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Value Chain Study: *Offshore* Wind Power

Executive Summary

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Summary

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Abbreviations

ABEEólica – Brazilian Wind Power Association

ACL– Free Contracting Environment

ACR – Regulated Contracting Environment

ANEEL – National Electric Energy Agency

CAPEX – Capital Expenditure AC – Alternating Current

DC – Direct Current

CLI – Lower limit scenario CLS – Upper limit scenario CO_2 – Carbon dioxide

CTEM – Science, Technology, Engineering and Mathematics

CTVs – *Cargo Transfer Vessel*

Dist – Distance

E&P– Exploration and production

EIA – Environmental Impact Study EO – Offshore Wind

EPE – Energetic Research Company

exc. - Except

GW – Gigawatts

GIS–SPOWER–BR Toolbox – *GIS–based method for Strategic Planning of the Offshore Wind Renewable Energy for Brazil*

H_2 – Hydrogen Gas

IBAMA – Brazilian Institute do Environment and Renewable Natural Resources

ICG – Transmission Installations of Exclusive Interest of Generation Plants for Shared Connection

ILO – *International Labour Organization*

IRENA – *International Renewable Energy Agency*

LFAC – *Low Frequency Alternating Current*

LCOE – *Levelized Cost of Energy*

LFAC – *Low Frequency Alternating Current*

MME – Ministry of Mines and Energy

Mt – Megaton

MtCO_2 – Megaton of Carbon dioxide

MW – Megawatts MWh – Megawatt–hour

O&G – Oil and gas

O&M – Operation and Maintenance

PDE – Ten-Year Energy Expansion Plan

RD&I – Research, Development and Innovation Projects

PEO – Offshore Wind Farm

PET – Polyethylene Terephthalate

PL– Law Bills

PROMINP - Mobilization Program of the National Oil and Natural Gas Industry

Rima – Environmental Impact Report

RN – Rio Grande do Norte

R$ – Real

SAR – *Synthetic Aperture Radar*

SIN – National Interconnected System

STAR – *Sweep Twist Adaptive Rotor*

TR – Reference Term

WTIV – *Wind Turbine Installation Vessel*

XLPE – *Cross–Linked Polyethylene*

Presentation

The project entitled "Value chain study: offshore wind power", sponsored by ABEEólica, aimed to map the current stage of the offshore wind power segment in Brazil. The intention was to identify opportunities, challenges and future prospects. This is a study that presents the main driving paths for the development of the offshore wind energy value chain, taking into account the planning and expansion of technology in the national context. The executing team was formed by specialists in energy planning and renewable sources from Essenz Soluções and PPE/COPPE/UFRJ. The technical coordination was provided by Maurício Tolmasquim, Main Professor at PPE/COPPE/UFRJ.

The work was developed from the elaboration of eleven technical notes, addressing the following topics: (I) Transmission Planning and Expansion, (II) Opportunities and planning of port and logistics infrastructure, (III) Socio-environmental and economic benefits of the source, (IV) Creation of jobs and scenarios, (V) Role of the source in relation to the power safety and transition, (VI) Cost forecast, LCOE and technological feasibility, (VII) Status of the technological innovations in the sector (VIII) Overview of the regulatory status, (IX) Demand for steel from the industry and demand for materials, (X) Financing and the role of the national banks in the value chain, and (XI) R&D and the need for qualification of labor force.

This executive summary presents a summary of the produced documents, containing their main results, conclusions and recommendations. The complete technical notes deepen all the topics discussed herein. In addition to this presentation, the executive summary contains section "Main results", which exposes the logical link between the topics of the technical notes, in addition to highlighting the main results of each topic. The next sections then present the summaries of the technical notes. Each abstract brings guiding questions, in order to make the reading more direct and flow better.

Have a pleasant reading!

Main results

The study begins by addressing the main challenges to be addressed regarding the planning of transmission infrastructure expansion and concludes that the main aspects relate to (i) the location of offshore wind projects, (ii) the misalignment between generation and transmission schedules, (iii) ownership and obligations related to the offshore transmission infrastructure and (iv) the environmental aspects of the transmission infrastructure. Although there are no solutions for these challenges, it appears that Brazilian regulation already incorporates enough tools to provide adequate incentives to transmission agents so as not to prove to be an obstacle to the development of transmission infrastructure.

As the transmission infrastructure is important for the flow of the offshore wind generation, the **port and logistics infrastructure** is fundamental for the development of this industry in Brazil. Ports and logistics enable the parts that make up the wind farm in Brazil to arrive, as well as their optimized manufacturing and transport. The analysis of the situation of the ports in the country verified that no Brazilian port, due to the lack of a history of offshore wind farms in the country, is completely ready for full and immediate operation in the assembly of offshore wind farms, but there is no need to build new ports or terminals. The set of Brazilian port infrastructure, with the appropriate additional training, is sufficient to meet demand more quickly and at a lower cost. In addition, cabotage is the preferred mode of transport for the offshore wind industry, given the demands required by the dimensions and weights of the new cargoes.

In addition to transmission and port infrastructure, the development of the offshore value chain depends on the availability of **components and materials.** As with any emerging offshore wind market, Brazil's supply chain will require extensive development to capture the maximum local benefit from offshore wind. However, Brazil is in an excellent starting position compared to many emerging markets, given its experience with the offshore oil and gas sector and with the onshore wind sector and its thriving civil construction industry. In relation to the materials for the construction of the farms, the most used is steel, but there is also dependence on copper for cabling and electricity, on rare earth elements, such as neodymium and dysprosium, for direct and hybrid drive wind turbines, among others. In Brazil, the limitations are due to the manufacturing and processing process of these materials. Therefore, the biggest challenge is to adapt existing industries to the new needs of offshore wind energy in a strategic and planned way.

Once issues related to transmission infrastructure, port, logistics and material availability are addressed, the value chain of offshore wind will be able to deliver its various **socio-environmental and economic** benefits. It is a renewable energy alternative, with low greenhouse gas emissions, which can help Brazil achieve its zero-carbon climate goals, requires fewer resources and raw materials during its operation compared to other sources of electricity, and contributes for parallel activities, such as tourism and aquaculture. In addition, it can bring economic benefits, such as the generation of jobs, income, added value, production gains and social well-being for the population. It is important that the environmental assessment, planning and management stages are carried out aiming to maximize the created benefits to the detriment of the negative impacts.

An additional benefit of the offshore wind value chain is the **creation of jobs**. As a transversal benefit, it transits in social and economic aspects. The developed scenarios showed that an average of 11 to 34 jobs per installed MW of offshore wind can be generated each year in Brazil. These are sustainable, direct and indirect jobs that require a variety of skills in the entire value chain of the sector. In addition, offshore wind energy offers a response to labor market disruptions arising from the energy transition, such as job displacement for offshore oil and gas and marine engineering workers due to synergies along their value chains.

The current context, driven by **energy transition and security,** tends to optimize the socio-environmental, economic and employment benefits mentioned above. In this context, offshore wind has three roles in terms of energy security and transition: (i) integration with the production of green hydrogen (H2), (ii) reduction of greenhouse gas emissions and (iii) complementarity with other sources of electricity. Additionally, an aspect that can encourage these contributions from offshore wind is the valuation of socio-environmental attributes of energy sources, in addition to the traditional technical-economic analysis.

Such roles will become viable as offshore wind farms are built. For the entry of offshore wind plants to occur, their costs must be competitive. Currently, **LCOE** of this technology is around 333 R$/MWh. The built scenarios indicate the possibility that offshore wind becomes competitive with marginal power plants throughout the 2030s, depending on the level of development of the offshore wind value chain.

The competitiveness of offshore wind can be fostered if there is a well-developed **financing** framework. The study showed that, historically, the capital contributions from national development banks were vital for the viability of electricity infrastructure projects. Although the provision of long-term funding for financing electricity generation projects has been diversifying, the role of public banks continues to be extremely relevant, with emphasis on BNDES resources in financing renewable power plant projects.

In addition to funding, a stable regulatory framework is an important prerequisite for the development of offshore wind in the country. The overview of the current **regulatory status** showed that despite the approval of a bill being the safest mechanism to establish a regulatory framework for the sector, the path chosen through the publication of a decree (Decree nº 10.946/2022) and its ordinances complementary, are acceptable for the realization of investments in this new activity in the country. The regulatory base provided was already sufficient to bring confidence and adequate signaling to agents with the aim of promoting the beginning of the development of offshore wind power and its value chain in Brazil.

The economic, regulatory, infrastructure, logistics and materials dimensions, mentioned so far, serve as a driver for the technical use of the offshore wind resource. A survey of the **status of technological innovations** in the sector showed that the offshore wind market is one of the fastest growing and evolving in the world. The constant search for innovations and their application has brought countless advances, such as cost reduction, technical improvements in the design, size and power of the turbines, increased energy efficiency of wind farms, increased efficiency in the supply chain, creation of new markets, among others. Despite the progress, the sector needs to continue innovating in order to take advantage of the wind potential in deeper waters, improve its processes and reduce the costs.

In general, the technological innovations, extremely relevant for the development of offshore wind technology in Brazil, come from **R&D** projects. For this reason, the study applied a questionnaire to understand the perceptions of specialists in the sector regarding R&D issues, workforce training needs and bottlenecks for the development of the offshore wind value chain in Brazil. The specialists suggested topics involving the mapping of the offshore wind resource. In addition, they highlighted topics that address issues of source competitiveness, environmental impacts, transmission, impacts on SIN, regulation, incentives, planning and climate change. Among the main bottlenecks mentioned, planning, regulation and costs stand out.

I. Transmission Planning and Expansion

What are the main challenges to be overcome in order to guarantee availability of transmission infrastructure for the offshore wind farms?

The offshore wind technology has been developing in the last years as an alternative for electricity generation from renewable sources. Given its production characteristics, the interest in the implementation of this technology has been highlighted in prospective studies of the energy sector (EPE, 2020a; MME and EPE, 2022), which show the trend of strong expansion of this form of electricity generation. However, as it is a new technology, there are still uncertainties and challenges for its expansion.

In this context, the purpose of the technical note about infrastructure planning was to address challenging aspects for the transmission expansion planning in the Brazilian electricity sector to what refers to the large-scale expansion of the offshore wind technology. The methodology was based on a complete review of the literature and interviews with specialists in offshore wind energy and energy planning.

The main challenges identified (Table 1) refer to (i) the location of offshore wind projects, (ii) the misalignment between generation and transmission schedules, (iii) ownership and obligations related to offshore transmission infrastructure and (iv) the environmental aspects of the transmission.

To what refers to the location of the projects, the lack of definition of the grid access points makes it difficult to predict the capacity of the transmission system to absorb this power injection. The sector planning has been deepening the analyses to assure the suitability of the proposals for expansion, reinforcements and improvements of the transmission facilities. It is known that significant increase in the power flow margin is expected for the North and Northeast areas and that it tends to improve the condition for the power flow in the region with the highest potential for offshore wind enterprises. However, it is still complex to state the real absorption capacity of SIN for offshore wind generation.

Regarding the misalignment of schedules, the planning has already been working to resolve this challenge. The most recent studies, such as the Ten-Year Energy Expansion Plan and the respective technical notes, started considering a bigger spectrum of information. Previously, the amounts of power contracted in ACR and the indicative expansion of the official planning generation expansion models were discussed. As of PDE 2031, information such as the power of ACL enterprises in advanced phase of access to the grid and the specific location of the indicative expansion results defined in PDE 2031 started to be considered.

Table 1: Main challenges and possible solutions for the transmission expansion planning

Challenge	Description	Guidelines
Project localization	Lack of transmission infrastructure and flow capacity at points with high offshore wind potential.	Improvement of the studies about the impact on the grid to assure adequate investment in expansion, reinforcements and improvements of the transmission facilities
Misalignment of schedules	Transmission infrastructure must be ready for operation at the time the offshore wind farms start operating.	Adequate sizing and recommendation of the transmission works plan, resulting from the planning studies.
Offshore Transmission Infrastructure	Discussion on the right of ownership and obligation to install underwater transmission equipment.	Improvement of the regulatory framework, in order to guarantee incentives for the installation of offshore wind projects.
Environmental Aspects	Determination of the different environmental impacts of the construction and operation of offshore transmission lines.	Integrated environmental licensing of onshore and offshore lines.

