SYSTEMIQ

CAPTURING THE OFFSHORE WIND OPPORTUNITY

THE CRITICAL ROLE OF PORT DEVELOPMENT AND REGIONAL COORDINATION IN SCALING OFFSHORE WIND IN EMERGING MARKETS AND DEVELOPING ECONOMIES

JUNE 2025

EXECUTIVE SUMMARY

Offshore wind offers important advantages for sustainable energy systems given its high capacity factor, strong complementarity with solar generation, and low land footprint. Globally, offshore wind electricity generation has the potential to scale by several orders of magnitude, particularly in emerging markets and developing economies (EMDEs), where it can play a critical role in meeting rising power demand. Beyond low-carbon electricity, offshore wind drives industrial development and job creation by stimulating local economies, supporting supply chains, and attracting energy-intensive industries to coastal regions.

Ports are central to unlocking the offshore wind opportunity. They serve as hubs for component manufacturing, as marshalling ports where components are assembled and loaded onto installation vessels, and as bases for operations and maintenance activities. However, the infrastructure demands on offshore wind ports – such as high-load bearing quays, deep berths, and large laydown areas – require significant planning and investment, especially in new offshore wind regions.

To ensure emerging markets can develop offshore wind efficiently and capitalize on the economic and strategic benefits offshore wind can bring, regional coordination and collaboration around port infrastructure development are crucial.

Strategic co-ordination is essential to unlock investment into offshore wind ports. Regional co-ordination must align port selection with existing port infrastructure and offshore wind development zones. Temporal coordination should ensure ports are developed on time to support deployment. Pipeline coordination must provide long-term visibility and stability to unlock investment into ports.
In this paper, we illustrate this need for co-ordination through a case study on offshore wind ports in the South of Brazil.Once a regional offshore wind pipeline reaches sufficient scale, local manufacturing may yield significant benefits to the region. While not always cost-optimal when considering only the levelized costs of energy, local production of offshore wind components can create industrial capacity, jobs, and wider economic benefits. Onshoring (part of) these manufacturing capabilities and capacity is a common policy goal. However, achieving this goal requires clear industrial policy support and active sector engagement to build out new local manufacturing.

This paper recommends five key actions to build an efficient offshore wind port ecosystem:

1. ESTABLISH A STABLE, FIRM AND LONG-TERM OFFSHORE WIND PROJECT PIPELINE.
2. FACILITATE AND SECURE COORDINATED SELECTION OF OFFSHORE WIND PORTS TO FULFIL KEY ROLES (MARSHALLING, MANUFACTURING, OPERATIONS AND MAINTENANCE (O&M)) IN THE OFFSHORE WIND VALUE CHAIN.
3. COLLABORATE ON A COMPREHENSIVE VALUE CHAIN-BACKED ROADMAP FOR OFFSHORE WIND PORTS, WHICH INCLUDES (SUB)NATIONAL GOVERNMENTS, PORTS, OFFSHORE WIND DEVELOPERS AND LOCAL COMMUNITIES.
4. MARSHALLING PORTS: ALIGN PORT DEVELOPMENT PLANNING WITH MARINE SPATIAL PLANNING.
5. MANUFACTURING PORTS: DEVELOP A LONG-TERM STRATEGIC VISION FOR OFFSHORE WIND COMPONENT MANUFACTURING, COMBINED WITH SUPPORTIVE POLICIES AND SECTOR ENGAGEMENT.

CONTENTS

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Ocean Energy Pathway

Ocean Energy Pathway

Ocean Energy Pathway fast-tracks the development of a sustainable, high ambition, global offshore wind sector, as part of a thriving blue economy. As a not for-profit organization, Ocean Energy Pathway delivers expert, independent technical assistance to governments and stakeholders and works with policymakers, industry, conservation leaders, and other stakeholders to build strategies to sustainable scale for the sector. Ocean Energy Pathway is scaling in diverse markets around the world and over the last year has launched operations in Brazil, India, Japan, the Philippines, and South Korea.

SYSTEMIQ

Systemiq

This report was developed by Systemiq, a system-change company founded in 2016 to transform markets and business models in five key systems: nature and food, materials and circularity, energy, urban areas, and sustainable finance. A certified B-Corp, Systemiq combines strategic advisory with high-impact, on-the-ground work, and partners with business, finance, policymakers and civil society to deliver system change.

Energy Transitions Commission

Energy Transitions Commission

The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C. The ETC Secretariat is hosted by Systemiq.

1
THE OFFSHORE WIND OPPORTUNITY FOR COUNTRIES AND LOCAL ECONOMIES

1.1 OFFSHORE WIND IS BENEFICIAL FOR DOMESTIC ENERGY SUPPLY

Offshore wind is an attractive source of renewable electricity for several reasons. First, coastal regions are home to around 40% of the global population, and in many markets, especially emerging ones, electricity demand from households is set to grow.[1] Offshore wind is well-suited to help satisfy this rising power demand, as it is less constrained by available land space than solar and onshore wind, making it especially attractive for densely populated areas.[2] By tapping into domestic offshore wind resources, countries can increase energy security and reduce reliance on imported energy.

Second, offshore wind electricity generation has a high capacity factor, especially compared to other sources of renewable electricity generation. Global average offshore wind farm capacity factors are between 40–50%,[3] compared to 10–30% for solar photovoltaic (PV) where the higher end of the range is only achieved by top-performing utility-scale tracking system solar PV.

Third, the times when solar and offshore wind generate electricity can complement each other: solar generation peaks during the day and in summer, offshore wind also delivers power at night and peaks in the winter in some regions. Together, they can lower the overall system imbalance, reducing price volatility and costs in frequency regulation and reserve markets.

The costs of offshore wind have followed a long-term downward trend, despite short-term fluctuations. Between 2015 and 2020, the levelized cost of energy (LCOE) for offshore wind more than halved from approximately €200/megawatt-hours (MWh)[4] to €60–100/MWh,[5] driven by advancements in technology, economies of scale, and strategic industrial planning and auctioning processes.

Recent market pressures, including rising material costs and higher interest rates, have temporarily slowed this trend in Europe and North America. However, many of these challenges appear cyclical rather than structural: steel prices have already returned to pre-2020 levels, and interest rates are beginning to decline. Meanwhile, China continues to demonstrate that further cost reductions are possible, with Chinese-manufactured turbines priced up to 60% below the global average,[6] highlighting continued efficiency gains in the sector.

1.2 OFFSHORE WIND ELECTRICITY GENERATION COULD SCALE UP BY SEVERAL ORDERS OF MAGNITUDE

Despite challenges in the deployment of offshore wind, global capacity expanded six-fold from 12 gigawatts (GW) in 2015[7] to over 75 GW[8] in 2024. Offshore wind now supplies electricity for roughly 90 million households. Most offshore wind is deployed in China (~46%) and greater Europe (~46%), see Figure 1. The IEA estimates the global technical offshore wind potential is more than 120 terawatts (TW), with the potential to generate over 420 000 terawatt-hours (TWh)[9] per year. This could satisfy almost five times the projected 2050 power demand.[10]

Almost 20% of this technical potential is in shallow coastal waters (less than 60 meters deep). These waters are suitable for fixed-bottom technologies, which are mature and already deployed on an industrial scale. For deeper waters (80% of total generation potential), floating offshore wind offers a potential solution. Although commercial projects have been announced globally, including in Japan, the UK and the Philippines, this technology has not yet been deployed at commercial scale.[11,12] Due to increased cost and development risk, suitable areas for fixed-bottom offshore wind are likely to be developed first, followed by floating offshore wind: the Global Wind Energy Council (GWEC) expects only 8.5 GW of floating offshore wind to be built globally between 2023 and 2030, versus 225 GW fixed-bottom offshore wind in the same period.[13]

