hydrogen hubs could be set up in Brazilian ports from which hydrogen could be exported (e.g., green ammonia). Given the war in Ukraine, Europe, which is experiencing one of the worst energy crises in its history, would be an important buyer for this hydrogen.

In order to create a strong infrastructure in the country, it is necessary to understand the technical limitations of the players in the offshore wind power and low-carbon hydrogen industries and to address the shortcomings of the professionals who are expected to work in these markets (IB.5). To this end, we recommend establishing agreements with universities and other institutions, such as SEBRAE and SENAI, that can provide more qualified training for the professionals who are expected to work in these two sectors. We also recommend the establishment of research centers in locations with the greatest offshore wind power potential as a form of regional development (BEP, 2020).

Even if an offshore wind project is dedicated to the production of low-carbon hydrogen, it is important that this facility be connected to the power grid, since it needs to be stable. In addition, offshore wind projects must be large and require transmission planning studies (IB.6). We therefore recommend that the EPE and ONS carry out a forward-looking assessment of transmission in relation to the electrical performance of the grid, taking into account the mapping of offshore wind power potential and the location of viable projects (EPE, 2020), especially those that are already registered with Ibama.

Likewise, as the offshore wind power market grows, there will be great demand for cranes currently used in other sectors of the economy, such as the oil and gas industry (IB.7). It is therefore necessary to map the companies in Brazil that provide lifting and crane services in strategic sectors such as construction, ports, and energy (wind power and oil). In addition, the vessels currently providing services to the oil and gas market should be adapted to accommodate larger cranes suitable for the offshore wind power industry.

5.4 TECHNOLOGICAL BARRIERS AND RESPECTIVE RECOMMENDATIONS

The list of technological barriers is shown in Table 14. The recommendations for overcoming them are listed in Table 15. Finally, we present the considerations for such barriers and recommendations for overcoming them.

TABLE 14 – Technological barriers

Technological barriers (TB)	Code
The country's embryonic stage of standardizing processes, materials, and equipment for the offshore wind power and hydrogen markets	TB.1
Limited local industrial infrastructure and lack of technical maturity of some companies to participate in the offshore wind power and hydrogen value chain	TB.2
Lack of vessels adapted to the challenges of the offshore wind power industry.	TB.3
Growing demand for electrolysers	TB.4

Source: Prepared by the author

TABLE 15 – Recommendations for technological barriers

Recommendations for Technological Barriers (RTB)	Barrier
RTB.1 – Adapt the industry currently focused on the onshore market to the offshore market	TB.1, TB.2
RTB.2 – Create an industrial development program for the offshore wind power sector, taking into account the experiences and infrastructure of onshore wind power.	TB.1, TB.2
RTB.3 – Understand the hydrogen diffusion model in the energy mix to reveal the market development sequence that will drive the growth of this industry	TB.1, TB.2
RTB.4 – Define or promote the development of a pilot project using offshore O&G platforms in the decommissioning phase to produce low-carbon hydrogen for installation in offshore wind turbines.	TB.1, TB.2
RTB.5 – Map the fleet of vessels available in the country to support offshore activities	TB.3
RTB.6 – Invest in a local electrolyzer industry	TB.2 and TB.4

Source: Prepared by the author

As the market for offshore wind power and hydrogen from renewable sources is still in its early stages, there is no standardization of processes, materials, and equipment to supply these markets (TB.1). In addition, the limited infrastructure of the local industry and the lack of technical capacity of some companies to participate in the offshore wind power and hydrogen value chain pose major challenges in creating these markets (TB.2).

Nevertheless, the offshore wind power market can benefit from more than a decade of experience in the onshore market. Therefore, we recommend identifying possible supply chain adaptation opportunities by studying and evaluating the technologies offered by current suppliers and manufacturers from all segments operating in the Brazilian wind power market. Taking into account the experience and infrastructure of onshore wind power, industrial development programs could also be created for the offshore wind power sector.

In the case of low-carbon hydrogen, advances in standardization and certification of industries and partnerships with countries that have developed technologies in this area are part of a strategy for the development of this industry in the country. Furthermore, it is necessary to understand the hydrogen diffusion model in the energy mix to reveal the market development sequence that will drive the growth of this industry and to avoid technological blockages in segments that could be served by hydrogen in the future (EPE, 2021).

We recommend promoting the development of pilot projects that use offshore oil and gas platforms in the decommissioning phase to produce low-carbon hydrogen or install offshore wind turbines.

There are currently not many vessels operating in the oil and gas market that are fully adapted to the needs of the offshore wind power industry (TB.3). We therefore recommend that the existing fleet of vessels in the country that support offshore activities be mapped to explore the possibility of adapting them to meet the demand of the offshore wind power industry.

Several countries around the world are interested in investing in the hydrogen market. For this reason, there is a growing demand for electrolysers (TB.4). Brazil can thus benefit from investing in a local industry for this equipment, as there are great expectations for the creation of hydrogen hubs to sell this input in the local industry or for export purposes.

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APPENDIX A – GOVERNMENTAL BODIES RELEVANT TO THE ENVIRONMENTAL PERMITTING PROCESS

Institution / Agency	Acronym
National Civil Aviation Agency	ANAC
National Electric Energy Agency	ANEEL
National Agency for Waterway Transportation	ANTAQ
National Agency for Petroleum, Natural Gas. and Biofuels	ANP
Aeronautical Command	COMAER
National Environmental Council	CONAMA
Palmares Cultural Foundation	FCP
National Indian Foundation	FUNAI
Brazilian Institute of Environment and Renewable Natural Resources	IBAMA
Chico Mendes Institute for Biodiversity Conservation	ICMBio
Institute of National Historical and Artistic Heritage	IPHAN
Brazilian Navy	MB
Ministry of Mines and Energy	MME
Ministry of the Environment	MMA
National Electric System Operator	ONS
Secretariat for Coordination and Governance of Federal Assets	SPU/ME
Special Secretariat for Aquaculture and Fisheries	SEAP/PR
Geological Survey of Brazil	CPRM

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