Source: Own preparation based on (EPE, 2018, 2020b; IBAMA,2020)

Considering the maritime transmission infrastructure, ownership of the transmission infrastructure that connects the power to the Basic Grid would more appropriately incorporate offshore wind technology based on certain regulatory improvements. For example, the possibility of ICG is interesting for the entrepreneurs to obtain reduction in the investment costs of the cables that connect the offshore wind farms to the Basic grid. However, the regulatory design of ICG could be reviewed and reassessed in order to consider all involved agents, their obligations, rights and penalties for any non-fulfillment of the established guidelines. In addition, the international experience highlights two additional relevant points: (i) the need for coordination between the entrepreneurs responsible for the wind farms and the transmission system operators and (ii) the alignment of the regulatory incentives so that agents work at the peak of their capabilities around all project phases.

To what refers to the environmental challenges, a possible solution highlighted by EPE (2020) would be the preparation of environmental licensing that enables definition of processes capable of reducing the socio-environmental impacts of the installation of the transmission infrastructure. Additionally, an integrated vision of onshore and offshore transmission equipment is necessary, in order to mitigate the environmental impacts generated throughout the course of the electricity generated by offshore wind farms.

The bibliographic review and the interviews showed that Brazil has sufficient planning tools to address the main identified challenges. The specialists point out that the industry model is robust enough to handle them. For this purpose, the model must be aware of the technological progress and the emerging energy policies, not only in relation to the offshore wind, but also other technologies (for example, hydrogen, batteries, reversible hydroelectric power plants, among others). After all, the purpose of the transmission planning is to seek to provide adaptability and flexibility to the grid always with a holistic view of the system, regardless of the technologies that compose it.

In the specific case of offshore wind, despite the concern about the magnitude of the amounts of power to be connected, the technical challenges were minimized by the specialists due to the compatibility of the deadlines between the implementation time of these projects and the construction time of a new transmission infrastructure for it (which does not happen with onshore enterprises, as they are implemented more quickly). On the other hand, there are bottlenecks in terms of regulatory, and mainly, environmental aspects, which still seem to be far from being solved. In this context, it is necessary that the energy policy in the country to have clear position regarding offshore wind to promote the expansion of the investigations on these subjects aiming to assist the decision-making on the best practices. Likewise, the energy policy must also take into account that the transmission costs have to be seen as investments that will bring bigger benefits, once they will enable better arrangement for the market and the entry of several enterprises, adding systemic benefits.

II. Opportunities and planning of the port infrastructure and logistics

Is the port structure sufficient for the development of the offshore wind in Brazil?

Due to the remote nature of offshore wind energy sites, there is a trend to use state-of-the-art wind turbines in order to add time to the service life of the farm This aspect requires a service platform that is also always at the edge of technology. Therefore, it is correct to say that none of the Brazilian ports is completely ready for immediate full operation, due to the lack of history of offshore wind farms. The unprecedented installation of equipment for offshore wind energy in Brazil indicates that all ports will be subject to adaptations, on a smaller or larger scale. The lack of certain resource should not be understood as a technological delay of the Brazilian ports. This study does not intend to reject or point out the optimum port, but to help in decision making.

In this context, the purpose of the technical note about opportunities and planning for port infrastructure and logistics was to assess the main issues related to installation ports for the offshore wind energy industry, focusing on the characteristics that could make a port viable or unfeasible for this purpose.

The study used as a methodology the choice of a reference installation port for the movement of assets characteristic of an offshore wind energy plant and service to the vessels involved in the implementation and operation phases of the farms. Two standards were used for the offers of each port considered as “Recommended” or “Acceptable” to make the inclusion or exclusion of the Brazilian port according to its aptitude for the new demand. In addition, an assessment of the location of the ports, considering the intended plans, was made to increase the offer of the logistics platform to serve smaller vessels that require speed in the provision of their services, releasing the installation ports. Offshore wind power plants were segregated into clusters, according to regions (Figure 1) for more adequate assessment of the locational aspects, and the methodology used identified in which aspect the Brazilian ports have to be improved and whether they can be improved.

Figure 1: Concentrations of the Offshore Wind Energy in Brazil

Source: Own elaboration with data from IBAMA on the geographical basis of Google Earth (IBAMA, 2022)

This study does not recommend the construction of new ports, no matter how specialized they may be announced. The Brazilian coast of continental dimensions can be said to be privileged in the distribution of port facilities and terminals according to their current specializations. There is at least one port per state and a good number of thriving industrial and port complexes distributed across the country's political regions. Not by chance, such complexes coincide with the concentration of Brazilian offshore wind farms. The set of Brazilian port infrastructure, with the appropriate additional training, is sufficient to meet port demand more quickly and at a lower cost.

Bigger or smaller adaptations will be necessary in the existing ports; however, without allocating high resources in a single point, given that the destination of the loads is not also in a single point of the coast.

The study showed the existence of a port and logistics platform that should be used in a complementary way to existing ports to the detriment of building new ports for this purpose only. The set of Brazilian port supply is sufficient to meet the demand for installation of offshore wind farms, even more so with ports practically overlapping from a geographic point of view due to disturbance effect and in view of the peak moment of deployments and the number of turbines involved. Regardless of which Brazilian port the cargo and labor leave from, the important thing is that the volumes and teams are at the installation site at the required time in a harmonious way. Certainly, this will demand a managerial logistical and tax effort to meet the need, however, this will still have an infinitely lower cost for society than the investment in new ports.

In addition, the study pointed out the most suitable port for each Brazilian region, based on the intentions of implantations manifested, in the sense of subsidizing the capacity building of the infrastructure, and in terms of obtaining results in a shorter time.

The most demanded port characteristics refer to the increase in the load capacity of the mooring piers, increase in the supply of storage area adjacent to the pier, as well as the training of soil resistance by geotechnical treatment.

In relation to port infrastructure, some demands can be met more quickly, such as storage areas, in terms of space, as long as there is an area for expansion or reuse. However, such available areas will need to have their geotechnical capacity assessed and mitigated. Certainly, this demand would be one of the lightest imposed on the port of installation and could be met without interfering with pre-existing activities.

More serious issues, such as reaching the bathymetry of the access channel or the mooring berths, require dredging to modify their capacity. A time-consuming, expensive process, with great environmental control and highly disruptive to current activities, which can lead to the non-feasibility of a port for the purposes desired here. Likewise, the increase in the dimensions of the the piers, especially for the ports that are now highly demanded, which, in addition to the demanding engineering work, would still have their operations disrupted during the additional construction phase.

Is the current intermodal transport logistics structure sufficient for the development of offshore wind in Brazil? What is the preferred transport mode?

The players that intend to participate in the offshore wind energy value chain in a more optimal way should seek greater proximity to ports as the main factor for their industrial location, as this is the nature of the offshore wind energy industry. It is important to take into account the evaluation of the region with the highest concentration of wind turbines as the region with the lowest logistical cost due to the distance from the plants. This criterion will make a big difference in the financial economy of the projects, as well as in the installation deadlines of the wind farms. In this context, it should be noted that almost half of the more than

12,000 wind turbines will be domiciled on the north coast of the northeast coast of Brazil (46%), more than one third in the extreme south of Brazil (35%) and less than one fifth on the east coast of southeast Brazil (19%), not considering overlaps.

This concentration (charge density) is an important technical factor used as a factor weighting method as a criterion for industrial location. It is important to take into account the origin of the cargo, whether from the industrial and port complex domains or from a distant factory. For support vessels, those that transport assembly and operation teams, a controlled dispersion of their starting points is recommended in order to provide a shorter route. This will bring logistical optimization with super positive consequences, such as agility in service, less staff time on board and more time dedicated to the service, greater connectivity with other modes of transport, mainly air, and all of this is reflected in the cost and time of implementation, operation and maintenance.

The railway mode in Brazil has disappeared, leaving only stretches for specialized cargo or very short stretches, limiting the reach of the rail network. Sections of the network were transformed into roads or invaded by other activities, causing significant discontinuity in the integration between the load centers. The greater probability of using the railway mode may be for the transfer of cargo to a storage area in the hinterland, the region outside the port walls, but which exists as a function thereof. With higher capacity for cargo transport, both in terms of volume and weight, the railroad becomes attractive for the growing scale of dimensions of the wind turbines.

Far from daring to evaluate the Brazilian road network, it is worth remembering that the country has an important onshore wind energy industry and this has found its roads. Assets are already transported by road within the wind energy supply chain and will continue to use these routes, including for the offshore market. From a constructive and operational point of view, roads are incompatible with the size of the new cargo under analysis and it is inconceivable that long stretches of roads will be built to enable the transport of products of increasing dimensions, such as a nacelle and other loads characteristic of the offshore wind . Cargoes with this profile should use cabotage for internal transport, which have a greater cargo capacity per ship than any other mode.

The final destination of the assets in the offshore environment, with the port as the preassembly center, points to cabotage as the preferred mode of transport, given the demands required by the dimensions and weights of the new cargo. This transport mode has the lowest fuel consumption per ton-kilometer transported, resulting in lower emission of pollutants for the benefit of the environment.

Are the current shipyards in Brazil capable of meeting the demand of the future offshore wind industry in Brazil?

Brazil is one of the largest offshore structures players in the world in the Oil & Gas market, with many services similar to offshore wind energy. There is a large fleet of vessels whose synergy deserves to be studied and taken advantage of, especially regarding the support vessels for the transport of teams and operation. It can even be said that the cost pattern is known, as it will be very close to that in the O&G sector. The shipyards in Brazil are also able to modernize existing vessels, for example upgrading supply vessels to add walk-to-work systems or new CTVs (Cargo Transfer Vessel) specializing in offshore wind energy.

The problem with naval supply is mainly in vessels specialized in the vertical assembly of wind turbines at the implementation site, jack-up type. These vessels currently serve the international market in the exact measure of the existing demand, without any idle capacity, obeying a planned and agreed schedule. The 176.5 GW of offshore wind supply promised to Brazil will have to supply its own future demand for vessels compatible with the future demand and will have to offer a fleet compatible with the magnitude of the enterprises. Mainly because there are 20 MW turbines among the installation intentions in Brazil, demanding a different profile from the existing offer in the world today.

III. Socio-environmental and economic benefits of the source

What is the return in terms of socio-environmental benefits and economic development for Brazil from investments in the offshore wind chain?

Offshore wind energy has shown to be an increasingly more feasible option for renewable energy generation around the world and is related to several socio-environmental and economic benefits. Among them, the fact that it is a renewable energy alternative, with low greenhouse gas emissions, stands out, which can help Brazil reach the zero carbon climate goals (U.S. DEPARTMENT OF ENERGY, 2022). This source also demands less resources and raw materials during its operation compared to other sources of electricity (AECOM, 2017). It can contribute to activities parallel to offshore wind activity, such as tourism and aquaculture (LAL et al., 2021; WEVER; KRAUSE; BUCK, 2015). In addition to bringing economic benefits, such as job creation during the installation, operation and maintenance of these projects, added to the effect of increased consumption as a result of all these activities (GWEC, 2021). Finally, as a result of the benefits already mentioned and depending on individual orientations of personal value, offshore wind energy can also generate personal well-being for the population (LANGE et al., 2010).

In this context, the purpose of the technical note about socio-environmental and economic benefits of the source was to assess the positive socio-economic and environmental impacts of offshore wind energy generation in the country, based on international experiences with offshore wind projects and national experiences with other electric energy sources.

Table 2 and Table 3 list the main benefits that can result from the implementation of an offshore wind power generation project, separating them into environmental and socioeconomic benefits, respectively. These benefits include direct and indirect benefits, which may come from preventing the expansion of other sources (for example, thermoelectric plants using fossil resources), or even from the implementation of offshore wind energy projects.. It should be noted that this list is not an exhaustive compilation of all expected effects, but a sampling of potential effects.