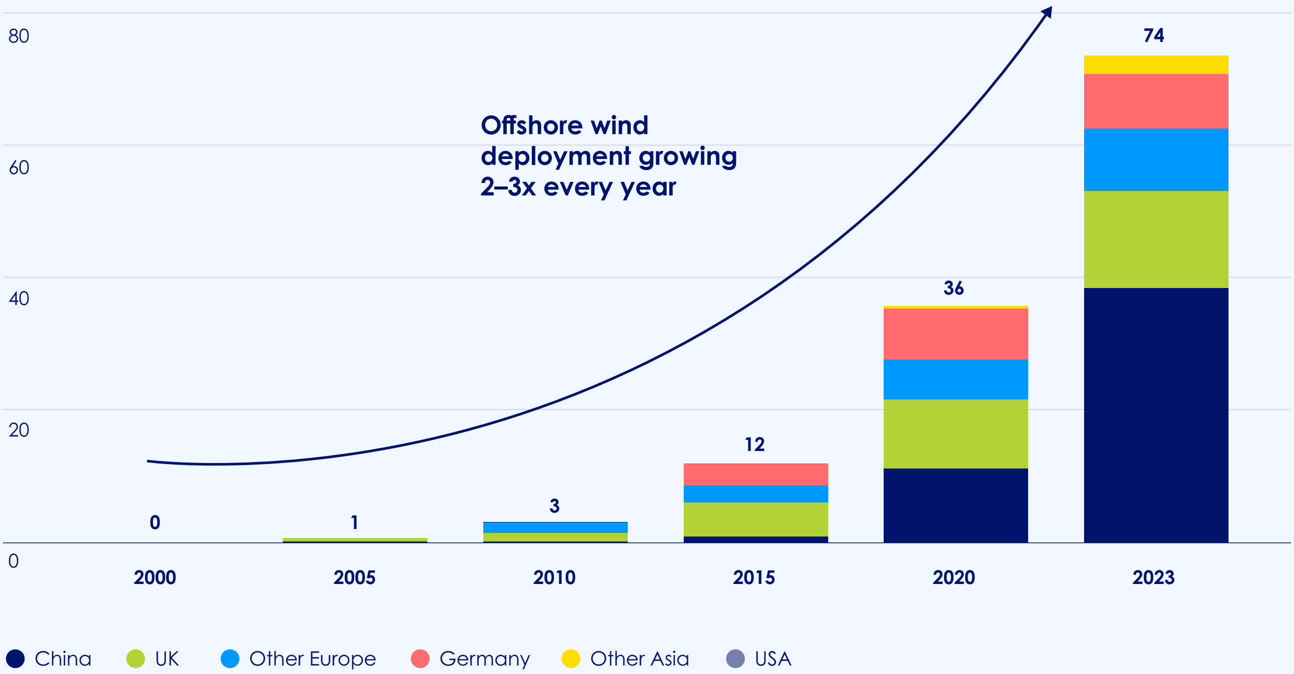
According to the World Bank, low- and middle-income countries (LMICs) hold approximately 22% of global offshore wind potential, estimated at 16 TW, enough capacity to generate twice the current global electricity demand of 25,300 TWh.[14] However, the deployment of offshore wind in LMICs, and more generally in Emerging Markets and Developing Economies[15] (EMDE) remains minimal. Inadequate port infrastructure, essential for offshore wind deployment and maintenance, remains a significant barrier, along with a combination of financing challenges, lack of comprehensive policy frameworks, and insufficient local supply chains and expertise.

1.3 LOCAL ECONOMIES BENEFIT FROM OFFSHORE WIND DEVELOPMENT

Expanding offshore wind in EMDE regions can offer a wide range of benefits, including satisfying rising energy demand and improving energy independence, creating jobs, stimulating industrial development and positioning countries competitively in the energy transition.

First, with rapid growth in energy consumption across EMDEs and the urgent need to transition to renewable energy, the case for harnessing offshore wind resources is compelling. The opportunity exists to not only meet growing local energy needs but also foster energy independence.

FIGURE 1 HISTORIC OFFSHORE WIND DEPLOYMENT (ETC 2024)



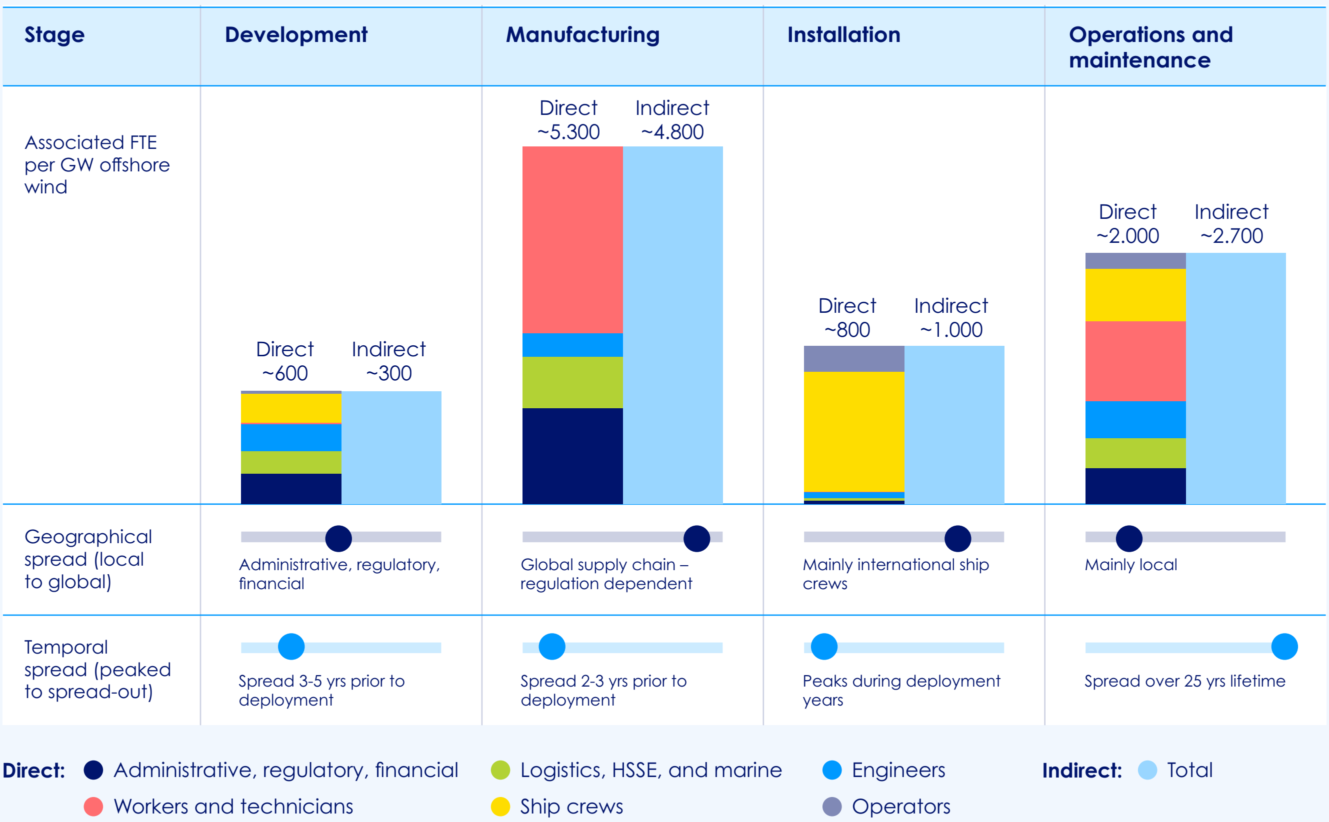
Deploying offshore wind at scale could drive job creation in these markets, foster new industries, and stimulate economic development. The development, installation, and operation of offshore wind farms supports employment across multiple sectors, including development, manufacturing, installation, and operations & maintenance, strengthening local economies and creating long-term workforce opportunities, **see Figure 2**. Over the full lifetime of an offshore wind farm, about 17,500 full-time equivalent roles (FTE) are created by every GW of offshore wind developed (including both direct and indirect employment).

