WORLD BANK GROUP

Offshore Wind Development Program

SCENARIOS FOR OFFSHORE WIND DEVELOPMENT IN BRAZIL

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SCENARIOS FOR OFFSHORE WIND DEVELOPMENT IN BRAZIL

1 EXECUTIVE SUMMARY

Brazil possesses an abundance of natural resources that contribute to meeting its energy demand. Thanks to a traditional base of hydroelectric power and the more recent development of onshore wind and solar, Brazil enjoys one of the world's cleanest and most cost-competitive generation mixes. Brazil also happens to have one of the world's best offshore wind resources, with a technical potential of over 1,200 Gigawatts (GW), including 480 GW of fixed foundation potential (at water depths less than 70 m) and 748 GW of floating foundation potential (at water depths from 70 m to 1,000 m). This offshore wind resource is vigorous, consistent, geographically diverse, and located close to demand centers; all factors that suggest that offshore wind could figure prominently in the country's long-term energy mix. At the same time, the first offshore wind projects will have a higher cost of generation than onshore projects and require a significant ramp-up in national capacities if Brazil is to compete with established markets in Europe or even new markets in the Americas.

This leads to an obvious question: Why would Brazil seek to develop offshore wind at scale when it already has so many options from which to choose? The answer will ultimately be provided by policymakers and stakeholders seeking to chart a long-term path to Brazil's energy needs while also meeting objectives around climate mitigation, energy security, electricity affordability, and economic development. This Scenarios for Offshore Wind Development in Brazil is intended to inform that decision making by outlining the challenges and opportunities associated with different offshore wind development pathways from a technical, commercial, economic, environmental, and social perspective. The report does not advocate for one path over another; rather it provides a vision for a future under different growth scenarios and describes what would be required to make each scenario a reality, depending on the path chosen.

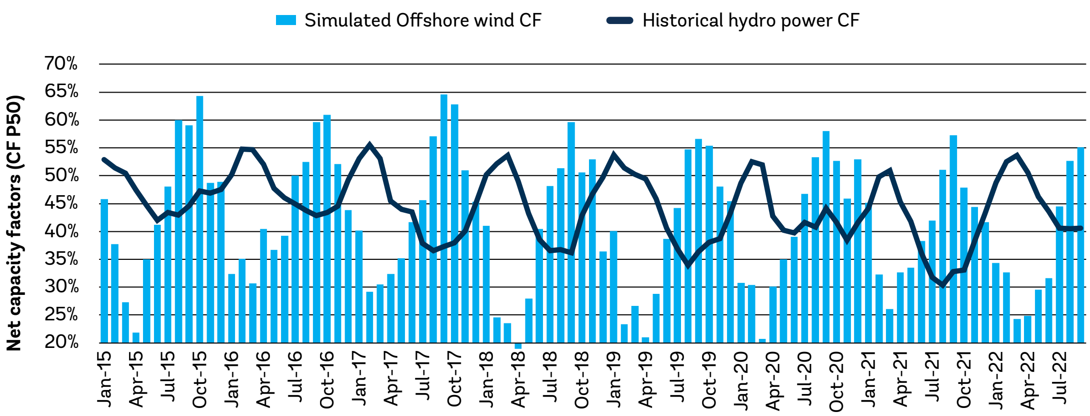
This report was prepared with the aim of supporting the government of Brazil in setting public policies towards its energy transition by looking at offshore wind development. The report was initiated by the World Bank (WB) and the International Finance Corporation (IFC) under the umbrella of the World Bank Group's Offshore Wind Development Program, and was done in collaboration with the Brazil Ministry of Mines and Energy (MME) and the Energy Research Office (EPE). Founded in 2019, the WBG's Offshore Wind Development Program aims to accelerate offshore wind development in emerging markets. This report was funded by the World Bank Group's Energy Sector Management Assistance Program (ESMAP) and Blue Economy Program (PROBLUE).

RATIONALE FOR OFFSHORE WIND IN BRAZIL

There are a variety of reasons why Brazil might choose to pursue offshore wind development at scale.