Table 2. Summary of the environmental benefits of the offshore wind energy

Topic		**Potential Environmental Benefits**
Water	Use of Water	There is no use of water in the operation (for example: dust control, boiler cooling, panel cleaning). Aquaculture in PEOs [1] contributes to reducing the water demand for freshwater aquaculture.
	Wastewater discharge	There is no discharge of thermal effluent or concentrated water.
	Flooded Areas	There are no impacts on ecosystems in flooded areas by means of construction of gas pipelines or other infrastructure.
Resources	Biological resources	Minimum fragmentation of habitat in the construction (for example, as it occurs when building access roads and pipeline corridors). Rigid *offshore* substrate in areas of uniform soft substrate. There is no change in the course of the rivers (as in hydroelectric plants). Increased biodiversity through the effect of artificial reefs.
	Cultural resources	Prior identification of submerged cultural, historical and archaeological heritage.
	Recreation and tourism	Tourists traveling to see PEOsi (sights). Incentive to visit museums. Promotion of environmental and technological education. Awareness of climate change. Attraction for the scenic beauty.
	Fishing	Increased recreational and commercial fishing due to the higher concentration of fish. Benefit for the fishing using equipment that would be used in the wind farm operation. Aquaculture in PEOs [1] contributes to food security.

[1] PEOs: *Offshore* Wind Farms

Source: Own elaboration.

Table 3. Summary of the social-environmental benefits of the offshore *wind energy*

Topic		Potential Environmental Benefits
Safety	Safety	Wind turbine structures can help navigation in low visibility situations. Increased energy security.
Geology	Soil	There is no removal of sediments from flow systems It does not use terrestrial soil or flood areas for energy production.
	Land use	Reduced need to condemn private property (except for power transmission).
Health Public	Solid waste	It does not generate ash (as the coal plants). There is no fuel waste (as in nuclear)
	Air Quality and Climate Change	Reduction or elimination of GHG emissions and pollutant emissions. No harmful effects on public health. Free of volatile organic compounds/nitrous oxides No particulate emissions (no particulate matter)
	Sound pollution	Isolation of the construction and operation noise as it is located far from houses and population centers.
Social	Local Population and Workers	Population directly affected during construction and work is small compared to other sources. Social projects can compensate and benefit the local population, mainly with education and infrastructure. Increased social well-being (recreation, food, health, infrastructure, etc.).
Economy	Job creation	Creation of direct and indirect jobs, considering the entire production chain. Creation of jobs in the manufacture and installation of PEOs (temporary jobs) Creation of long-term jobs for remote monitoring, inspections and repair services (permanent). Creation of more local expertise and resources, such as specialized vessels for *the offshore* wind industry. Increased activity in local trade & services. Increase in activities related to tourism (hotels, food, recreation).
	Income Generation	Expansion of the manufacturing capacity and the economic activity of the domestic supply chains. Increase in income due to the increase in jobs. Income generation by increasing the tourist activity.

Source: Own elaboration.

The environmental benefits may be associated with water use, wastewater discharges, wetlands, biological resources, cultural resources, recreation, tourism, fishing, security, soil, land use, solid waste, air quality, climate change, pollution sound and local population. The installation of an offshore wind farm, to the detriment of another energy source, already provides benefits in terms of avoided impacts, such as solid waste, liquid effluents and greenhouse gas emissions, which do not occur during the operation of the farms offshore wind, but are observed in fossil thermoelectric plants, for example.

The scenarios elaborated in the project with different penetrations of offshore wind in Brazil until 2050 resulted in an installed capacity interval between 15.5 GW and 28.5 GW. Thus, offshore wind has the potential to avoid 37 to 112 MtCO2 over the entire analyzed period, when compared to SIN emissions. Compared to the emissions from combined cycle gas thermoelectric plants, the avoided emissions are even higher in the period, between 160 and 480 MtCO2.

In addition, there is the creation of artificial reefs, increasing the biodiversity in the place, creating favorable environmental conditions for the development and reproduction of several species. It should be pointed out that for Brazil, it is important studies to be carried out considering the specificities of the local biota and fauna. Along the same lines, aquaculture can increase local biodiversity and benefit businesses on both sides. The aquaculture companies could use the turbine structures to secure their equipment and the energy necessary to operate the aquaculture farm could be purchased directly from the wind farm. It is important to highlight the need to evaluate and adapt some rules to make these activities feasible, for example the norms of the Brazilian Navy.

Another positively impacted activity is tourism, which can bring economic, educational and social benefits, as it impacts the creation of jobs, income, value added, production gains, in addition to promoting meetings and educational activities of an environmental and technological nature.

In relation to the economic benefits, job creation stands out, because when fully developed (according to the scenarios), offshore wind energy has the potential to generate between 72 and 163 thousand jobs in 2050. Furthermore, the renewable energy sector is characterized by a greater gender balance in relation to the energy sector as a whole. Brazil has the opportunity to contribute to increasing female representation in this growing segment, as diversity increases performance and competitiveness, contributing to the energy transition.

Finally, all the activities mentioned are directly and indirectly linked to social well-being, given that offshore wind farms offer different ecosystem services of different intensities for the local population and visitors.

It should be pointed out that offshore wind energy, as well as other electricity generation technologies, can also cause negative socio-environmental interference, which has to be analyzed in advance. Therefore, it is important the environmental assessment, planning and management stages to be carried out aiming to maximize the created benefits to the detriment of the negative impacts.

IV. Generation of jobs and scenarios

What is the return in terms of jobs to Brazil from investments in the offshore wind chain?

In addition to providing zero-carbon electricity in the operation, wind power has the ability to bring socio-economic benefits to the local communities. Large-scale offshore wind projects create a variety of sustainable jobs that require a variety of skills in the entire value chain of the sector (GWEC, 2020). In 2021, wind power created 1.4 million jobs, with predominance of onshore projects, but the offshore segment is gaining strength and can be based on knowledge and infrastructure in the offshore oil and gas sector (IRENA & ILO, 2022).

Socio-economic gains in terms of local income and job creation can be maximized by leveraging the existing economy in building domestic supply chain markets for the offshore wind industry. Education and training are crucial to building local supply chains (IRENA, 2018). To create a skilled workforce is essential. This requires balancing the demand and supply of skills, which requires close coordination among the industry, government, and education and training institutions to attract a broader and more diverse population of applicants for the future workforce (Figure 2**Error! Reference source not found.).**

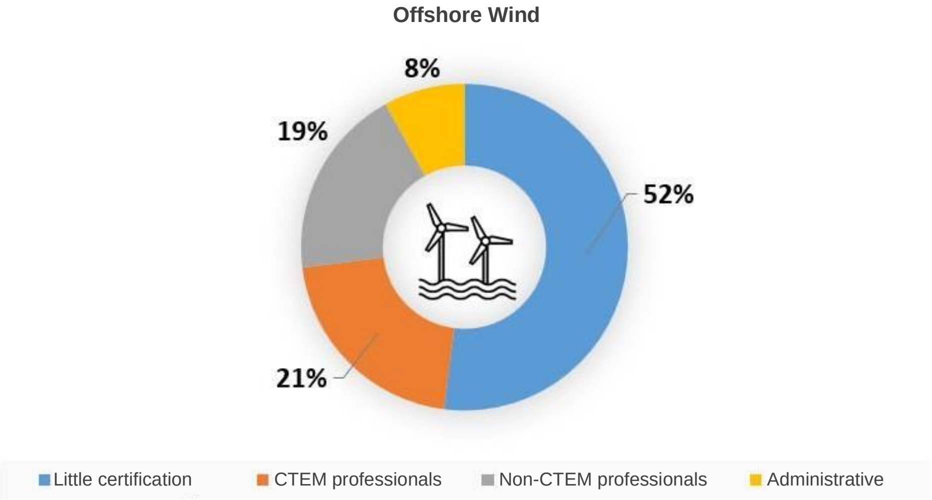

Figure 2. Human resource requirements for workers in solar PV, wind energy (onshore and offshore).

Source:(IRENA, ILO, 2021).

In this context, the purpose of this report was to analyze the potential impact of the offshore wind power in Brazil, in terms of job creation (direct and indirect). For this purpose, a methodology based on the analysis of the value chain throughout the life cycle of temporary and permanent activities was adopted. Thus, the study makes a balance of the multiplier effects of the investments made by the companies in the offshore wind sector, by means of the input-output matrix methodology, which shows how investment breaks down reaching other industries and impacting other services, creating direct and indirect jobs.

It was found that the offshore wind power offers a response to the disruptions in the job market arising from the energy transition, such as job displacement for offshore oil and gas and naval engineering workers (Figure 3). There are job opportunities for qualified labor to be employed by the oil and gas industry in the renewable sector as the offshore wind industry develops, as there are synergies along their value chains. Foundation design and manufacture, offshore construction and installation, vessel operation and underwater O&M are similar in the offshore wind and the oil and gas industry. In addition, the implementation of offshore wind power generation plants can be a vector for job creation at national, regional and local levels.

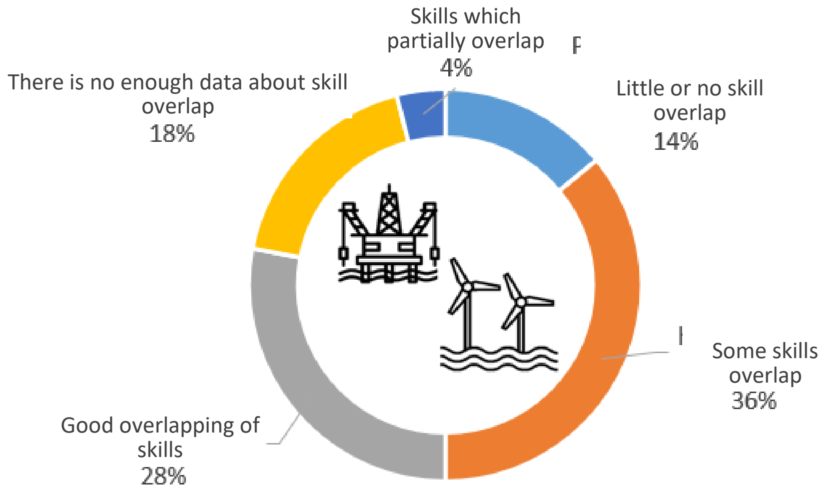

Figure 3. Ability to transfer skills from the offshore oil and gas industry to the offshore renewable.

Source: (EY, 2015, MUTTITT, MARKOVA, *et al.*, 2019).

The trend of job creation in the energy sector is shaped by several factors, the rate at which the renewable energy equipment is manufactured, installed and operated is highlighted. The cost trend for offshore wind, as well as solar and onshore wind, is to continue to decrease. With relatively stable annual investment, the lower costs translate into wider implementation, boosting the job creation.

The results derived from the input-output model highlight the relevant effects on the national job creation. Most of the jobs are triggered by temporary activities, which means that it depends on new installed capacities. Then, market or institutional instability can disrupt these economic benefits. A big part of temporary job creation is in the industrial sector (manufacturing of metal products), therefore, the created job is characterized by high work productivity.

The rates of job created by means of production of electricity by the sources can vary significantly between studies due to local, temporal and methodological aspects. There is a great variation in the values of the job indexes generated per MW installed from the data found in the literature. In this data, offshore wind creates average of 24 jobs per MW installed, this number is higher than for non-renewable sources, 5, 2 and 16 jobs/MW installed for coal, natural gas and nuclear, respectively (Figure 4) , due to longer design, construction, assembly and installation times. Therefore, each case must be analyzed separately, it is not possible to use indexes produced in other contexts to estimate job creation by a renewable energy technology in another period or location (SIMAS, PACCA, 2014). The value calculated by the present study for Brazil is contained within the range of variation in the literature. The results show that, on average, 11 to 34 jobs are created per MW every year, depending on the analyzed scenario. For the specific calculation of the value for Brazil, studies were necessary that include technological evolution curves, learning rates, level of nationalization and other factors necessary for a national base.