By developing local value chains, EMDE countries can build capacity and establish a competitive edge in the global clean energy transition. Investment in offshore wind also attracts critical infrastructure development, such as the port facilities essential for the sector's growth.

Once operational, offshore wind farms provide reliable low-carbon electricity so that industrial growth is not held back by constraints due to lack of new power generation. Depending on local power system regulation and market dynamics, offshore wind can support port-industrial clusters and attract new energy intensive industries,[16] like data centers and hydrogen and ammonia production. This can help diversify the energy mix, reduce dependence on imported fossil fuels, and enhance energy security.

By aligning with international sustainability goals, EMDEs can position themselves as key players in the global green energy transformation.

FIGURE 2 JOBS CREATED BY OFFSHORE WIND DEVELOPMENT[17]



Source: Danish shipping, wind Denmark and Danish energy with support from the Danish maritime foundation – "Socio-economic impact study of offshore wind" 2020. Cross-checked with NREL – "The demand for a domestic offshore wind energy supply chain".

2
COORDINATED INFRASTRUCTURE DEVELOPMENT TO CAPTURE THE OFFSHORE WIND OPPORTUNITY

2.1 SEAPORTS PERFORM CRUCIAL ROLES THROUGHOUT THE LIFETIME OF AN OFFSHORE WIND FARM

Ports are the linchpins of the offshore wind supply chain throughout the wind farm's lifetime. Every stage of an offshore wind project relies heavily on port infrastructure and services, with the port acting as a strategic hub.

To illustrate: initial planning of an offshore wind farm relies on surveying activities launched from ports, including site selection and environmental assessments. Next, manufacturing facilities for offshore wind components such as turbine blades, towers, and foundations are often located in port regions, ensuring easy access to global shipping routes. These components are exceptionally large and heavy, making transportation by road impractical.

Once manufactured, components need to be gathered, stored, and pre-assembled at marshalling ports to streamline offshore installation, ideally close to the offshore wind site. Installation vessels then transport the components to offshore sites, and ports serve as logistical bases for crews and equipment.

Once a wind farm is operational, ports play a crucial role in its upkeep, supporting maintenance teams and housing service vessels that ensure turbines remain in peak condition. Even after decades of operation, ports remain essential, facilitating the decommissioning or repowering of wind farms by handling the retrieval and recycling of aging components, **see Figure 3**.

FIGURE 3 ROLES OF PORTS OVER THE LIFETIME OF AN OFFSHORE WIND FARM

Offshore wind development stage	**Planning & design**	**Manufacturing & procurement**	**Construction & installation**	**Operation & maintenance**	**Decommissioning**
Key activities per phase	Site selection, environmental checks, permits & regulatory approvals, wind farm design finalization	Manufacturing of components; purchase of turbines key components	Installation of foundations, turbines and associated infra (electrical systems, substructures)	Ongoing wind farm operations (and optimization); regular maintenance and repairs	Decommissioning and dismantling of turbines and associated infra; recovery of recyclable materials; site restoration
Key roles for ports	**Ports nearby offshore wind site** act as departure point for site investigations	**Manufacturing ports** produce components for offshore wind, and ship out manufactured components overseas.	**Marshalling ports** serve as marshalling yards where all components for a project are gathered, stored and pre-assembled before being loaded onto installation vessels.	**O&M ports** act as O&M bases for operational wind farms. Crew transfer vessels and service operations vessels depart from these ports to conduct maintenance.	**Decommissioning ports** at the wind farm's end-of-life (or repowering), turbines and foundations will be brought back onshore through these ports.

Note: Most ports can play multiple roles.

FIGURE 4 INFRASTRUCTURAL REQUIREMENTS FOR MANUFACTURING PORTS, MARSHALLING PORTS AND OPERATIONS AND MAINTENANCE PORTS

	Manufacturing ports	**Marshalling ports**	**Operations and maintenance ports**
Distance from offshore wind development	No limit	Max. 200–400 km	Max. 70–200 km[2]

Infrastructure requirements Based on fixed-bottom offshore wind	• Storage space depending on component:
	  • Nacelles: 3–6 ha
	  • Blades: 5–20 ha
	  • Towers: 4–30 ha
	  • Foundations: 15–60 ha
	• Port access:
	  • Water depth: 9–12 m below LAT,
	  • Port entrance width of 200 m
	  • Air draft of 40–150 m (depends on component)
	• Good hinterland connection (rail, road, waterways)
	• Long quay: ~200 m at which transport vessels can berth
	• Load-bearing capacity: quay with load bearing capacity of 15–40 t/m^2
		• Storage space: ~20–30 ha required to develop 1 GW offshore wind from a port over one-two years1
		• Port access:
		  • Water depth: 9–12 m below LAT,
		  • Port entrance width of 200 m
		  • Air draft of >150 m
		• Long quay: 350–700 m at which two installation vessels can berth + 400 m for inbound vessels with components
		• Load-bearing capacity: quay with load bearing capacity of 15–30 t/m^2
			• Space: ~0.75–1.5 ha onshore area for facilities, 1–3 ha sheltered water area for vessel berthing
			• Port access:
			  • Water depth: 3–8 m below LAT[2]
			  • Port entrance width of 15–25 m[2]
			  • Air draft of 12–50 m[2]
			• Moderate quay: 20–100 m at which crew transfer vessels or service operation vessels can berth[2]

Additional requirements for floating offshore wind	• No commercial-scale examples yet, but likely similar to fixed-bottom offshore wind manufacturing except for production of floating substructures
	• Floating substructures are likely manufactured as smaller sub-components and only brought together in the marshalling port
		• Increased storage space per GW:
		  • 30–40 ha onshore storage
		  • 20–25 ha of wet storage for floating substructures
		• Increased port access
		  • Quayside water depth of 12–20 m
		  • No air draft restrictions
		• Quay with increased load bearing capacity of 40–100 t/m^2
			• No operational examples yet, but likely similar to fixed-bottom offshore wind operations and maintenance ports

Example port	 Port of Esbjerg, Denmark	 Port of Hull, United Kingdom	 Newhaven Port, United Kingdom

Source: Stakeholder interviews; Systemiq analysis; World Bank (2022) Key Factors for Successful Development of Offshore Wind in Emerging Markets; Parkison et al. (2022) Marshalling ports required to meet US policy targets for offshore wind power; BVGA (2023) Guide to a Floating Offshore Wind Farm; Rampion Offshore Wind Farm; BW Magazine (2020) Siemens Gamesa to double size of Hull offshore wind turbine blade factory; Port of Esbjerg

Notes: 1. If sufficient space is not available, marshalling operations can also be conducted from two ports – but this increases vessel costs. **2.** Lower end of range for Crew Transfer Vessels (CTV), used for daily operations at wind farms 50–75 km from the port. Higher end of range for Service Operation Vessels (SOV), used for wind farms further from the shore (>75 km)

2.2 DEDICATED LOCAL PORT INFRASTRUCTURE IS REQUIRED TO DEVELOP NEW OFFSHORE WIND REGIONS

Developing offshore wind in new regions requires dedicated local port infrastructure. The North Sea region is an example. It has seen rapid deployment of ~25 GW offshore wind over the past 10 years and is a success story in offshore wind.[18,19] Ports played a crucial role in this scale-up: around 30 ports are involved in the offshore wind supply chain.[20,21]

For any new region to scale offshore wind successfully, critical local port infrastructure must be in place, especially for marshalling and the operations and maintenance of deployed offshore wind farms. Manufacturing, if local, see Box 2, also requires port infrastructure as most components are too large to transport by road.