Offshore wind as "Brazil's new hydro." Although hydro currently satisfies 72 percent of Brazil's electricity demand, projections indicate that net hydro generation capacity will not expand significantly over the next 25 years. In the face of expected population growth and rising demand, hydro's contribution to the grid is therefore expected to fall to 46 percent by 2050. Offshore wind—alongside onshore wind and solar—represents an interesting option not only to fill this gap but to serve as a mitigant for hydro's interannual variability. Analysis in this report indicates that offshore wind is particularly complementary to hydro as it is both countercyclical on a seasonal basis and has lower variability on an interannual basis. Figure 1.1 compares actual hydro output with simulated offshore wind output over a seven-year period, indicating that offshore wind output would be strongest in months when water levels are low. The analysis also suggests that the year-on-year variability of offshore wind is expected to be much lower than hydro output in much of the country. As such, if deployed at scale then offshore wind may serve as an "energy hedge" against unusually dry years such as those observed in the past decade. In this case, offshore wind may take its place alongside hydro as an intrinsic part of the country's clean generation base.

FIGURE 1.1 MONTHLY CAPACITY FACTORS (2015-2022) FOR OFFSHORE WIND AND HYDRO IN BRAZIL.

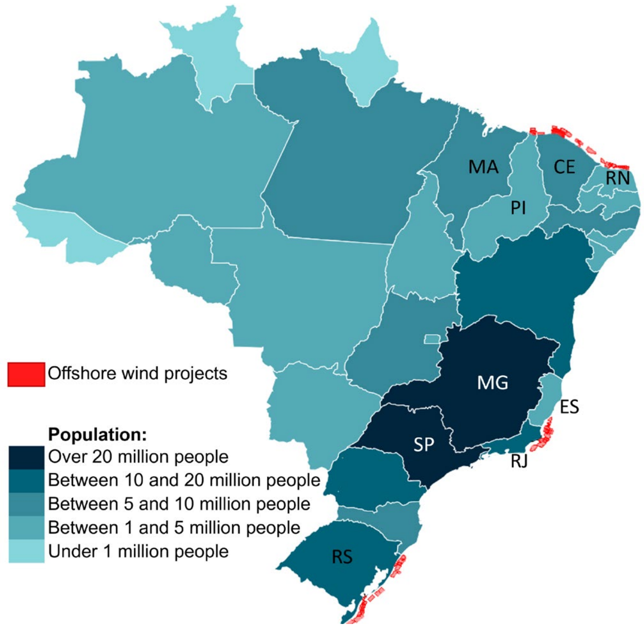


Source: DNV

Long-term cost-competitiveness and price stability. Offshore wind is currently one of the most cost-competitive sources of new generation in developed markets such as Europe and China. However, in new markets such as Brazil, the initial cost of the first projects is expected to be significantly higher. Analysis in this report suggests that with high volume targets and appropriate conditions, the cost of offshore wind could fall from US$64 per MWh for the first projects (roughly 50 percent higher than onshore wind and solar) to US$52 to 40 per MWh by 2050, at which point it would be competitive with conventional forms of generation. This situation is not dissimilar to the historic case of onshore wind in Brazil which was initiated through PROINFA over 20 years ago and is now one of Brazil's largest (at 30 GW installed capacity as of 2024) and lowest cost generation sources. It is worth noting that there are expected to be regional variations in offshore wind cost, with the cheapest tariffs expected in the Northeast region, having the highest wind speeds in Brazil.

Generation close to demand to reduce transmission losses. Brazil's favorable offshore wind resources are located relatively close to shore and tend to be clustered around large population centers. As illustrated in Figure 1.2, strong offshore wind zones in the Northeast, Southeast, and Southern regions are near to large cities including Rio de Janeiro, Fortaleza, and Porto Alegre. Locating generation close to demand can in principle reduce transmission losses, provided adequate regional supply-demand balance is maintained. Note that higher amounts of offshore wind may lead to congestion at a local level if demand is not high enough or evacuation capacity is insufficient. This could be potentially mitigated at a local level by adding storage, or by adding demand (e.g., green hydrogen (GH2) production).