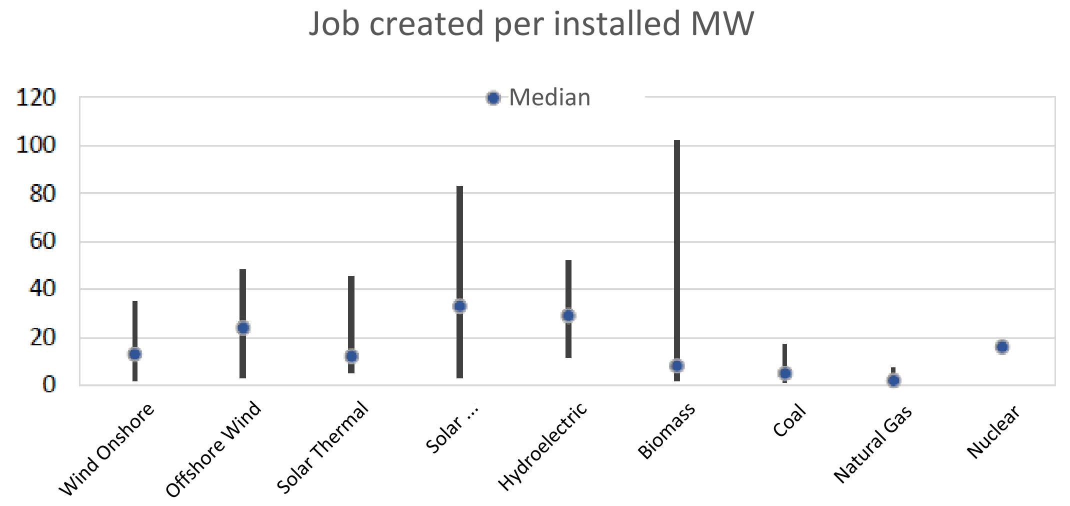

Figure 4. Job creation indexes per installed MW of different power generation technologies found in literature.. The blue dot is the median between the values found.

Source: Own elaboration based on (DALTON, G. J.; LEWIS, 2011, EWEA, 2008, GWEC, 2021, MORENO, B.; LÓPEZ, 2008, RUTOVITZ, J.; ATHERTON, 2009, SIMAS, PACCA, 2014, TOURKOLIAS, C.; MIRASGEDIS, 2011, UNEP/ILO/IOE/ITUC, 2008, WEI, M.; PATADIA, S.; KAMMEN, 2010).

The wind industry has to be prepared for the significant growth projected in the offshore wind market over the next three decades. The study provides potentially critical information about the capacity requirements in the labor market, and given the dynamics of the sector, it is essential to establish public policies to promote the offshore wind sector and its value chain in short and long terms.

V. Role of the source in relation to energy security and transition

What is energy transition? What is energy security?

The current energy transition is defined by changes in energy systems seeking sustainability, accessibility, value creation, security and lower environmental impacts (WEF, 2021). Its differential in relation to past energy transitions is that the recent energy transition is motivated by the fight against climate change, as highlighted by IPCC (2019) and IPCC (2021). Hence the importance of this transition being based on renewable energy sources.

Energy security and energy access is about assurance of universal access to safe and reliable energy (WEF, 2021). The International Energy Agency complements this definition by adding that energy security is the uninterrupted availability of energy resources at affordable prices (IEA, 2022).

What are the roles of the offshore wind in relation to energy security and energy transition in the Brazilian context?

The technical note highlighted three possible roles for offshore wind:

1. ***Input for the production of green hydrogen (H2):***

Offshore wind can serve as an input for the production of green hydrogen through the electrolysis of water, an intensive activity in the consumption of electricity. Renewable and carbon-free hydrogen will play three fundamental roles in the energy transition (MME/EPE, 2022): (i) decarbonize segments of emissions hard to abate, such as the heavy long-haul transport sector (trucks, trains and vessels), the air sector and industry (fertilizers, steel and cement), (ii) facilitate energy storage of variable renewable sources such as wind and solar, and (iii) enable coupling among the sectors: electric, transport and industrial.

Offshore wind is a renewable source, which enables several end uses of energy, not only electricity, but also the production of green hydrogen and renewable ammonia. Offshore renewable resources stand out with enormous technical potential for hydrogen production. The global demand for green hydrogen places Brazil in the spotlight as a potential international supplier, given the local wealth of renewable resources and consequent generation competitiveness (MME/EPE, 2022). The technical potential of the offshore wind resource in Brazil for H2 generation is 350.4 Mt/year total, as shown in Table 4 (MME/EPE, 2022).

Table 4. Details of the technical potential for hydrogen production from offshore wind resources

Offshore Renewable Energy Source	Hydrogen Potential Mt/year
Offshore wind – 10 km dist.	11.2
Offshore wind – 50 km (exc. 10 km dist)	39.8
Offshore wind – 100 km (exc. 50 km dist)	50.2
Offshore wind – ZEE (exc. 100 km dist)	249.2
Total	350.4

Source: Adapted from (MME/EPE, 2022)

In addition to analyzing the total resource, it is indispensable to analyze the wind availability for H2 production. Figure 5 shows the complementarity between the offshore wind resource 100 km off the coast of the Northeast and the load in the Northeast and Brazil, showing that there may be moments of possible curtailment, if the offshore wind source is used directly to supply the load.

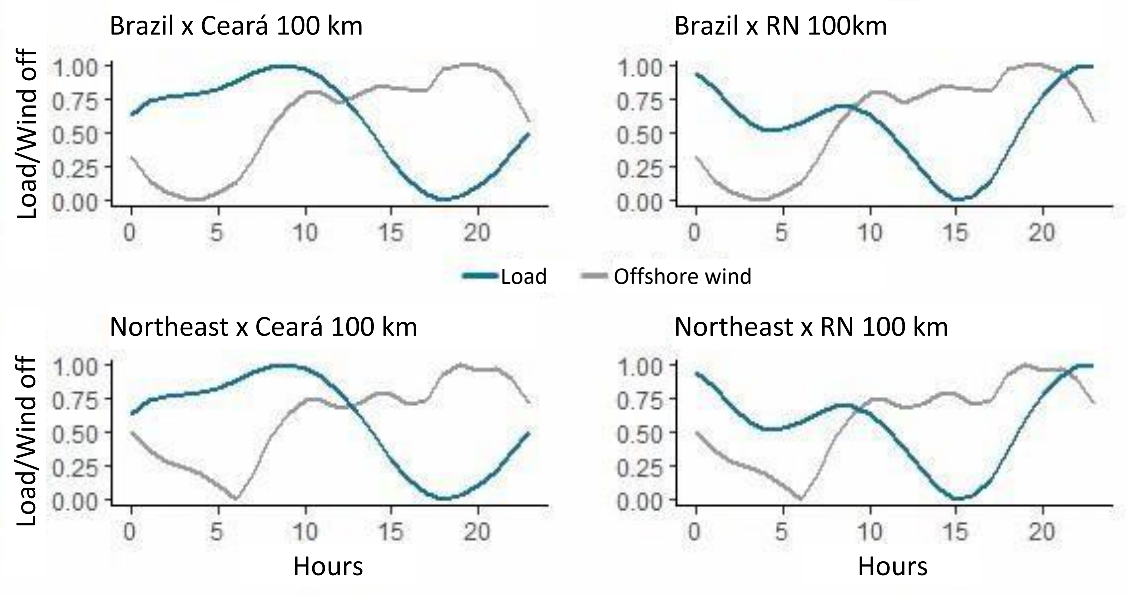

Figure 5. Hourly complementarity panel between load and the offshore wind on a typical day. The gray line represents the load and the blue one, the offshore wind (a) Load of Brazil and offshore wind in Ceará (b) Load of Brazil and offshore wind in Rio Grande do Norte (c) Load of the Northeast region and offshore wind in Ceará (d)) Load of the Northeast region and offshore wind in Rio Grande do Norte. Source: Own elaboration.

The complementary curves indicate the possibility of using offshore energy for other uses, in addition to serving the load of the National Interconnected System (SIN). Among them, the production of green hydrogen stands out.

2. *Reduction of greenhouse gas emissions:*

Offshore wind generation can provide reduction in greenhouse gas emissions both in the planning of the expansion and operation of the electrical systems and in the oil and gas sector. When integrated into SIN, offshore wind displaces generation of plants powered by fossil sources, reducing the emission factor of the electrical system. Additionally, they can contribute to reducing the emissions on oil E&P platforms, which require high volume of electricity in their processes. Electricity can be generated from offshore wind, which means an electricity transformation unit close to these load centers, reducing transmission costs. Therefore, the installation of offshore wind turbines can represent a measure to mitigate greenhouse gases for the oil and gas sector.

3. *Complementarity with other energy sources:*

Offshore wind, in the Northeast and Southeast regions, complements the water resources of Brazil as a whole, synergies with oil and is close to the largest consumer center. The use of complementary energy resources has the potential to improve the quality of the supplied energy, as less irregularity is expected in the generation curve of the system. The seasonal complementarity is illustrated in Figure 6 for the Northeast and Southeast regions.

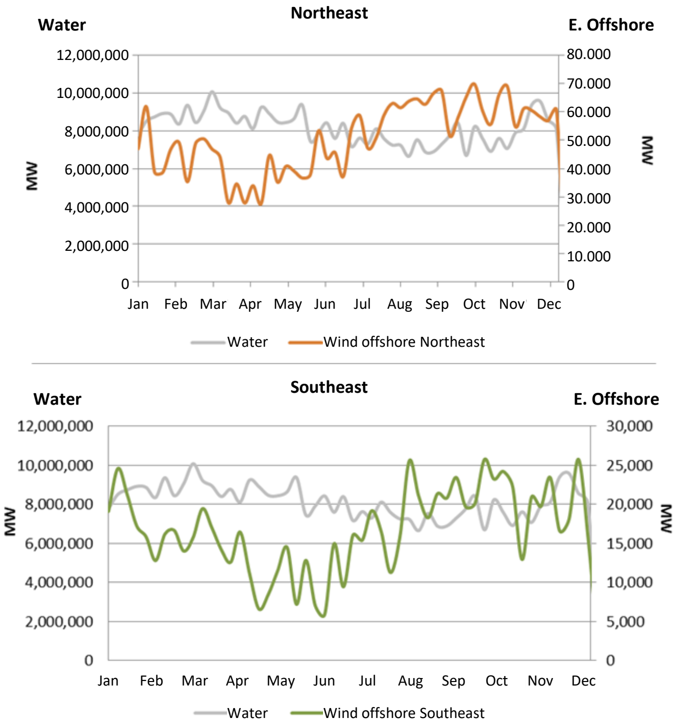

Figure 6. Complementarity between hydroelectric generation and simulated offshore wind generation in Brazil for a typical year (2013).

Source: (NOGUEIRA, 2020)

What is necessary for the energy transition to be effective?

For the energy transition to be effective, the countries must have energy security, which involves uninterrupted availability of energy resources at affordable prices. Brazil has a privileged position in terms of security and decarbonization, with significant competitive advantage due to the high share of renewable in its energy matrix, the storage of hydroelectric reservoirs and the fossil resources that complement the renewable.

One of the challenges of the country is to manage the abundance and the diversity of energy resources with low greenhouse gas emissions, which are competitive and present spatial and temporal complementarity. The diversification of the matrix can be the basis of the search for energy security in Brazil. Offshore wind production is a technology that stands out in this context of energy transition because it presents several possibilities for contribution.

Finally, Brazil can lead and become an example of a low-carbon economy in the world. The country can offer low-carbon and low-cost alternatives. An important additional role for Brazil is in potentially helping countries to achieve their climate neutrality goals in a more affordable way.

VI. Cost Forecast, LCOE and Technological Feasibility

What is Levelized Cost of Electricity (LCOE)?

LCOE consists of the ratio between the estimated costs and the estimated generation of the plant over its service life (SHORT, PACKEY, et al., 1995). In other words, LCOE can be taken as a theoretical electricity sales price. On these bases, it consists of an important tool for comparison of the economic attractiveness of different sources of electric power generation (MARTINEZ and IGLESIAS, 2022).

What are the prospects for the evolution of the levelized cost of offshore wind in Brazil?