Manufacturing and marshalling ports have significant infrastructural requirements, **see Figure 4**. Offshore wind components are massive: blades can reach 140 meters in length, and monopile foundations can weigh up to 2,500 tons. These requirements place unique demands on port infrastructure: manufacturing and marshalling ports require long, high-load-bearing quays at which large offshore installation vessels can berth and load components, as well as extensive storage space.

In marshalling ports, components from multiple suppliers are gathered, staged, and in some cases pre-assembled before installation at sea. This requires large, unobstructed areas to accommodate all components for a full wind farm, as well as buffer space to absorb weather-related installation delays. Manufacturing ports also need substantial storage capacity, since production typically occurs year-round, while installation windows are seasonal and weather dependent. Once floating offshore wind reaches commercial scale, demands on port infrastructure will increase even further, as the floating substructures increase in size and weight.

O&M ports are less infrastructure-intensive than manufacturing or marshalling ports but are vital for long-term wind farm performance. They require space for facilities for maintenance teams, port access and sufficient quayside length for crew transfer vessels (CTVs) and/or larger service operation vessels (SOVs). Proximity to the wind farm is key to minimize crew transit times.

Box 1: Onshore electricity infrastructure and demand for offshore wind electricity

Although this paper focusses on coordinating port infrastructure, electricity infrastructure requires advance planning too. Electricity demand and efficient grid integration are essential for the successful deployment of offshore wind. Without a credible source of demand for the generated electricity, offshore wind farms will likely fail to attract investment. The demand for (additional) offshore wind electricity comes from multiple sources: replacing fossil fuel-based generation, meeting growing electricity needs driven by economic and population growth, enabling large-scale electrification of industries and transport, and supporting emerging applications such as Power-to-X (e.g., hydrogen or ammonia production). As discussed earlier, electricity demand in EMDE regions is likely to grow rapidly, and offshore wind could play a key role in satisfying this demand.

To reach end users, offshore wind electricity must be physically integrated into the power system. Today, offshore wind is connected to the onshore high-voltage transmission grid via an offshore substation, export cable, and onshore substation. This requires a nearby onshore grid connection point and sufficient grid capacity to handle large and variable electricity inflows. Often, this means costly grid infrastructure upgrades are needed, which can take 2–10 years.[22,23] Battery energy storage systems at or near the grid connection point can help smooth electricity peaks and reduce the extent of required grid reinforcements. Combining offshore wind connections with solar PV generation may also provide balancing benefits, as wind and solar generation profiles are often complementary, improving the overall stability of renewable power supply and maximizing the use of shared power infrastructure.[24]

To avoid transmission losses and reduce the need for costly long-distance grid upgrades, it is beneficial to support the growth of electricity offtake near the landing hub. Attracting electricity-intensive users – such as data centers or hydrogen production facilities – shortens the distance between supply and demand, improving grid efficiency.[25,26]

In the future, offshore wind electricity may also be connected directly to industrial or local users. These users – such as those producing green hydrogen, ammonia, or steel – may require on-site battery storage or flexible load management systems to handle variations in wind generation and ensure a stable electricity supply. As industrial electrification expands, integrating offshore wind with localized energy storage and demand-response strategies will be key to ensuring a reliable and cost-effective electricity supply.

While offshore Power-to-X concepts, such as hydrogen production at sea, are being explored as future integration models,[27] these concepts are not yet commercially mature and are therefore beyond the scope of this report.

2.3 STRATEGIC COORDINATION IS NEEDED TO DEVELOP OFFSHORE WIND PORTS

Strategic collaboration and coordination are essential to ensure the development of an efficient offshore wind ecosystem, particularly given the large investments and long lead times required for offshore wind ports. Marshalling and manufacturing ports demand the most substantial infrastructure and should therefore be the primary focus of coordination efforts. Looking ahead, floating offshore wind will require even more space, specialized infrastructure, and complex logistics than fixed-bottom projects – further amplifying the need for early and strategic coordination.

Not every coastal port can – or should – become an offshore wind hub. Instead, a region (whether province, country, or multi-state area) should coordinate to develop an ecosystem of complementary ports, each focusing on the roles for which it is best suited. This division of roles not only improves cost efficiency and avoids duplication of infrastructure but also helps to minimize the physical and environmental footprint of port development. Concentrating activities in the most suitable locations reduces the total land required for offshore wind logistics, easing pressure on coastal areas. By avoiding fragmented development across multiple ports, regional coordination can limit impacts on natural habitats and local communities. It also creates an opportunity to engage local communities early in the planning process, allowing concerns to be addressed and benefits to be shared. When communities are included from the outset, projects are more likely to build long-term support and avoid costly delays. A well-planned port ecosystem delivers the benefits of offshore wind with fewer adverse effects on people and nature.

Three types of strategic coordination are essential to develop ports that can support offshore wind: regional coordination, temporal coordination and pipeline coordination.

“

A REGION SHOULD COORDINATE TO DEVELOP AN ECOSYSTEM OF COMPLEMENTARY PORTS, EACH FOCUSING ON THE ROLES FOR WHICH IT IS BEST SUITED.

REGIONAL COORDINATION: STRATEGIC ROLE ALLOCATION IS CRITICAL FOR AN EFFICIENT PORT ECOSYSTEM

Within a region, coordinated planning is essential to determine which ports will take on which roles – marshalling, manufacturing, or operations & maintenance – in the offshore wind value chain. Without this alignment, there is a risk of either overbuilding redundant infrastructure or leaving critical gaps that delay offshore wind deployment.

Governments can play a leading role in this process, working with port authorities to assess which ports are well-positioned to support offshore wind development, based on their location relative to the planned development and current infrastructure. Based on this, governments can convene coordination discussions between port authorities, offshore wind developers, and the wider offshore wind supply chain to jointly identify priority ports for offshore wind and align public and private investment decisions and offshore wind policy accordingly.

One example of successful coordination can be found in Scotland, where offshore wind developers and the government work together through the Strategic Investment Model to identify infrastructure needs across the offshore wind value chain and coordinate and prioritize investments accordingly.[28] The working group has recently identified 10 priority projects, including 5 port facilities, for which it will facilitate meetings between offshore wind developers and the project owners.[29]