FIGURE 1.2 PROXIMITY OF OFFSHORE WIND ZONES TO POPULATION.



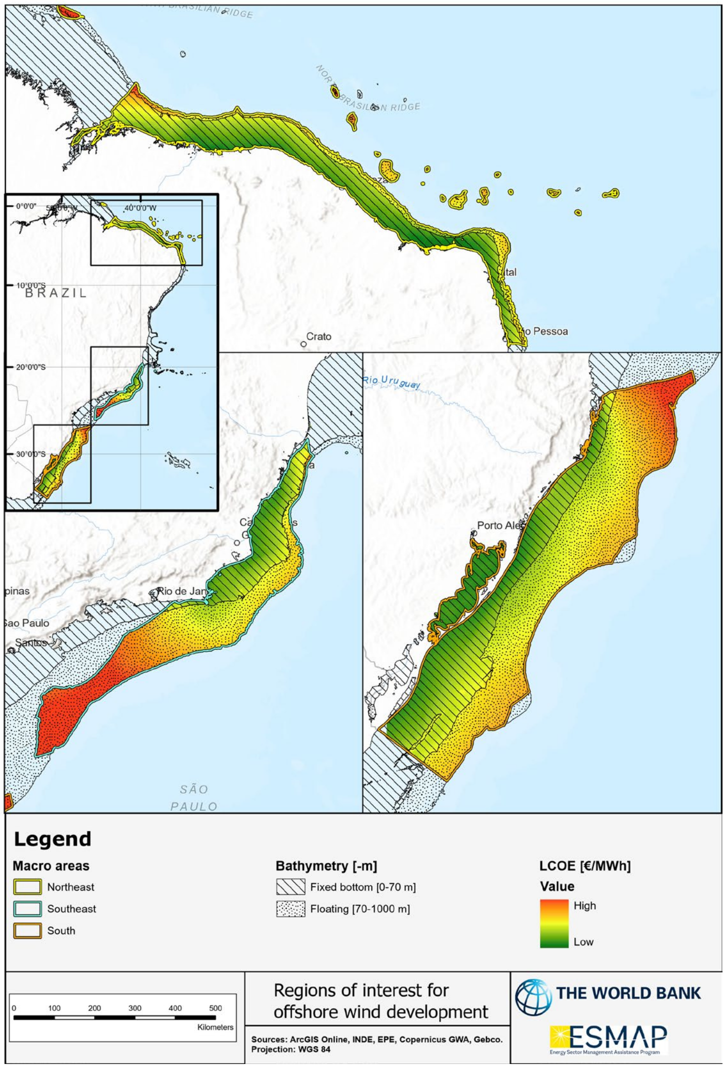
Offshore wind as a foundation for GH2 production. Brazil has announced ambitious targets for GH2 production with a focus on major ports such as Pecém and Açu that may serve both domestic and international markets by the creation of hydrogen hubs. To be eligible to participate in and be competitive with international GH2 markets, Brazil will require a substantial buildout of renewable power, particularly in the face of flat hydro capacity and limitations in onshore wind and solar expansion. Analysis in this report suggests that if Brazil wants to satisfy five percent of global GH2 demand by 2050, it would require close to 100 GW of new renewables; offshore wind may satisfy a significant portion of this demand, particularly if built near designated GH2 hubs.

Economic development and job creation. Brazil has a long history of both offshore oil and gas production and large-scale development of onshore wind. These sectors provide useful starting points for offshore wind development, from the perspective of existing infrastructure, supply chain, and human resources. Indeed, the offshore wind industry in much of Europe started from a similar base less than 20 years ago. Analysis in this report suggests that Brazil could, under the most ambitious offshore wind development scenario, see the creation of over 516,000 Full-time Equivalent (FTE) jobs by 2050, accompanied by a National Gross Value Add (GVA) of US$168 billion.

BRAZIL'S OFFSHORE WIND POTENTIAL

Through a preliminary geospatial analysis, this report identified three macro areas of possible offshore development within Brazil's Exclusive Economic Zone (EEZ). Figure 1.3 presents relative Levelized Cost of Energy (LCoE) across each area, reflecting the relative expected capital expenditure (CapEx) (as a function of distance from shore, water depth), operating expense (OpEx) (largely as a function of distance from shore), and energy output (as a function of wind speed). It is clear that each area represents significant potential, albeit with different levels of attractiveness from a price standpoint.