The technical note on cost projection, LCOE and technological feasibility calculated LCOE for offshore wind projects in Brazil of 332.76 R$/MWh. In the most direct comparison with other renewable technologies, the current LCOE of offshore wind projects is still not competitive, as the other sources tend to have LCOE below 250 R$/MWh. For onshore wind farms and photovoltaic projects, typical LCOE are less than 150 R$/MWh. Only biomass projects, especially biogas, can present LCOE close to the current value of 332.76 R$/MWh of offshore wind projects. When comparing with non-renewable sources, it can be noted that offshore wind projects are already competitive compared to nuclear energy.

However, as with incoming technologies, it is expected that the technology's maturity gain will generate a learning curve, so that the investment cost will decrease as greater offshore wind capacities are included in the Brazilian electricity sector.

The evolution estimates of LCOE calculation parameters, including investment costs, operating costs and others, were based on two scenarios: “To Navigate is Necessary” and “Blue Sea”. Their full descriptions are presented in the technical note. In a few words, “To Navigate is Necessary” indicates more modest reductions in investment and operating costs compared to “Blue Sea”, which presents greater reductions. Figure 7 brings the leveled cost projections of offshore wind for both scenarios.

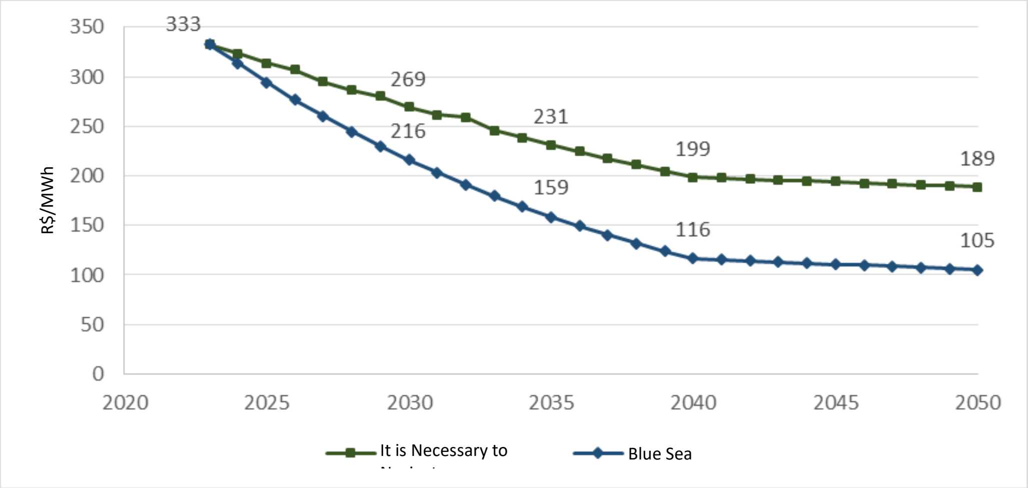

Figure 7. Evolution of LCOE of the offshore wind offshore in two scenarios.

Source: Own elaboration.

It should be noted that, in the scenario “To Navigate is Necessary”, LCOE close to 250 R$/MWh of offshore wind technology, in the early 2030s, would make it competitive in relation to small hydroelectric power plants and with some solar photovoltaic projects , especially when it comes to floating photovoltaic technology. This competitiveness will increase along the 2030s and 2040s, as the costs of offshore wind projects decrease and reach LCOE of around 200 R$/MWh.

In scenario “Blue Sea”, LCOE of less than 160 R$/MWh, already in 2035, makes offshore wind technology competitive when compared to other sources, including onshore wind projects. The gains of competitiveness continue over the years, and in the 2040s,, the offshore projects would be an extremely competitive alternative. At the end of the period, LCOE of 105 R$/MWh would make offshore wind projects competitive even with onshore wind projects.

Although international data on the costs of offshore wind technology is important reference, it is necessary to consider the presence of local specificities and characteristics that tend to considerably influence the costs and economic attractiveness of national projects. LCOE projections presented in the technical note on leveled costs show that there is significant room for this technology to become competitive as its market develops.

Which aspects are not captured by LCOE calculation?

There are other relevant aspects that impact the feasibility of the offshore wind source and that are not considered in LCOE calculations, such as positive externalities arising from the reduction of emissions, integration with the green hydrogen industry, less visual impact of the source, complementarity with other sources and contribution to energy security. In addition, risks intrinsic to each technology, regulatory guidelines, commercial frameworks, the tax framework and the associated tax burden and charges can also impact the viability of electricity generation plants and are not covered by LCOE calculation.

VII. Status of technological innovations in the sector

What is the role of the innovations in the development of offshore wind farms and how was this addressed in the study?

The offshore wind market is one of the fastest growing and evolving in the world. This statement becomes clear when analyzing not only the increase in installed capacity, but also the innovations that have emerged and have been implemented since the installation of the first farm, in 1991. Among the main progress achieved, the cost reduction, the technology progress, increased efficiency in the supply chain, creation of new markets, among other factors stand out, which together form a capacitative and promising market. Considering the technical evolutions, we highlight the increase in the distance of the farms from the coast and the depth of installation, which demands more resistant foundations, the installation of turbines with higher rated power and larger size, and the adoption of new technologies in the turbines (MUSIAL, 2021).

The progress of offshore wind energy involves several aspects that correlate in a complex way, such as turbine characteristics (turbine size, hub height, rotor diameter), distance from shore, water depth, creation and adoption of standards, development of patents, among others. In summary, it is the interconnection of three spheres that lead to this progress: innovation ecosystem; technology; and market formation.

Innovation takes place in a cyclic, and at the same time continuous, process of feedback between different stages, providing information on gaps and opportunities. This cycle contributes to the accumulation of knowledge, strengthening the collaboration among different actors, reducing installation costs and LCOE, reducing technological risk, increasing technological maturity, and consequently, increasing the installed capacity (IRENA, 2021).

Figure summarizes how innovation can contribute to the evolution of the offshore wind sector and how these different aspects correlate.

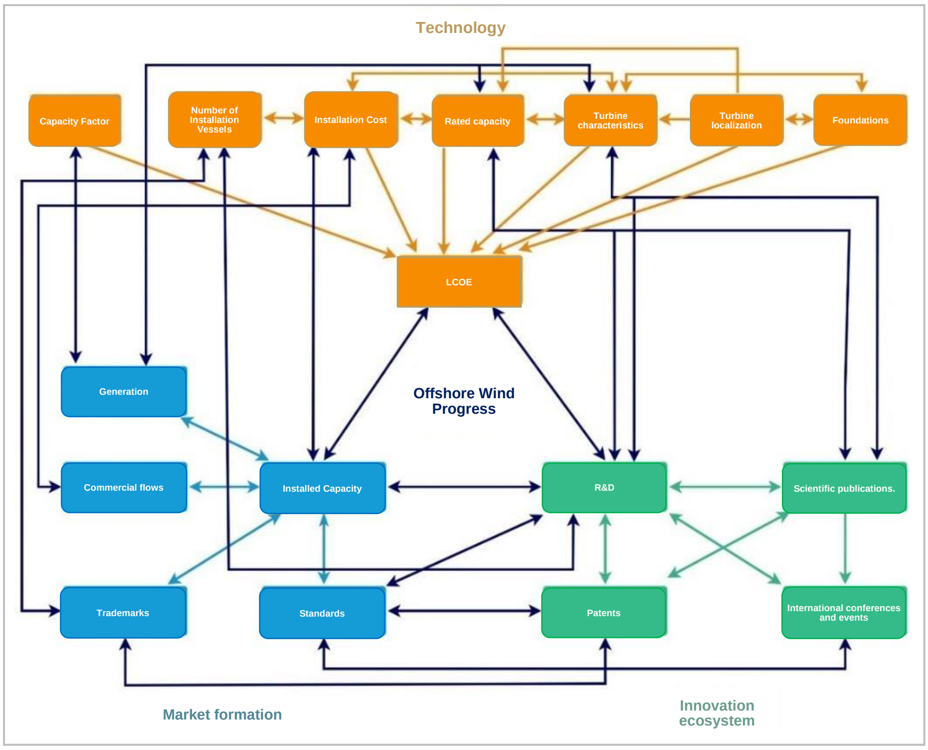

Figure 8: Aspects related to the progress of the offshore wind power and its interconnections

Source: Adapted from IRENA, 2021.

Technical note "Status of the sector technological innovations" aimed to describe the evolution of offshore wind farms installed around the world, identify the potential and techniques that are being considered for the development of this technology in Brazil and describe some of the main innovations under development and in application in the world.

What are the main innovations identified?

Despite the progress, the sector needs to continue innovating in order to take advantage of the wind potential in deeper waters, improve its processes and reduce the costs. Considering that, a review of the main innovations related to the following topics was made: (i) previous planning stages; (ii) turbines; (iii) foundations; (iv) electrical infrastructure;
(v) operation and maintenance and (vi) port infrastructure.

Within the scope of the prior planning stages, solutions focused on computer forecast analysis and analysis of meteoceanographic and environmental data stand out, in addition to programs capable of designing future offshore wind farms, aiming at adoption of the most cost-effective solutions possible. The innovations aimed at the wind turbines are mostly focused on creating more powerful turbines, aiming at expanding the generation capacity at the lowest cost. For this purpose, innovations have emerged aimed at methodologies for optimization of the turbine manufacture. In addition, there is increasing concern about the types of materials used in the manufacturer and their recycling capacity.

In relation to the foundations of the wind turbines, the innovations aim to increase the structural safety, essential for the installation of increasingly larger and heavier wind turbines and for the wind farms to be installed in deeper areas and farther from the coast. Initially, there is movement in the development of foundations of the monopile and jacket type capable of withstanding greater efforts, but the future trend is the expansion of the use of floating foundations. This can be explained by the fact that the sector is looking for lighter structures and easier to transport and install, reducing the costs of production, implementation and operation of the wind farms.

Regarding the electrical infrastructure, the innovations related to cable and substation technologies stand out. Regarding the cables used, important innovation that will result in lower costs and more efficient systems is the use of LFAC technology, which enables reduction of losses and costs for more distant farms: between 60 and 80 km to 200 km. Still about cables, a necessary solution for the farms which will adopt floating structures is the dynamic cable. These cables have excellent mechanical strength, proving to be adequate to withstand conditions, such as the movement of floating platforms, large tensile loads due to water depths and significant hydrodynamic stresses generated by waves and currents. Finally, the progress in studies on floating substations stands out as the most cost-effective solution for offshore wind farms at greater depths.

The innovations associated with the operation and maintenance activities of PEOs are generally related to the areas of automation, digitization of procedures, artificial intelligence and other solutions linked to information technology. The use of these technologies enables quick and accurate identification of problems, which can be done virtually, increasing the employee safety, by reducing the trips to the farm area, in addition to reducing the costs. Regarding the port infrastructure, most of the innovations are aimed at increasing the efficiency and optimizing logistics. Due to the magnitude of the offshore wind farms and their components, both in terms of size, weight and volume of movements, any innovations that contribute to improving the logistics result in significant cost reductions, whether in the installation or in the operation and maintenance phase. In this context, within the scope of ports, the creation of specific terminals for offshore wind projects or use of technologies belonging to industry 4.0 is mentioned.

On the other hand, the specific vessels, which reduce the installation or maintenance time of the farms, resulting in reductions in both CAPEX and OPEX of the farms, stand out. As for ports, 4.0 technologies will also serve for process optimization purposes. Finally, it is worth pointing out the role the incremental innovations will have on the offshore wind industry. As it is a new industry, without complete specific infrastructure for its activities or with limited availability, adaptations in vessels from other sectors, such as oil and gas, will serve to boost the offshore wind industry until it is mature for have all its specific logistics developed.

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Table 5 summarizes the main innovations identified divided into the categories of: (i) previous planning stages; (ii) turbines; (iii) foundations; (iv) electrical infrastructure; (v) operation and maintenance and (vi) port infrastructure.

Table 5: Main innovations identified by category.