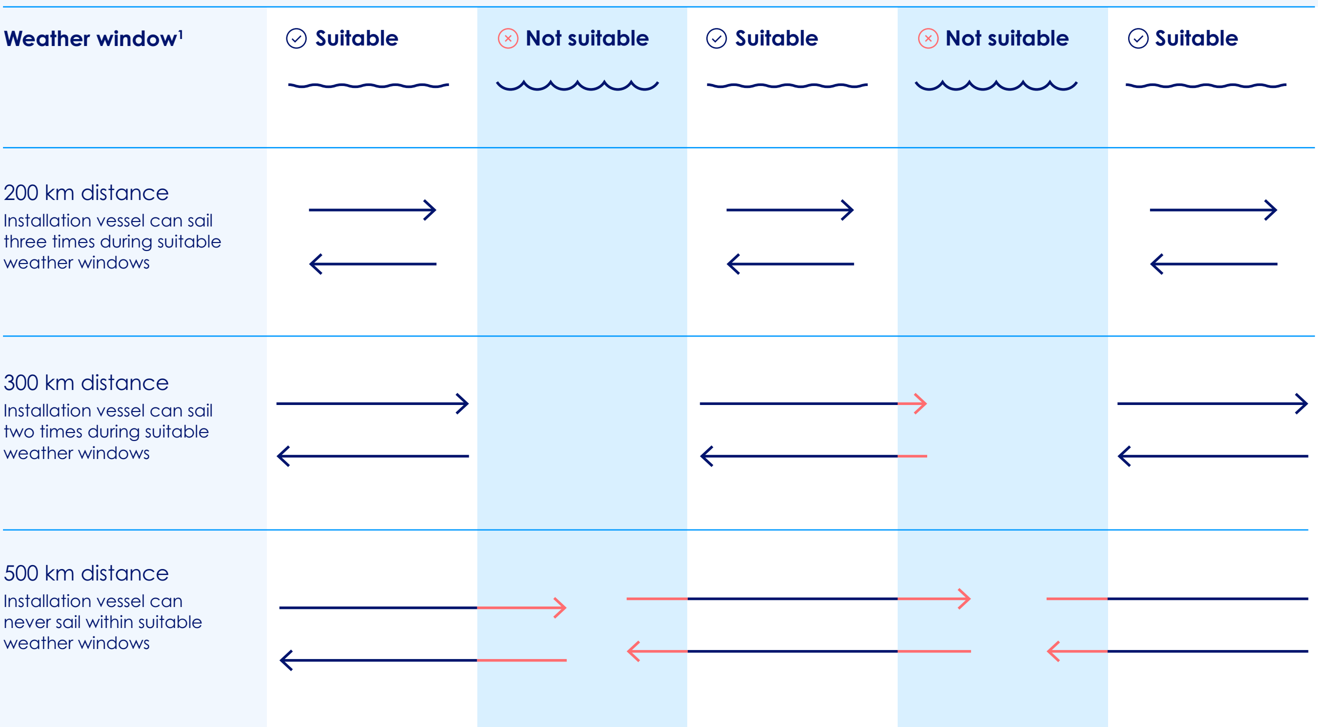
Specific considerations for regional coordination of port roles differ between marshalling and manufacturing functions and are discussed in the following sections.

Marshalling ports

Ultimately, the choice of marshalling port for a given offshore wind project lies with the developer, often in collaboration with component manufacturers. This choice is based on a combination of strategic, technical, and commercial considerations. To ensure investments in port infrastructure flow to the right number of ports in the right locations, coordination (as described in the section above) is essential – whether this means upgrading existing ports or developing new ports.

Two key drivers determine how many marshalling ports are needed in a region and which are geospatially the most suitable. First, the service area of marshalling ports: to minimize operational costs of installation vessels sailing to and from the installation site, offshore wind developers will aim to minimize the distance between the marshalling port and the site. Ideally, the port is located within 200 km of the offshore wind development. However, to justify the investments required for a new marshalling port, it also needs sufficient activity. This brings us to the second driver: deployment capacity of marshaling ports. Studies and industry experience suggest that well-equipped marshalling ports – with adequate storage capacity, quays and handling infrastructure – can typically support ~1 GW of offshore wind deployment per year.[30,31,32] To accommodate this, in some regions and under the right conditions, the service area of a marshalling port can reach up to ~ 400 km. Local weather conditions heavily influence the feasible distance between marshalling ports and project sites, as they directly influence the 'weather windows' in which installation vessels can operate, **see Figure 5**.

FIGURE 5 ILLUSTRATIVE MARSHALLING PORTS AT A LARGER DISTANCE FROM OSW DEVELOPMENT CAN LEAD TO A DISPROPORTIONATELY INCREASED INSTALLATION TIMELINE BECAUSE OF WEATHER CONDITIONS



Note: 1. Whether a weather window is suitable for sailing and installation depends on the significant wave height (should be < 2 m) and wind speed (should be < 12m/s at 10 m height).

Manufacturing ports

Regional coordination of manufacturing ports must occur at the national or international level, as proximity to offshore wind sites is not essential. Offshore wind components, including turbines, foundations, substations, and cables, are standardized and can be shipped globally. Even the largest components – such as blades, foundations, and towers – are routinely transported across continents.[33,34,35] This allows countries to source equipment from the most competitive suppliers worldwide.

At present, China has established a dominant position in offshore wind manufacturing, supplying 60–80% of global components[36] and benefiting from economies of scale, integrated supply chains, and cost-efficient production. As a result, importing components from China – or other established manufacturing hubs – can often appear to be the most attractive option from a purely cost-driven perspective. However, relying entirely on foreign manufacturing means missing out on the economic benefits of building a domestic supply chain. Although potentially higher cost, local manufacturing creates jobs, stimulates industrial development, and contributes to economic resilience. This tradeoff inherently depends on industrial policy, see Box 2.

What happens without regional coordination?
Lessons from LNG development in the Baltic region

Between 2011 and 2015, several Baltic countries – including Finland, Estonia, and Lithuania – each pursued their own LNG terminals, despite early analyses showing that only one was commercially viable.[37] Driven by energy security concerns, they moved ahead independently.[38]

Finland and Estonia failed to agree on a joint terminal despite years of negotiations. Finland built two small-scale terminals; Estonia developed its own floating storage and regasification unit, while also relying on Lithuania's import terminal.

The result of each country focusing on its own security of supply, without regional coordination: duplicated investments, inefficient use of EU funds, and underutilized infrastructure. A coordinated approach could have delivered a single, well-connected terminal with lower costs and stronger regional integration.[39]

This case offers a clear lesson: without effective regional coordination, the pursuit of national solutions alone can lead to redundant infrastructure, increased costs, and missed opportunities for energy resilience. For regions facing similar energy planning challenges, this example underscores the importance of aligning national interests with regional strategy.

Involving local communities in energy infrastructure projects: Lessons from an onshore wind farm in Kenya

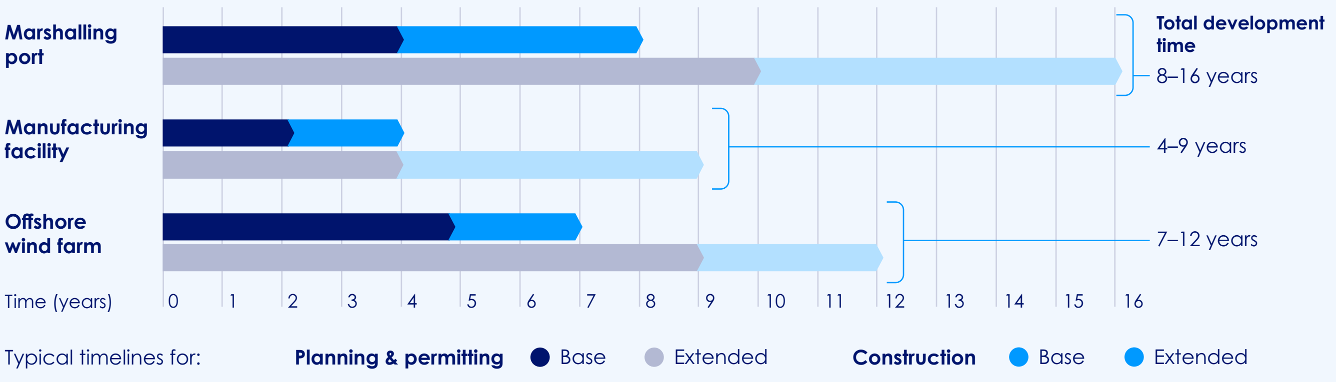
The 100 MW Kipeto Wind Power Project in Kenya's Kajiado County exemplifies effective collaboration with local communities in renewable energy development. Situated on communal Maasai land, the project prioritized early and continuous engagement with local communities.[40]