FIGURE 1.3 RELATIVE LCOE WITHIN THE THREE DESIGNATED AREAS.



Northeast. This area has some of the best offshore wind conditions in Brazil, with areas of 7 to 10 m/s average wind speed at 100 m a.s.l. in shallow waters relatively close to the coastline. Total potential is 356 GW across a technically viable seabed area of 89,000 km^2. Several of the most favorable zones are in proximity to the Port of Pecém which would be suited for the development of offshore wind projects with minor to moderate upgrades. At the same time, there are significant artisanal and commercial fishing areas near to these zones, as well as significant tourism activities. As such, it is expected that social sensitivities will be high, requiring careful consideration.

Southeast. This area has good potential for both fixed and floating wind, with areas of 8 m/s average winds and a total potential of 340 GW across a seabed area of 85,000 km^2. This area also hosts significant oil and gas activity concentrated in deeper waters, which represents both an opportunity for offshore wind (through use of existing infrastructure) and a challenge (coexistence with platforms). The area also sees relatively intense marine traffic which would require careful planning to avoid undue interference with major shipping lanes.

South. This area represents the largest seabed (165,000 km^2) and has good wind speeds over 8 m/s in shallow waters close to major industrial demand centers. It has the highest technical potential of all three areas (660 GW). However, it is located almost entirely within an Ecologically or Biologically Significant Area (EBSA) which increases the need for risk mitigation and careful designation of development zones.

It is clear that Brazil has sufficient *technical* potential (i.e., area and wind resource) for offshore wind development at scale. As a next step, it is necessary to refine the *commercial* potential which accounts for constraints and exclusions that limit the developable areas. This includes social constraints (e.g., tourism and fisheries), environmental constraints (i.e., minimizing impact on sensitive biodiversity), and commercial constraints (i.e., areas where the resulting LCoE would be so high as to render them non-feasible). This report provides analysis to inform these constraints through a pragmatic Marine Spatial Plan (MSP) or a targeted sectoral spatial planning required to designate specific polygons for offshore wind development. As such, it does not specify "go" and "no go" areas, but rather provides risk and sensitivity mapping from an environmental, social, and commercial perspective.

SCENARIOS FOR OFFSHORE WIND DEVELOPMENT

The analysis underpinning this report is based on three potential growth scenarios for offshore wind development in Brazil. The most notable impacts of the three scenarios are summarized in Figure 1.4.

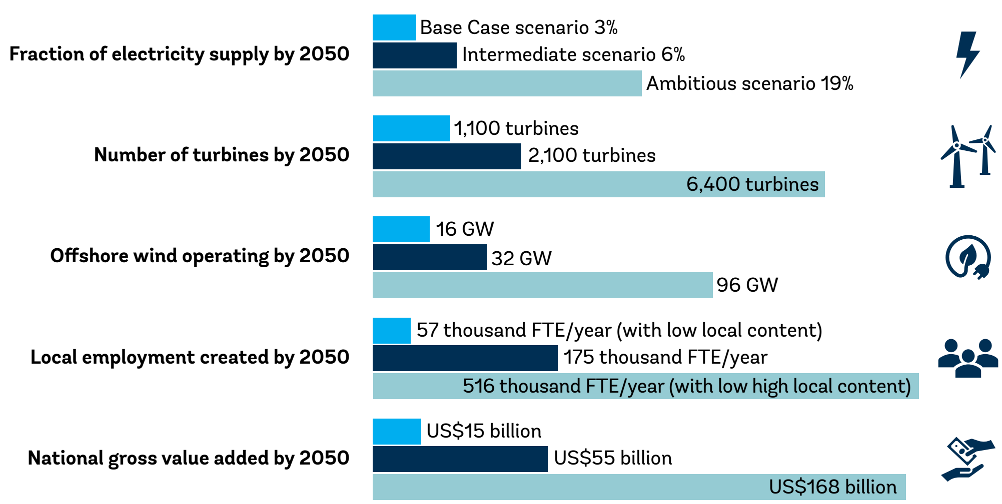
#1 Base Case. This scenario considers modest growth of offshore wind in line with projections from the EPE Offshore Wind Roadmap, which projects 4 GW operational in 2035 and 16 GW by 2050, at which point offshore wind would represent 3 percent of the country's total generation. This represents an investment of US$40 billion by 2050, and an average rate of installation of a little less than 1 GW per year. Given Brazil's expansive coastline, this would represent a utilization of only 1.2 percent of the available seabed. Given distribution of resources, it is likely that a majority of this development would occur in the Northeast region, although this would depend on constraints around tourism, fisheries, and grid evacuation capacity. The modest levels of growth would be unlikely to trigger significant investments in associated infrastructure (ports, vessels, and grid) and manufacturing (turbines, foundations, cabling, balance of plant, etc.). Under this scenario, offshore wind development would be dwarfed by onshore wind and solar development as well as existing hydro and thermal production.