Prior planning stages	Coupled Computer Modeling
	LIDAR in floating structure
	Estimation of wind potential with SAR data
	GIS-SPOWER-BR Toolbox
	Computational fluid dynamics to minimize the turbine wake effects
	Strategic Plan for Energy Technologies
Turbines	Bigger and more powerful turbines
	Recyclable turbines
	Sweep Twist Adaptive Rotor (STAR)
	3D production of turbine molds
	Black color on one blade to reduce bird mortality
Foundations	“Extra-Large” Monopile
	Floating foundations
	Versatile and adaptable foundations
	PivotBuoy
	Foundations as a coral nursery
Electrical infrastructure	More cost-effective technologies for transport of power to the coast in wind farms over longer distances: AC; DC; and LFAC;
	Solution for scale and corrosion for cooling systems (Chloropac)
	Cable insulation with XLPE technology
	Floating substations
	Dynamic cables for wind turbines with floating structures
	Inclusion of fiber optics
	OrcaFlex Dynamic Analysis Software
Operation and maintenance	Digitization for generation follow-up and monitoring
	Remote and automated asset inspection
	Artificial intelligence to monitor species
	Different strategies for external or on-site turbine repairs
Port infrastructure and vessels	Management and coordination for optimization of the port logistics
	Creation of specific terminals dedicated to the wind industry *offshore*
	Application of industry 4.0 solutions in the port infrastructure
	De-carbonization and creation of collaborative networks between ports and wind players
	Dedicated vessels to keep up with the technological progress and the size of the turbines
	X-BOW System
	Use of modern WTIVs to reduce costs in the installation and commissioning phase.
	Industry 4.0 on the vessels
	Incremental innovations

Source: Own elaboration.

VIII. Regulatory status overview

What are the main regulatory mechanisms in force and under discussion in Brazil for offshore wind?

Recently, Brazil has taken important steps for the offshore wind power to be included in its matrix. With the purpose to provide subsidy to entrepreneurs and competent government bodies, this technical note about the regulatory status overview aimed to evaluate the legal and regulatory standards that are being designed and implemented in the country and to bring experiences from other countries, in order to assess the advantages and disadvantages of adopting the numerous rules associated with offshore wind projects.

In 2020, EPE launched Roadmap Eólica Offshore Brasil, whose main purpose was to identify barriers and challenges to be faced for the implementation of the offshore wind power in Brazil (EPE, 2020b). In the same year, IBAMA launched the Term of Reference linked to offshore wind complexes, whose objective was to determine guidelines and general technical criteria that should support the preparation of EIA and Rima, in order to subsidize the environmental licensing process.

In Brazil, until 2021, the offshore wind power projects faced a regulatory obstacle for their implementation, as it was impossible to obtain a grant due to the lack of definition of criteria for the use of offshore areas. The first step to overcome this obstacle was taken upon issuance of Decree 10,946/2022, which provides about the grant to use physical spaces and use of natural resources in inland waters under the domain of the Federation for the generation of offshore wind power. Thus Decree sets the most general rules for the regulatory organization of the offshore wind power in Brazil.

As provided for in the decree itself, this was complemented by the publication of norms, a movement that took place with the publication of Normative Ordinance nº 52/GM/MME and Inter-Ministry Ordinance MME / MMA nº 3, both in October 2022. It should be pointed out; however, that in the regulatory framework for offshore wind power, there is still lack of some additional specific regulations, which must be edited and published by July 023.

In parallel to the publication of Decree 10.946/2022, there are currently three Law Bills (PL) in progress that also intend to format the regulation of the offshore wind farm exploration in the national territory: i) Bill No. 576/2021, author Senator Jean Paul Prates; ii) Bill No. 11,247/2018 (originally PLS No. 484/2017), by Senator Fernando Collor; and iii) Bill No. 3,655/2021, by congressman Danilo Forte.

Figure 9 compiles in a timeline the main normative, technical and regulatory milestones that occurred in the offshore wind sector in Brazil.

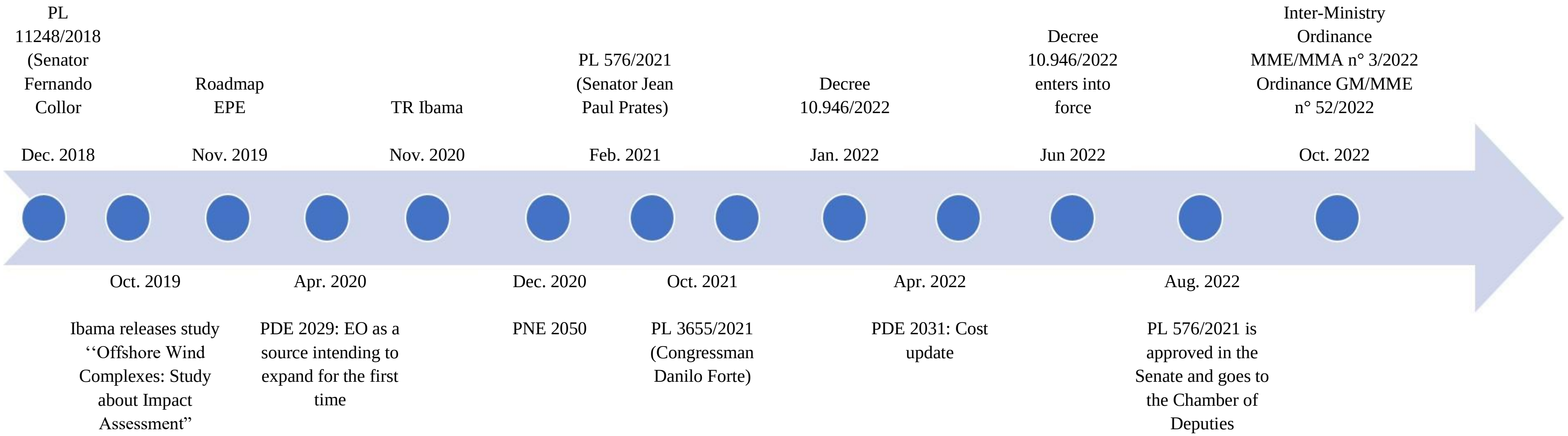

Figure 9: Timeline of normative, technical and regulatory breakdown of the offshore wind power in Brazil

Source: Own elaboration.

Regulation of the offshore wind farms in Brazil: by bill of law or decree?

Unlike the traditional chain of Brazilian legislation, which is constituted from the publication of the law, followed by the decree and the ordinance, the regulatory framework for offshore wind energy in Brazil began with the publication of Decree No. 10,946/2022. This choice was made in order to bring speed to the process in order to provide the normative basis for agents and the market to start investing in the sector, promoting the beginning of the development of offshore wind power and its supply value chain in Brazil.

The main risk associated with the path chosen is the possibility of conflicts between the decree and its complementary norms and a potential future law that should be enacted after the completion of the processing of the bills. In this context, it is very important that the bills move in a direction that allows the area grants and grants granted on a date prior to the publication of the law to be preserved, so that these bills do not need to start a new grant and grant process. when the new law is published.

In accordance with what was established by Decree No. 10,946/2022 and its ordinances, the contract for the grant of use for an offshore area can take place for the exploitation of an electric power generation plant, by means of an onerous grant, or for the realization of RD&I activities, which will be assigned free of charge. This is a relevant decision, as it will encourage the development of RD&I projects for offshore wind generation, contributing decisively to the beginning of the development of the complex industry and value chain of the source in Brazil.

The note concluded that the path chosen for the establishment of the regulatory framework by publication of a decree was the right choice, as it is faster and more flexible. Naturally, the bills in progress may create a new law, which will bring even more legal and regulatory security to the sector and the entrepreneurs. However, the regulatory basis provided through the decree and its complementary ordinances were already sufficient to bring confidence and adequate signaling to agents.

How is the grant of use of physical spaces and the use of natural resources to generate offshore wind energy provided?

There are two paths to follow: the planned grant model, which consists of offering prisms previously defined by MME to interested parties; and the independent assignment model, which consists of the assignment of prisms required on the initiative of those interested in exploring them. Both paths foresee the occurrence of a bidding process to ensure competition of the areas to be assigned. However, a mandatory stage is the collection of the Prior Interference Statements, which consist of several standardized declarations requested from the different bodies and institutions potentially affected by an area grant.

To facilitate this process, the creation of the Single Offshore Management Portal was planned, an important tool within the regulatory framework, as it enables the introduction of a kind of one-stop-shop for the sector. International experience shows the importance of establishing a single portal, its main benefits being the reduction in the number of bodies involved in the processing of processes in offshore areas, the reduction of costs and regulatory uncertainty and the increase in predictability of processes and transparency. Although the responsibilities for carrying out the activities of the Single Management Portal are clear in the ordinance, the origin of the budget and the institution responsible for its construction are not clear.

Is the regulatory framework designed today for offshore wind sufficiently detailed for the full development of the source in Brazil?

Despite providing the regulatory basis for the beginning of the development of the offshore wind sector, the publications of the decree and complementary ordinances still lack some relevant definitions, which need to be disciplined quickly to provide the necessary security to the nascent offshore wind industry.

A first point is the definition of the methodology for calculating the value for the use of the public asset. This methodology is important, because it will serve as a guideline for the bidding processes, and should provide a fair value for the grant, in which the offshore wind projects are not excessively burdened, without to higher penalties for the potential gains of the Federation.

It should be noted that a possible path would be the definition of this methodology via an infra-legal path, considering that this would bring flexibility of adjustment and calibration over time. It should be noted that this matter will be dealt with by specific MME ordinance with maximum deadline July 30, 2023.

Another aspect that needs legal treatment is the maximum area granted in the same contract. This issue is already present in the wording of the acts, but without presenting the specific rule. The maximum limit of area granted by contract or company is a practice commonly used in other jurisdictions and sectors, and serves mainly to avoid speculative practices, in addition to stimulating competition and the diversity of agents in the sector. The international experience reveals that there are restrictions in terms of area extension limits, power limits, farm energy density limits, or even limits on the number of areas assigned to each company in the same bidding process.

As Brazil is a country with a large coastline, an area limitation would probably not be related to the scarcity of areas, but rather to the interest in promoting an offshore wind sector with a diversity of actors and ensuring the efficient energy use of the granted areas. Furthermore, limiting the size of the areas reduces the impact of an eventual situation in which an area is granted to an entrepreneur who decides not to carry out the development of the project. Limitations and restrictions, based on well-designed criteria, can bring efficiency to projects and foster diversity and competition in the sector, which is beneficial to the entire offshore wind industry.

What is the methodology defined for the selection and judgment criteria for the area granting process?

As presented by the decree and by the ordinances, the criterion for judging the bid will be the highest economic return for the grant of the prism. However, it should be noted that this is yet another point that needs further detail, as it is not yet clear which aspects will be considered in this analysis. For example, it is possible to consider positive externalities, such as impacts on the main sectors of the value chain, on the creation of jobs and income, socio-environmental impacts, as well as the consideration of the values offered by the use of the area.

Within the procedural flow, the normative acts provide that the bidding documents for the grant of use of the areas must present the technical, operational, economic-financial and legal credentials, by the interested parties, in order to ensure the feasibility and effectiveness installation, operation and decommissioning of facilities. This is an extremely relevant point, as they are the necessary requirements that enable the interested parties to compete for the area in question. However, the wording of the acts has not yet presented a specification regarding these credentials.

International experience reveals the existence of two main aspects in relation to this selection methodology and judgment criteria for the area granting process: pure competition and multi-criteria competition. The main criterion of the pure competition process is the price variable, so that the chosen developer is the one that offers the highest payment bid for the grant of the area. Multi-criteria competition takes into account a set of factors, which can be financial, technical, environmental, social, etc., resulting in a scoring system. The winner is generally the one with the highest score.

The adoption of the highest value criterion offered by the area makes the competitive process simpler, more objective and clearer, with less chance of error or subsequent judicialization. In this case, a traditional tender model can be used, which is already widely known and applied not only in Brazil, but in several other jurisdictions. In addition, it has the potential to generate more revenue for the owner of the area, in general the Federation, which can bring benefits to the region where the offshore wind farms are installed and to society.