Key initiatives included the establishment of the Kipeto Community Trust, which receives 5% of project revenues to fund community development. During construction, over 500 of the 900 workers were from the local community and many continue to be employed in various roles, such as engineers and community liaison officers.[41] Additionally, a Biodiversity Action Plan was implemented to mitigate environmental impacts, including measures to protect endangered vulture species.[42] These collaborative efforts fostered trust, minimized disputes, and ensured the project's timely completion in 2021. It now supplies power to approximately 250,000 Kenyan homes.[43]

TEMPORAL COORDINATION: PORT INFRASTRUCTURE DEVELOPMENT CAN BE NEEDED AHEAD OF OFFSHORE WIND DEVELOPMENT

Developing offshore wind ports may require major infrastructure upgrades – such as deepening waterways, extending quays and increasing their load-bearing capacity, installing heavy-lift cranes, and organizing logistics and staging areas. The scale, timing, and cost of these upgrades depend heavily on the condition of existing port infrastructure and the complexity of local permitting processes. A key risk to timely offshore wind deployment is the lack of suitable port infrastructure. In some cases, port development may take longer than the development of offshore wind projects themselves, see Figure 6.[44,45,46]

FIGURE 6 TYPICAL TIMELINES ASSOCIATED WITH DEVELOPING OFFSHORE WIND AND PORTS[47]



Note: Actual timelines for port, manufacturing facility and offshore wind development highly dependent on existing infrastructure and local characteristics. Timelines are indicative and based on historical cases.

Source: BOEM (2023) California Floating Offshore Wind Regional Ports Feasibility Analysis; Royal Haskoning DHV (2023) North Seas offshore wind ports study 2030–2050 NREL (2023) A Supply Chain Road Map for Offshore wind Energy in the United States; Parkinson et al. (2022) Marshalling ports required to meet US policy targets for offshore wind power; WindEurope (2024) Investments in European manufacturing facilities; Iberdrola (2024) Construction of an offshore wind plant; ETC (2023) Streamlining planning and permitting to accelerate wind and solar deployment; Offshore wind timelines based on a selection of recently commissioned offshore wind farms, including Hornsea Two (UK); Moray East (UK), Borselle 1 & 2 (NL), Hollandse Kust Zuid (NL), Hohe See & Albatros (DE); Greater Changua 1 & 2a (TW)

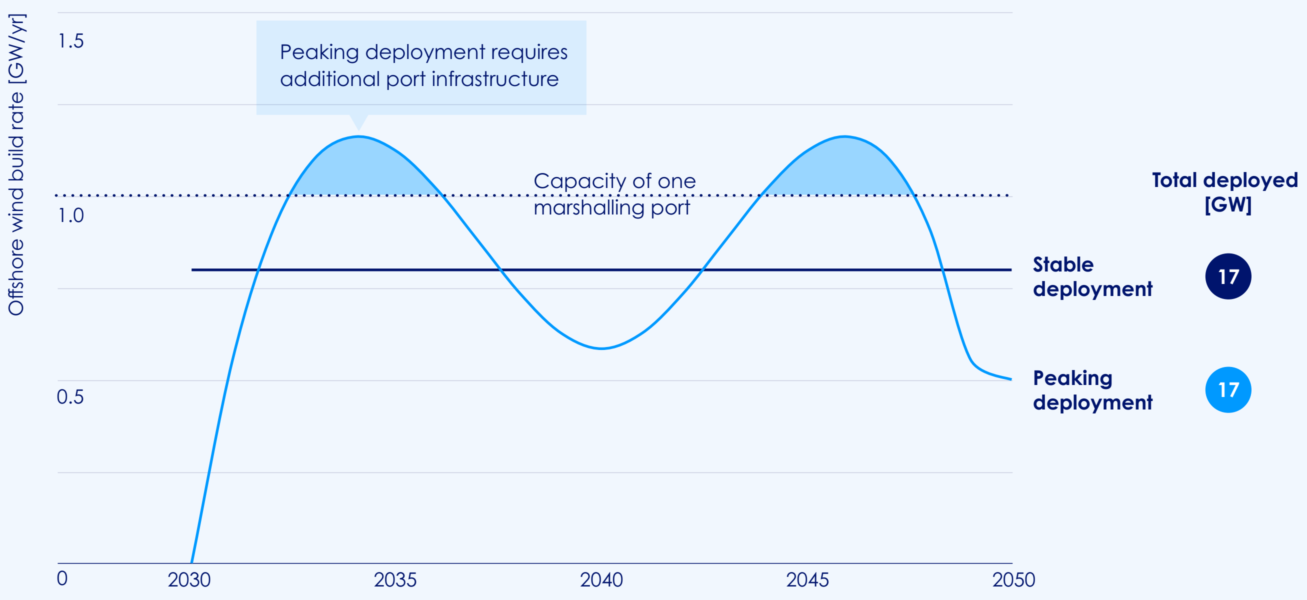
In practice, investment in port infrastructure often only follows after developers have secured offshore wind permits or seabed leases, creating a chicken-and-egg scenario. Developers are hesitant to commit to projects in regions without viable nearby ports, while investors and governments are reluctant to invest in port upgrades without a clear pipeline of projects. To prevent port capacity from becoming a bottleneck, early and strategic planning is essential. Governments overseeing offshore wind auctions can break this cycle, by facilitating early coordination between port authorities and developers and ensuring that infrastructure investment aligns with offshore wind deployment timelines.

PIPELINE COORDINATION: A RELIABLE, COORDINATED PIPELINE IS CRITICAL TO UNLOCK PORT INVESTMENTS

Upgrading existing ports for marshalling typically demands significant investment. Investment requirements can vary significantly from $100million up to $1,100 million depending on the type of infrastructure upgrades needed (such as increasing the load-bearing capacities of quays or dredging channels).[48,49,50] To justify these investments, there must be a sizable, stable, and reliable pipeline of offshore wind development close enough (see previous section) for a marshalling port to service. By proactively aligning offshore wind zones to be geographically concentrated around intended marshalling ports in the marine spatial planning process, and aiming for a stable, continuous pace of planning and auctions, governments can enable investments into port infrastructure, see Figure 7.[51]

Ideally, governments in offshore wind regions would coordinate strategically to attract manufacturing hubs. Once the project pipeline reaches sufficient scale – typically around 5–10 GW[52] – original equipment manufacturers (OEMs) may consider establishing local manufacturing facilities, such as blade or tower factories, at or near ports. These facilities require significant capital investment, ranging from €100–500 million depending on the component and manufacturer.[53]

FIGURE 7 ILLUSTRATIVE IMPACT OF OFFSHORE WIND BUILD RATE ON REQUIRED PORT INFRASTRUCTURE



While a robust project pipeline creates favorable conditions for local manufacturing, scale alone rarely ensures the localization of production facilities. As discussed earlier, attracting manufacturing depends on a country's industrial policy – see details in Box 2.

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SCALE ALONE RARELY ENSURES THE LOCALIZATION OF PRODUCTION FACILITIES.

The turbine sizing of projects in the pipeline is also best coordinated early to design future-proof port infrastructure. The physical requirements of marshalling and manufacturing ports – such as quay length, load-bearing capacity, and storage area – are directly influenced by the scale of offshore wind turbines. These infrastructure specifications affect not only port design and cost but also vessel selection and logistics. Early coordination between developers, OEMs, port authorities, and governments is essential to ensure port infrastructure is fit for purpose and aligned with the future needs of the offshore wind industry.

Box 2: Assessing the opportunity for local manufacturing

Whether a country develops a (partial) domestic supply chain for offshore wind is a strategic and political trade-off. Local manufacturing creates jobs, stimulates industrial development, and contributes to economic resilience. While initial Levelized Costs of Energy (LCOE) from domestically-manufactured offshore wind may be higher due to the need for infrastructure investments, workforce training, and supply chain development, the long-term benefits can outweigh the short-term cost advantages of imports.