The #2 Intermediate and #3 Ambitious scenarios were not established (and have not been tested) through energy system modeling, which is recommended in due course. They have been based on high-level assumptions of the offshore wind capacity needed to decarbonize the Brazilian economy and reach net-zero goals.

#2 Intermediate. This moderate-growth scenario looks at a future where offshore wind starts to play an important role in Brazil's energy mix, with 8 GW by 2035 and 32 GW by 2050 at which point it would represent 6 percent of the country's total generation capacity. Under this scenario, offshore wind takes up only 2.3 percent of the technically feasible seabed. Here, the installed capacity would be more evenly distributed in the three target areas, likely driven by transmission upgrades that facilitate evacuation to major demand centers and port upgrades to allow both construction/marshalling and operations and maintenance. These investments are justified by a steady rollout of 1.8 GW per year of projects with a total CapEx of US$80 billion.

#3 Ambitious. This scenario considers a future where offshore wind is a key contributor to Brazil's power mix, accounting for nearly one-fifth of the country's generation mix by 2050 with 96 GW of installed capacity. Here, offshore wind becomes a common sight along the coast in all three areas, occupying 7.1 percent of the technically feasible seabed. This scenario was designed with the objective to place Brazil as a major country in offshore wind development and considers what offshore wind capacity will be needed to reach electrification and industrial decarbonization targets, in particular renewable energy needs for the expected GH2 demand by 2050. This scenario would require a total CapEx of US$240 billion and an average installation rate of 5.3 GW per year, which would be a far greater new build rate than any country at present, except for China. As a reference, in 2022 only 2,460 MW of offshore wind was added across all of Europe (well behind China with 5 GW). Annual additions of 5.3 GW would require—and drive—substantial upgrades to existing infrastructure and new manufacturing capacity additions, resulting in US$168 billion of gross cumulated value added and 6 million cumulated FTE years from 2028 to 2050.

FIGURE 1.4 IMPACT OF THE THREE SCENARIOS.



CHALLENGES AND OPPORTUNITIES OF OFFSHORE WIND

This report demonstrates that offshore wind can play an important role in Brazil's energy future. However, there are a number of key challenges that will impact the nature of this development; each is a function of the path that the country chooses to take.

High initial cost. It is certain that the first offshore wind projects will have a relatively high initial cost as the industry establishes the foundations for the sector and "learns by doing." To close this cost gap, Brazil will need to explore options for concessional finance of both public and private sector portions of the projects. It will also need to ensure that initial seabed rights are allocated primarily on the basis of qualitative rather than price-based criteria that would ultimately inflate the costs of the project. It is expected that the costs would remain high in the #1 Base Case scenario, whereas a rapid fall in LCoE would be seen in the #3 Ambitious scenario.