On the other hand, choosing the highest value offered criterion may lead to disregard of a more holistic analysis regarding the advantages of each of the proposals, which would consider not only economic effects, but also socio-environmental ones. The dispute over who pays the most can make the source even less competitive and make the product (electricity, hydrogen) more expensive, whether for the captive consumer or on the free market. Thus, due to the potential to lead to higher prices, this model may end up favoring larger companies with greater financial strength, and not necessarily the best entrepreneur, who could explore the area in the best way and with the best overall return.

Multi-criteria competition, on the other hand, takes into account attributes other than just finance, giving weight to other potential positive externalities, such as a greater guarantee of success in the construction techniques adopted, the quality of the environmental studies carried out, the number of local jobs generated, the use of components with local content, the application of socio-environmental programs for the region and local communities, among others. If combined with the adoption of a price cap, it can lead to a reduction in the value of the final product (electricity, hydrogen).

However, depending on the criteria adopted, especially in case of criteria of a more subjective nature, there is a risk of inaccurate assessments, giving rise to judicialization and contestation, given that the criteria are often based on qualitative attributes. Thus, for it to be an effective model, very well-defined criteria must be established a priori, including their application and scoring rules.

In case of choosing a higher price criterion, there is also the possibility of establishing a price cap. In this modality, bids are given until a stipulated maximum value is reached. In this case, another criterion must be used to evaluate the winning entrepreneur in case of a tie in the price cap. This artifice aims at attributing greater financial security to the projects and greater security for the cost of energy in the future, when operating the wind farm. In this way, there is a combination of pure and multi-criteria competition criteria. Therefore, transparency and assertiveness are necessary, that is, the criteria must be objective, easily calculated and comparable.

It is important that the rules associated with any type of competition are specified in advance, generating greater legal certainty. On the other hand, it is important to have flexibility to update these rules, so that lessons learned from the development of the sector in the country can be incorporated. Considering the possibility of flexibility, a solution that could be applied is the choice of a model that encourages the development of the offshore wind source through a lower payment for the use of the Use of the public asset, at first, with a subsequent readjustment to a methodology that benefits the collection of the Federation in a second moment, when the industry and the value chain are more consolidated.

IX. Demand and supply of components and materials

What are the main components and materials of an offshore wind farm and how were they analyzed in this study?

The hostile environment of the offshore zone with turbulent weather, high waves, currents, high wind speeds and its (ir)regularity, in addition to a framework of promising energy potential, are structural challenges that need to be faced and overcome. The success of this industry is largely dependent on highly durable structures capable of surviving the hostile conditions imposed on it. Whether optimally sized or not, there is only one way for structures to resist active efforts and the increase in generation capacity: the intensive use of materials.

The construction of offshore wind farms creates intensive demand for steel, the most used material in its construction. Other wind turbine components, such as electrical, electronic and magnetic components (such as nacelles, rotors, generators, gearboxes and cables) create significant demand for critical minerals including copper, nickel, zinc, rare earth, such as neodymium and dysprosium for permanent magnet turbines, chromium and cobalt. In the construction of the blades, the primary materials are marine plywood, glass fibers and epoxy resins, in addition to more sustainable alternatives, such as polyethylene terephthalate (PET) and pultruded carbon fibers (IEA, 2022b).

In this study on the demand and supply of components and materials, a detailed survey of the value chain was made. The studied sections took a holistic view of the Brazilian offshore wind energy supply chain to identify the main anticipated gaps. For this purpose, a description of the wind turbine components was elaborated, including the subcomponents, subsets and materials necessary for an offshore wind energy project, using the construction of hierarchy maps according to the study by Shields et al. (2022). Then, the present availability of the domestic supply chain to supply the necessary subassemblies for the manufacture of national wind components was evaluated. The components analyzed in the hierarchy maps were: Wind turbines; Monopile foundations; Monopile transition pieces; Jacket bases; Gravity-based foundations; Floating semi-submersible platform; Mooring system; Cables; Offshore substations; and Power grid on land.

In addition, offshore wind energy development scenarios in Brazil and the consequent demand for materials associated with these scenarios were presented. Finally, we also present the state of the art of the industries that will suffer the greatest increase in demand in the coming years, based on these scenarios.

It is important to point out that in addition to the bibliographical research, this study also included conducting interviews with specialists in specific subjects related to the demand for components and materials. These interviews provided important insight into component-related details, the manufacturing process, and logistical considerations.

Is the Brazilian industry ready for the development of offshore wind farms?

Due to the remote nature of offshore wind farms, there is a trend to use increasingly more state-of-the-art wind turbines, in order to add time to the service life of the farm with greater electricity generation. This aspect will require an input platform that is also always state-of-the-art technology. Therefore, it is correct to say that none of the Brazilian industries is complete for these activities due to the lack of history of offshore plants.

Certainly, existing suppliers to other industries, such as onshore wind energy, aerospace, oil and gas, shipbuilding or even civil construction, could leverage their existing capabilities to develop such components and begin to transfer manufacturing expertise and workforce. for the new demand. For example, onshore wind production facilities can expand their operations and use their trained workforce to produce offshore wind components, although the size of offshore components requires re-equipment, plant expansion and proximity to ports to transport the finished products. This manufacturing capability represents an opportunity in the transition to an all-in-house supply chain as more underlying components are built locally. However, the specialized components needed for offshore wind energy projects also pose a challenge for industries that still do not have sufficient knowledge or certifications to deliver the quality of projects demanded by the sector.

This potential restriction shows to be motivation for a domestic supply chain that can reduce the risk of facilities proposing to supply components dedicated to the local market.

The huge quantity and types of components necessary to build offshore wind projects provide an opportunity for domestic manufacturers to leverage their existing strengths to support the implementation pipeline. Several components are identified that are currently not manufactured in Brazil, such as permanent magnets, large diameter flanges and bearings, larger wind turbine blades, and anchor chains. This limitation represents a challenge to establishing a domestic supply chain, but also an opportunity for industry pioneers to build capabilities in Brazil.

Approximately 55 GW of power have already been installed around the globe. In a way, the value chain for offshore wind energy is in balance for current demand. In Brazil, by December 2022, intentions to install a capacity of around 176 GW had already been announced, more than triple the installed capacity accumulated worldwide (IBAMA, 2022).

Considering some of the main materials necessary for the construction of these farms and the conformation of the global industries that manufacture these materials, we have that steel, iron, aluminum and concrete have very global production supply chains. On the other hand, mining and processing of essential minerals for wind turbines is concentrated in certain geographic regions, presenting logistical potential and security risks.

The consideration of the entry of this Brazilian potential in the market can certainly cause an imbalance and it is not difficult to conclude that the country will not be able to rely much on external value chains, given its commitment to the current world demand, which obliges us to train to meeting expected demand.

As such, as with any emerging offshore wind market, Brazil's supply chain will require extensive development if the country is to capture the maximum local benefit from this source of electricity. However, as one of the world's largest exporters in mining and agriculture and with mature supply chains of onshore wind (40 GW forecast by 2029), oil and gas (5.5 million barrels per day forecast by 2029) and a thriving construction industry, Brazil is in an excellent starting position compared to many emerging markets (RambØll, 2022).

What is the expected demand for materials in natura considering the development of offshore wind farms in Brazil?

In terms of raw material, if there is a country that can supply a large amount of materials for the wind industry, that country is Brazil. The limitations are due to the manufacturing and processing. There is a specialization in the Brazilian industrial farm for the established market and not for an emerging market of the magnitude of offshore wind energy as intended. To have an idea, the electricity generation park in the country has approximately 181 GW of installed capacity against the 176 GW of offshore wind energy currently under licensing at IBAMA (EPE, 2022; IBAMA, 2022). Therefore, the construction of these farms would represent a new Brazil in terms of electricity generation.

Regarding the demand for in natura materials, two scenarios were considered in the study, showing a wide range of possibilities, depending on the speed with which the offshore prisms are granted and the offshore wind farms installed: (i) lower limit scenario (CLI) and (ii) upper limit scenario (CLS). Figure 10 illustrates the materials used for the construction of a typical 500 MW offshore wind farm, showing the importance of steel, copper and lead for the development of this new sector.

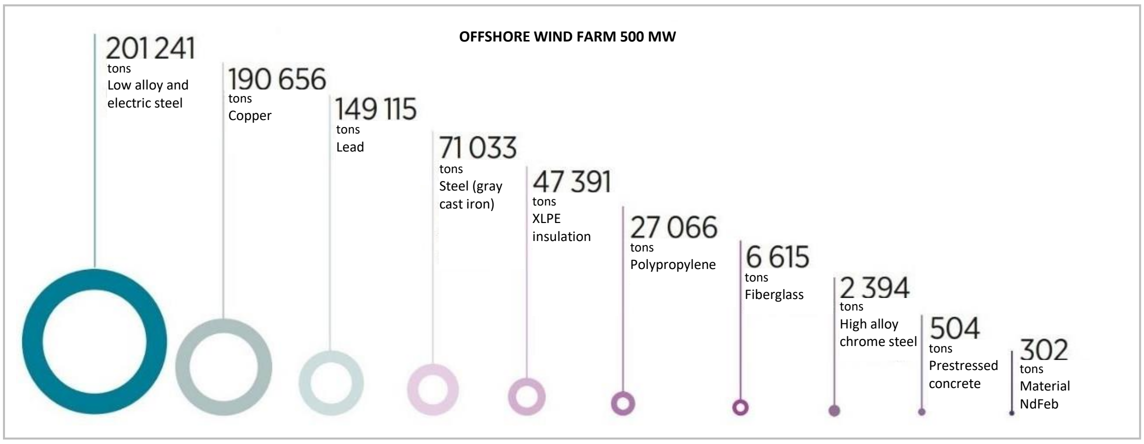

Figure 10: Materials necessary for a 500 MW offshore wind farm

Source: IRENA (2018).

In the lower limit scenario, the demand for materials shows a slower evolution, reaching a more intense growth from 2045 onwards, reaching the peak demand of more than 20 million tons of the various materials in 2050. In the upper limit scenario, this more intense demand happens even earlier, since in 2040 it already exceeds 15 million tons, reaching approximately 40 million in 2050.

Among the analyzed materials, steel stands out as the material with the highest demand. In 2050, adding all types of steel, demand varies from 6.3 to 11.5 Mt in CLI and CLS scenarios, respectively. The second most used is copper, which ranges from 5.9 to 10.9 Mt, followed by lead, which ranges from 4.6 to 8.5, and XLPE insulation, which ranges from 1.5 to 2.7 Mt. The other materials show increase in demand which is always less than 1.5 Mt in 2050.

Thus, it is clear that the transition to a cleaner energy system, as is the case with offshore wind, will generate a huge increase in material requirements. One of the concerns is the reliability, accessibility and sustainability of the supply of mineral resources for the production of these various components Some of the risks associated with the increase in this demand are: concentration of the supply chain in a small number of geographies, amplification of the influence of geopolitical issues, greater exposure of regulatory structures to international standards, greater exposure to price and risk of delay in the energy transition (GWEC, 2022).

How is it possible to increase the security of the supply of equipment and materials necessary for the development of offshore wind in Brazil?

According to IEA (2021), adequate investment in diversified sources of new supplies must be ensured; promote technological innovation at all points in the value chain; increase recycling; increase supply chain resilience and market transparency; integrate higher environmental, social and governance standards; and strengthen international collaboration between producers and consumers. Therefore, another important aspect is to be prepared for the new geopolitics of the supply chain, creating a stronger international regulatory framework to deal with the increased competition for commodities and critical minerals (GWEC, 2022).

In order to expand its clean energy matrix, based on the development of offshore wind energy, Brazil must use its competitive advantages over other countries and seek to adapt to the new demands for materials, which are evolving every year, with the purpose to benefit from the development of new activities and new markets, bringing economic and social benefits to the Brazilians. Therefore, the country has the ability to stand out both as a supplier of materials and as an exporter to meet its domestic demand, and it must plan and organize itself to achieve its future goals.