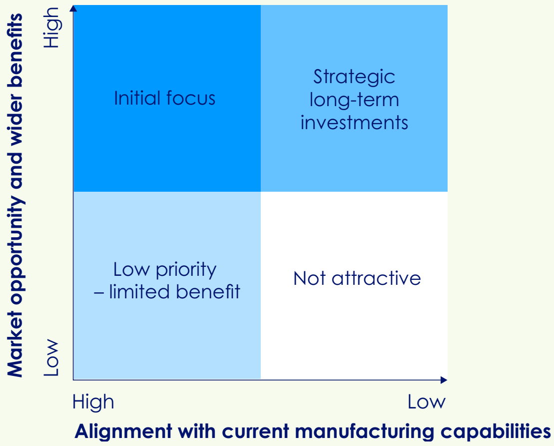
To develop a domestic offshore wind manufacturing sector, policymakers can implement industrial policies such as local content requirements, financial incentives for manufacturers, and regulatory frameworks that support local industry growth. Such policies require careful design to balance the goals of cost efficiency, industry competitiveness, and economic development. For example, the UK encourages local manufacturing by linking local content to eligibility for Contracts for Difference,[54] while Taiwan attempted to jump-start a domestic supply chain by requiring a minimum of 60% local content for all offshore wind projects, which was later relaxed as it resulted in expensive projects.[55,56,57]

To guide strategic decisions on developing local offshore wind supply chains, the opportunity for local manufacturing of specific offshore wind components can be assessed based on alignment with a region's current manufacturing capabilities versus the market opportunity and wider benefits associated with local production of components, **see Figure 8**. Production of some base components (e.g., towers, foundations) may not be far removed from skills and production capabilities already available in other manufacturing sectors (e.g., steel welding). On the other hand, production of some components (e.g., nacelles) is highly specialized and demands significant expertise, capital, and longer lead times.

Assessing the market opportunity and wider benefits of producing a component locally incorporates the size and firmness of regional demand, job creation, wider economic benefits and synergies with other industries and export opportunities. A great example of such an assessment is the United Kingdom's Offshore Wind Industrial Growth Plan, which uses a 'make or buy' framework to prioritize components for local manufacturing.[58]

For emerging markets entering the offshore wind industry keen to localize (part of) the offshore wind supply chain, production of components close to current manufacturing capabilities and with high market opportunities can be the initial focus to establish industrial capability, attract investment, and create immediate economic value. After successfully establishing initial manufacturing capacities, emerging markets can gradually transition toward strategic, selective investments in components further removed from existing manufacturing capabilities with high market opportunities, balancing long-term ambition with realistic assessments of local industry readiness and competitive advantage.

Figure 8 Assessing the local manufacturing opportunity



3
CASE STUDY FOR DEVELOPING THE OFFSHORE WIND REGION IN THE SOUTH OF BRAZIL

3.1 THE SOUTH OF BRAZIL IS A PROMISING REGION FOR OFFSHORE WIND

Brazil is a promising country for offshore wind development, with an estimated technical potential of approximately 1,200 GW – comprising 480 GW for fixed-bottom foundations and 748 GW for floating installations.[59,60] The Brazilian government has recently passed a regulatory framework for offshore wind energy production and there is a large pipeline of announced projects of 234 GW.[61]

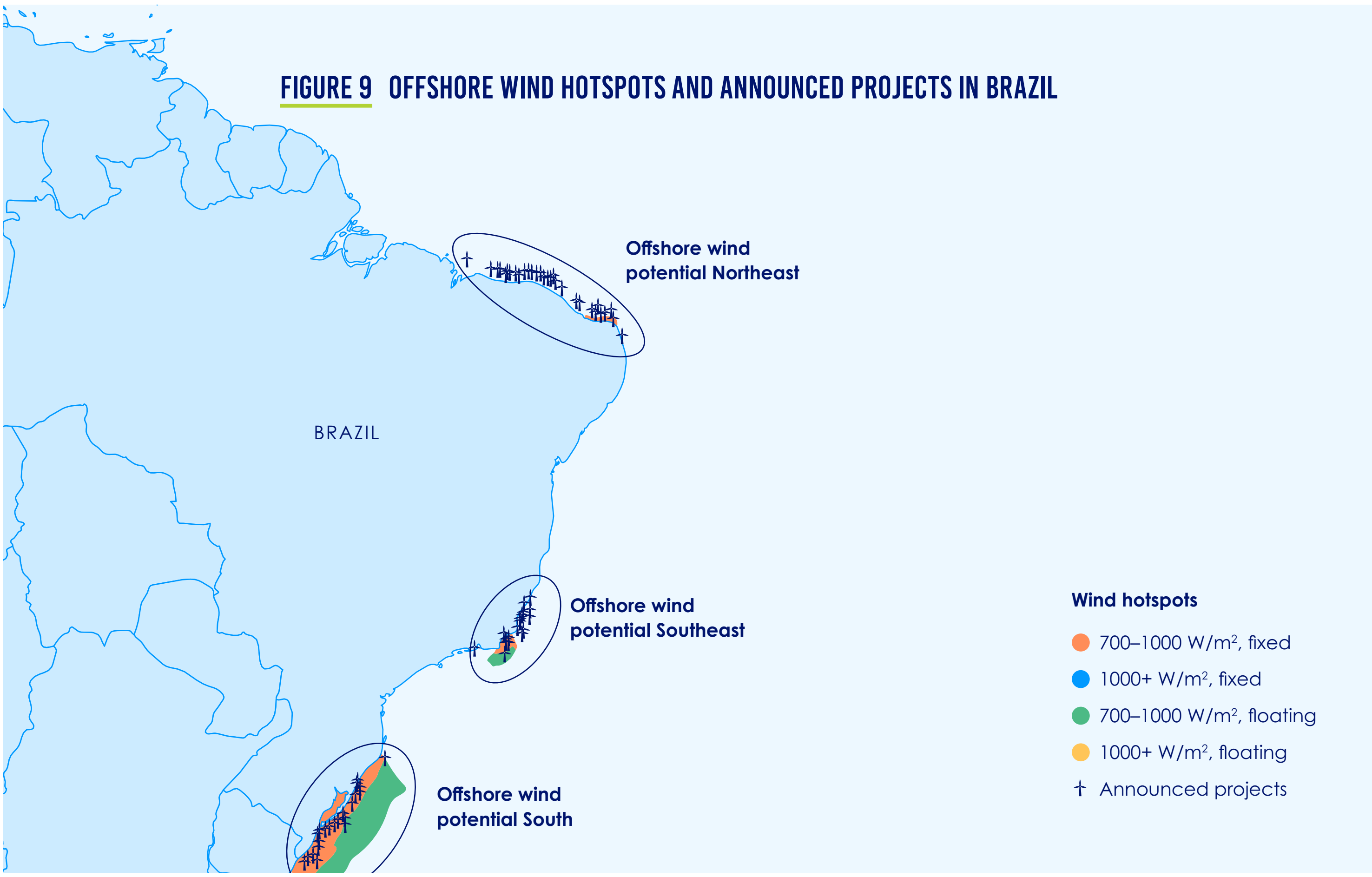
Brazil has three regions with concentrated offshore wind potential: the Northeast, the Southeast, and the South, **see Figure 9**. All three regions have great offshore wind resource and are likely to see offshore wind developments in the future. All three also have several suitable ports that could play critical roles in offshore wind development locally, such as the ports of Pecém (Northeast), Açu (Southeast) and Rio Grande (South).

This case study focuses on the South, as its proximity to Urugay and Argentina allows us to explore regional cooperation and coordination of port infrastructure across borders.