Access to financing. Brazil has built its existing onshore wind industry primarily through a strong role of the National Bank for Economic and Social Development (*Banco Nacional de Desenvolvimento Econômico e Social*, BNDES). The offshore wind industry is different than onshore if deployed at scale; that is, it is a much more capital-intensive sector requiring complex finance structures and involvement of many actors from public and private financial institutions. Under the #1 Base Case scenario, it is expected that BNDES would continue to take a lead role given the relatively modest CapEx requirements. Under the #3 Ambitious scenario, commercial banks and international financial institutions would be expected (and required) to take a leading role.

Procurement. Brazil has traditionally secured power through target-year-based, technology-neutral regulated auctions, as well as—more recently—bilateral Power Purchase Agreements (PPAs). The high initial cost of the first offshore wind projects may require a modified approach whereby offshore wind is given a specific allocation, with the cost delta covered by ratepayers and—to the extent possible—concessional finance. It is expected that auctions may change in a few years to depend less on revenue support and more on the free market for energy sales. Under the #3 Ambitious scenario and regular procurements, it is expected that this delta would be quickly reduced.

Grid integration. Experience in other countries suggests that significant offshore wind development may lead to congestion (either overloads or voltage excursion issues) at a local level if connected to transmission systems with limited evacuation potential. Here, the complementarity of offshore wind with hydro and onshore renewables would have an impact on power evacuation, although this would be less pronounced in certain regions. At higher penetration levels such as those foreseen under the #2 Intermediate and #3 Ambitious scenarios, it is likely that transmission upgrades will be required. There would also be a role for greater grid flexibility through the local use of energy storage to manage short-term over- and under-supply. Increased demand from GH2 and e-fuel production may also serve to reduce grid impacts.

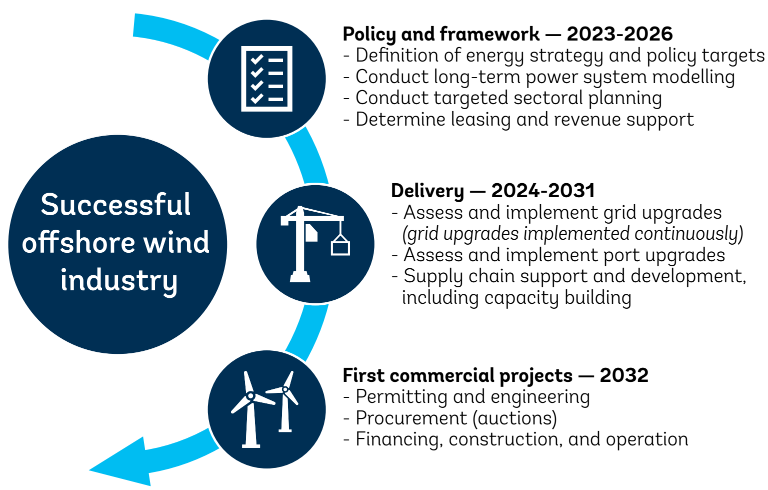
Environmental and social considerations. The Environmental & Social (E&S) considerations for offshore wind are different than those for onshore wind in terms of both receptors and affected populations, which in the case of offshore wind include fishers, marine traffic, and other sea users. Pressure on marine biodiversity, especially avifauna, marine mammals, and turtles might rise with an increase in maritime traffic. In the #1 Base Case scenario, there would be relatively little impact given the low usage of the available seabed. Under the #2 Intermediate scenario, the impacts will be greater, particularly if development extends into the Southern area, as offshore potential is located almost entirely within an EBSA. In the #3 Ambitious scenario, coverage of the seabed (7.1 percent) would be significant enough to drive higher-level concerns around E&S sensitivities. In these cases, it will be critical to align Environmental and Social Impact Assessment (ESIA) requirements with World Bank and IFC Performance Standards and conduct early consultations with affected communities. It is also recommended to conduct E&S sensitivity mapping to inform and complement spatial planning processes.

Ports and logistics. Brazil boasts a robust port infrastructure, including terminals and shipyards along its entire coastline. However, at present none of these ports are able to meet the demands of an offshore wind project, particularly from the perspective of construction and marshalling. Under the #1 Base Case scenario, there would be little port development required as the buildout scale and associated CapEx would not be sufficient to drive these investments. However, under the #2 Intermediate scenario, investments would be required in key regional ports identified in the three areas (e.g., Pecém, Açu, and Rio Grande) where upgrades on quayside bearing capacity and storage area are needed for both cargo handling and marshalling activities.