Most of the components for offshore wind cannot be manufactured internally and will require significant investment in new facilities to develop the necessary capacities if domestic production is chosen. However, each of the offshore wind components has a wide variety of sub-assemblies and sub-components that also have the potential to be manufactured in Brazil.

The new demands cannot be met by the existing industrial farm, therefore it is not a matter of modifying or expanding factories, even because the existing factories already have commitments with the current market. This involves establishing new plants specialized in the profile of new components and inputs for the new market. Another worrying factor is that the development of an operational plant requires time, not to mention the respective investments, from establishing the profile of specific demands to manufacturing the first unit of that product.

The option for manufacturing can be diversification, in order to increase the number of suppliers by considering other constructive forms. As an example, the assumption of reinforced concrete solutions for foundations with piles, concrete posts and the use of truss towers to the detriment of single posts and their respective requirements. It may seem that it is going against the grain of the world trend, but it is a feasible path within the Brazilian context, not being a fad, but the feasibility of creating a new industrial sector that can bring the polarization of the offshore wind energy market to the Brazilian territory.

The truss towers make it possible to bring the metallic parts to a size within the production capacity of their inputs in Brazil. Not that the large single poles and their metal foundations cannot be manufactured in the country, but that it will require more intensive welding work and specialized labor, demanding more time to manufacture the part. On the other hand, Brazilian civil construction has reached enviable maturity in the use of reinforced concrete as a constructive form of lower cost in the national canary. There are hundreds of companies able to take on the offer, which allows for the dispersion, even geographically, of the supply of prestressed and precast parts at lower costs than steel parts, if they could fully meet the needs.

A domestic industrial farm for the offshore wind energy assets would require a significant number of workers who would have to be readily available, resulting in an immediate need for workforce training. A favorable feature of civil construction products is that it is a sector with a large availability of labor, with a capacity to respond at great speed to filling vacancies.

Thus, some actions are highlighted that can guarantee greater security for the development of this new technology, such as relief on mining; relief for steel mills under threat of depletion; diversification of product supply: the current system relies on a few suppliers, so far all of them foreign; component cost reduction: Concrete is a cheaper product because it uses a fraction of the steel; geographical dispersion of production and consequent benefits; become more sustainable: less mining, less energy, less transport (in terms of raw materials and geographic dispersion of civil construction) etc.; diversification of suppliers, which multiplies the possibility of supplying the entire civil construction industry, which is of macro dimension; increase in employability: civil construction, as it is labor intensive, can contribute a lot to the generation of employment and income in the country, contributing to social development; attracting foreign investment in the new product; technological development.

X. Financing and the role of the national banks for the value chain

What is the situation of the financing of offshore wind projects?

At international level, the interest of the investors in the offshore wind industry is high. This interest goes through the recognition that this is a strategic sector in the power transition dynamics where renewable sources will have growing share in the energy matrix. At the same time, there is understanding that the project implementation risks are so high that the sector ended up creating reasonable capacity to manage these risks effectively.

This interest is accompanied by better perception of the project risks. As a consequence, the capital cost of these projects has been gradually reducing, as the risk premium demanded by the investors is smaller and smaller. To a large extent, this gradual reduction in the risk premium is a result of the history of offshore wind power projects which have been implemented respecting the previously set schedule and budget. In their operational phase, these projects have also been presented in line with assumptions considered in their financial modeling. In this context, the investors start to see more maturity in the technology and the projects with less uncertainty.

Namely, in countries where there is offshore wind power industry, the financial sector already places its plants within the scope of the category of projects in which financing can be considered conventional. Therefore, the environment for good projects turns out to be extremely favorable, also in terms of cost of capital regarding access to third-party capital at attractive conditions in a context in which the financing structures are increasingly more diversified.

What is the role of the national banks for the development of the offshore wind value chain?

The examination of the evolution of the projects financed over the last 20 years points out that the capital contributions of these banks were vital for the feasibility of electricity infrastructure projects, encompassing generation and transmission enterprises. The public development banks, by means of the project finance modality, acted as the main providers of long-term funds for the Brazilian electricity sector (SIFFERT et al., 2009). Table 6 brings the source of funds for implementation of projects in the Brazilian electricity sector.

Table 6. Resources for implementation of projects in the Brazilian electricity sector (billions reais)

Origin of the Funds	Period: 2009-2014	Period: 2015-2020
BNDES Approval	126	111
BNDES disbursement	101	88
Incentive Debentures	5	71

Source: Own elaboration based on CASTRO et al. (2021).

It can be observed that the provision of long-term funding for the financing of electricity generation projects has been diversifying, with the increase in the issuance of encouraged debentures in the period from 2015 to 2020. Even so, approvals and disbursements of BNDES amount to 73% of the total funds dedicated to projects in the national electricity sector. Therefore, it is reiterated that the role of public development banks continues to be extremely relevant, with emphasis on BNDES resources in the financing of wind and solar projects.

Within the scope of the development and the diffusion of new technologies, the work of public development banks has enabled the structuring of the productive chain of these new technologies at national level. Basically, this occurs through initiatives aimed to demand minimum percentages of local content for the granting of financing lines. This local content policy is very relevant, for example, for the development of the onshore wind power industry in Brazil, including its different stages of the value chain. However, it is necessary the content requirements not to constitute an obstacle to access to financing.

What are the main constraints, opportunities and challenges for the financing of offshore wind enterprises in Brazil?

There are still no specific models for financing of offshore wind projects in Brazil and public development banks have not yet defined guidelines for this purpose. However, the current environment and logic of financing of the Brazilian electricity sector tend to adhere to the needs of the offshore wind industry.

Good governance practices, technical qualification and a clear and stable regulatory framework together. If these issues are adequately addressed, the project financing will not be an obstacle to the implementation of offshore wind power projects on competitive bases any longer.

Finally, it can be observed that the formation of specific lines for the offshore wind sector is desirable and relevant. In addition to its complexity, its potential benefits justify a specific treatment with the intention to make this technology feasible in Brazil in a way that is compatible with the interests of the Brazilian electricity sector, the industry and the national economy more comprehensively.

XI. R&D and need for qualification of labor force

The purpose of this technical note was to identify R&D topics and needs for qualification of labor force and bottlenecks for the development of the offshore wind power value chain in Brazil. For this purpose, a questionnaire was applied in order to capture the perceptions of specialists from the sector. Thirty-one answers were obtained, which enabled raising reflections and findings for the consolidation of a common vision for the sector.

What are the main topics of interest in the offshore wind segment in Brazil?

The definition of the main topics of interest was preceded by a survey of thematic axes. The proposal of the thematic axis is to organize and allow classification of specific topics. For this purpose, the definition of these axes cannot be too specific to the point of being restricted to just one or a few specific topics, nor can it be too broad to the point of not being able to distinguish specific topics into categories. Table 7 summarizes the thematic axes suggested by the authors and those included by the responding specialists.

Table 7: Thematic axes suggested by the technical team and suggested by the specialists

Suggested thematic axes
Energy Resource and Role of the Source in the Matrix
Operation and Maintenance Procedures
Generation Technologies
Integration with the Transmission Grid
Offshore Transmission Infrastructure
Port Infrastructure and Material Logistics
Material Development and Demand
Regulation and Incentives
Social-Environmental and Economic Aspects
Included thematic axes
Development of the supply industry in Brazil
Demand for global assets - Special Vessels and others
Development of the production chain in the construction phase
Research test and validation
Professional Qualification
Synergy with green hydrogen
Zoning of the maritime airspace in areas of interest

Source: Own elaboration.

For this purpose, the definition of these axes cannot be too specific to the point of being restricted to just one or a few specific topics, nor can it be too broad to the point of not being able to distinguish specific topics into categories. This graph is shown in Figure 11.

Figure 11: Word cloud with the indications of topics by the respondents.
Source: Own elaboration.

There is a significant emphasis on topics involving the mapping and the study of the offshore wind resource. In addition, topics that address issues the source competitiveness, environmental impacts, transmission, impacts on SIN, regulation, incentives, planning and climate change stand out.

Are the education institutions prepared to qualify professionals in the offshore wind energy sector?

Regarding the assessment of the level of preparation of the Brazilian education institutions to qualify the professionals in the offshore wind power sector, the average of the specialists' answers was 6.3 and the median, 7. It is observed that most respondents (29%) gave score 8, followed by score 6 (25.8%) and 7 (22.65%). Therefore, it is consistent to state that the general assessment of the institutions presents a result between medium and good, with some more critical opinions regarding the level of preparation. The most critical opinions justified their answers by claiming a low number of education institutions specializing in offshore wind power, in addition to an answer that highlighted the lack of investment in Science and Technology in the country in the last years.

What is the priority order of the professional profiles for qualification of labor force?

Four professional profiles were suggested, for which the respondent should indicate the order of importance of the need for improvement in the qualification of their labor force. The four suggested professional profiles were: (i) **STEM** (Science, Technology, Engineering and Mathematics): highly qualified professionals in the areas of science, technology, engineering and mathematics; (ii) **Non-STEM** (Non Science, Technology, Engineering and Mathematics): highly qualified professionals in other areas, such as lawyers, logistics specialists, marketing professionals or specialists in regulation and standardization; (iii) **Administrative**: secretariat, assistants, Human Resources, accounting and general services; (iv) **Offshore Operations**: professionals qualified to provide services at sea, such as O&M technicians, divers, vessel pilots, among others.

The result of the answers was consistent to point out the category of STEM Professionals as a priority, with 24 indications (77% of respondents) in 1st place. The remaining 23% indicated the Offshore Operations Professionals category in first place. This category received more indications in 2nd place (17 answers). No respondent indicated the other categories in 1st place, and only the Administrative Professionals category did not get any indications in 2nd place. Therefore, mostly, the Administrative Professionals and Non-STEM Professionals categories were in the last two positions, with a robust number of indications (29 answers) placing the Administrative Professionals category as least priority.

Which aspects could be developed to promote an effective workforce qualification in the offshore wind power value chain?

In general, some relevant and common points observed in the answers are highlighted below: (i) expand the relationships with countries that are advancing more urgently in this technology to create learning gains; (ii) investments in technological equipment of the education centers to enable more accurate studies, (iii) creation of a laboratory for classes and practical research of subsea operations, (iv) creation of technical qualification, careers and postgraduate courses with content and specific lines of research for offshore wind, (v) development of research exchange programs, (vi) increased integration of the education institutions with the market, (vii) expansion of investments in R&D, focusing on the participation of the education institutions, (viii) identification of the most demanded professionals to direct the qualification efforts, (ix) consolidation of professional courses for quick qualification for the market absorption, (x) use of existing port infrastructure and logistics bases for hybrid theory and practice training, (xi) local qualification in regions where the Brazilian offshore wind hubs will be developed, (xii) development of partnerships between education institutions and increase of the involvement of Brazilian public institutions which have been working on the subject (ABEEólica, EPE, MME, ANEEL) and (xiii) Reference to the model of the Mobilization Program for the National Oil and Natural Gas Industry (PROMINP).

What are of the main bottlenecks for the development of the offshore wind sector in Brazil?

The main bottlenecks identified by the respondents were “planning”, followed by “costs” and “regulation”, as illustrated in Figure 12.

Figure 12: Word cloud with the answers to bottlenecks for the development of the offshore wind sector. Source: own elaboration.

The word “planning” has a broad spectrum which, in part, justifies its higher number of mentions. In other words, references were made to the planning to address different issues, such as integration with the transmission system, organization of maritime space, expansion of the energy matrix, forecast of the electricity demand, among others. In relation to the costs, the question of the source cost competitiveness, in fact, is still a bottleneck considerably indicated by specialists.

Regarding the word “regulation”, the recurrence of the word “legal certainty” can also be associated with it (reinforcing the concern regarding the uncertainties in the sector, mentioned above), which limits the decisions of the investors and the Brazilian bodies themselves. It is worth pointing out that the ordinances of the decree were published, but there is still lack of definition of aspects and methodologies for the consolidation of a regulatory framework to support the evolution of the sector and bring legal certainty to the investors. Therefore, it is observed that the specific regulatory discussions about the offshore wind power sector are still incipient in Brazil.

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