Supply chain. Brazil has developed a robust supply chain for onshore wind (generally 3 to 6 MW turbines); this would require significant investment to be capable of supplying the much larger turbines expected for offshore wind (15 MW+). Under the #1 Base Case scenario, it is unlikely that this would occur as the volumes of new offshore wind plants would be insufficient to drive new manufacturing capacity. Conversely, under the #3 Ambitious scenario there would be a substantial shift in the supply chain as manufacturers ramped up production of the larger turbines and established more of a presence near port infrastructure as many offshore wind components cannot be transported over land. To facilitate this, it will be necessary to establish a supply chain action plan through dialog with the industry. It is recommended that limited local content requirements (either explicit or through preferred funding from BNDES for qualifying manufacturers) be put in place initially as these would raise the price of the first projects. As the sector becomes established, local content incentives might be increased.

Green Hydrogen. With its predominantly hydropower base, Brazil is in a good position to become a leading producer of GH2 (particularly in Europe where recent directives set that at least 90 percent of the mix needs to be from renewable energy for the hydrogen production to be considered "green"). Offshore wind may contribute to this ambition provided that it is built at scale and its costs drop quickly enough for the resulting Levelized Cost of Hydrogen (LCoH) to reach competitive levels. Analysis in this report suggests that offshore wind-based LCoH may fall to around US$3 per kgH2 for bottom-fixed offshore wind by 2050. The viability of this LCoH on export markets would depend on market prices.

RECOMMENDED APPROACH



As described in the World Bank Group's Key Factors report[i], the most critical first step in any emerging offshore wind market is to establish a clear energy strategy that signals the long-term role of offshore wind in the country's energy future. It is clear that each of the three potential paths ahead represent a widely diverse outcome for Brazil. Under the #1 Base Case scenario, offshore becomes a very minor part of the energy mix and does not drive substantial economic change. Conversely, the #3 Ambitious scenario represents a widespread change from an economic, commercial, technical, and E&S perspective. In developing a long-term strategy, it is suggested that policymakers and stakeholders consider the following:

i https://www.esmap.org/key-factors-for-successful-development-of-offshore-wind-in-

- Offshore wind could be "Brazil's new hydro" but only if it is built at scale, consistent with the targets set out under the #2 Intermediate or #3 Ambitious scenarios.
- Brazil will need to invest heavily in transmission network expansion, port development, and manufacturing capacity if it wants to achieve the #2 Intermediate or #3 Ambitious scenarios, as pre-conditions for offshore wind development. As such, Brazil may want to consider focusing auctions for multiple areas within proximity of designated ports to allow for shared investment costs and to lower the LCoE across projects on a regional basis.
- Brazil will need to act quickly to build on current interest, particularly in light of market conditions that are reducing investor appetite for non-core markets. Investors will require a clear path to market, including a process to gain seabed exclusivity and the possibility of participating in initial offshore wind-specific auctions.
- Given offshore wind's long development timeline, Brazil should move early to complete E&S sensitivity mapping and designate initial zones for offshore wind development.

This report aims to evaluate offshore wind potential and possible growth scenarios for offshore wind in Brazil, through a broad view of current capabilities, potential synergies, necessary changes, and actions to inform decision-making. It is a first step in assessing how this source could be developed in the country, its opportunities and challenges, and most importantly, how to get there through a set of 45 actionable recommendations by topic.

The Brazilian offshore wind development scenarios report is structured as follows:

- Scenarios report summary
  - Section 1: Executive Summary.
  - Section 2: Description of three scenarios proposed for this study and the challenges and potential implications for offshore wind development in Brazil.
  - Section 3: Recommendations for offshore wind development in Brazil.
- Supporting Information
  - Sections 4–17: Analysis covering key aspects of the future of offshore wind in Brazil.
- Appendices
- Appendix A to G provide additional supporting information, including maps, reports, analysis, and methodologies related to biodiversity, regulatory framework, and hydrogen, among others.

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