3.2 SEVERAL PORTS COULD BE UPGRADED FOR MARSHALLING AND MANUFACTURING

This case study evaluates port infrastructure requirements across three distinct scenarios defined in the World Bank's *Scenarios for Offshore Wind Development in Brazil*, **see Figure 12**. The base and intermediate scenarios would warrant only 1 marshalling port in the South of Brazil, as annual deployment of offshore wind in that region would remain consistently below 1 GW. As such, regional coordination

FIGURE 9 OFFSHORE WIND HOTSPOTS AND ANNOUNCED PROJECTS IN BRAZIL



is needed for selecting a marshalling port, and offshore wind development should be planned and auctioned within a 200–400 km radius of that port. Consolidating marshalling activity around one strategically chosen port also minimizes land requirements – typically around 20–30 hectares for marshalling – significantly reducing the onshore footprint and impact on local communities.

In the ambitious scenario, the required number of marshalling ports in the South of Brazil would be 2 in 2030, up to 3 by 2040, as the deployment pace picks up to 3 GW per year. Proactive planning will be required to ensure sufficient marshalling port capacity is developed in line with the pace of offshore wind installations.

In all scenarios, the ports of Rio Grande, Itajaí, Paranagua, Tramandai and São Francisco could function as marshalling ports based on their proximity to the offshore wind zone and current port infrastructure,[63] **see Figure 10**. A high-level assessment of space available in the port suggests the ports of Rio Grande, Itajaí and Paranagua are most suitable.[64] The nearest ports in Uruguay and Argentina are not within marshalling distance from the offshore wind zone in the South of Brazil.

While in the base and intermediate scenarios the pipeline is likely not sufficiently large to warrant local manufacturing capacity, in the ambitious scenario it may be. However, while a robust pipeline creates favorable conditions for local manufacturing, it does not guarantee it (see Box 2).

FIGURE 10 MARSHALLING PORT CANDIDATES IN THE SOUTH OF BRAZIL[62]

In the ambitious scenario, if the country or region prioritizes local manufacturing of offshore wind components through industrial policies, for example the production of towers, foundations and cables may be localized. Together, these components make up ~20% of a wind farm's capex.[65] Between 2030–2050, 3–7 manufacturing facilities[66] would be needed to supply these components domestically.[67] Suitable manufacturing port candidates include the ports of Rio Grande and Açu,[68] given their strategic advantages, **see Figure 13**. Both ports could serve as manufacturing hubs supplying components for offshore wind projects in neighboring Argentina and Uruguay, further enhancing regional industrial opportunities. The main ports in Argentina and Uruguay (Buenos Aires, Montevideo) border on the capital cities and may have limited space available for offshore wind manufacturing.

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IF THE COUNTRY OR REGION PRIORITIZES LOCAL MANUFACTURING OF OFFSHORE WIND COMPONENTS THROUGH INDUSTRIAL POLICIES. FOUNDATIONS AND CABLES MAY BE LOCALIZED.

Brazil's onshore wind supply chain

Targeted policies have ensured a robust local supply chain for onshore wind components: the Proinfa system (2002–2011) initially required 60% of components to be manufactured locally. Following that, eligibility requirements for project financing in Reais and reduced-interest rate public financing (BNDES) required hubs and nacelles to be manufactured locally as well as 60% local content for towers and blades. These policies paved the way for 6 OEMs and over 100 sub-suppliers of parts and components to become active in onshore wind manufacturing in Brazil.[69]

However, recent growth in rooftop solar PV generation has offset the need for new electricity supply required by the country's demand growth, which has been mainly driven by the household segment in the last few years. Consequently, onshore wind generation capacity growth has almost stalled, and electricity prices in Brazil have dropped. This has caused some onshore wind manufacturers to pause or stop production in Brazil.[70,71] When demand for low-carbon electricity recovers and development of offshore wind reaches sufficient pipelines in the future, some existing onshore wind manufacturing facilities may be repurposed to produce offshore wind components, depending on their scale and location.

3.3 INVESTMENTS AND BENEFITS OF LOCAL OFFSHORE WIND PORT INFRASTRUCTURE

Investments in port infrastructure are essential to enable offshore wind development in the South of Brazil. Depending on the scale of offshore wind deployment, between 1–3 marshalling ports will require upgrades or new infrastructure development and 3–7 manufacturing facilities may be established.

Rio Grande do Sul – one of Brazil's three states in the South – is among the few that still depend on coal power. The state-level government has launched a Just Energy Transition plan, signaling its commitment to green economic growth and the replacement of coal plants with renewable energy.[72] Investments in offshore wind and port infrastructure align closely with this agenda: they ensure reliable access to low-carbon electricity for Brazil's densely populated South while driving local economic development and job creation.

In the base and intermediate scenarios, infrastructure investments for a single marshalling port are estimated to range between $0.1–0.5 billion, depending on the existing infrastructure at the chosen port (**see Figure 12**). Under the ambitious scenario, infrastructure requirements triple to approximately $0.3–1.5 billion, reflecting the need to develop up to three marshalling ports. The ambitious scenario could also warrant investments in local manufacturing facilities of approximately $1.4–2 billion, depending on the complexity and type of component.

Beyond direct investment, offshore wind can substantially boost regional employment: the base and intermediate scenarios would generate between 13,000–19,000 local FTE jobs spread over the offshore wind projects' lifetime, **see Figure 13**. Under the ambitious scenario, employment benefits increase fivefold, driven by a larger pipeline and the establishment of local manufacturing.

Both the ports of Açu and Rio Grande illustrate how low-carbon supply chain jobs can support a just transition for fossil-based workforces. Açu, historically focused on oil and gas, is now positioning itself as a hub for offshore wind and other clean industries. Similarly, the Rio Grande region, home to a coal mining workforce as well as manufacturing of offshore oil extraction platforms, offers strong potential for transitioning to low-carbon employment.[73]

4
RECOMMENDATIONS FOR STRATEGIC COORDINATION OF OFFSHORE WIND PORT INFRASTRUCTURE

To ensure emerging markets and developing economies can develop offshore wind efficiently and capitalize on the economic and strategic benefits it can bring, regional coordination and collaboration around port infrastructure development are crucial.

Five key actions to establish an efficient offshore wind port ecosystem:

1 ESTABLISH A STABLE, FIRM AND LONG-TERM OFFSHORE WIND PIPELINE

This is essential to justify significant upfront investments in dedicated port and manufacturing infrastructure. Governments should implement consistent and evenly-paced auction frameworks to avoid peaking port infrastructure requirements, accompanied by firm developer commitments that ensure investment certainty. This reliability allows port authorities and investors to plan and finance critical infrastructure developments. A complementary route to ensure continuous demand for new offshore wind is the establishment of a national industry policy program to foster demand for green energy (e.g., Power-to-X) or manufacturing (e.g., green steel) in the region. This will support a stable demand for offshore wind, allowing companies and investors to commit to new green ports.

2 FACILITATE A COORDINATED SELECTION OF OFFSHORE WIND PORTS TO FULFIL KEY ROLES IN THE OFFSHORE WIND VALUE CHAIN

(Sub)national governments and port authorities should proactively assess which ports are well-positioned to support offshore wind development as either marshalling, manufacturing and/or operations and maintenance ports, and map the readiness of critical infrastructure at these ports. Building on these assessments, governments can facilitate coordination discussions with port authorities, developers, and the wider offshore wind supply chain to select priority ports for the different functions and to jointly shape a complementary and efficient port ecosystem. This early-stage alignment helps prevent inefficient investments and ensures public and private sector efforts are directed toward ports with clear strategic potential.

3 COLLABORATE ON A COMPREHENSIVE VALUE-CHAIN-BACKED ROADMAP FOR OFFSHORE WIND PORTS

(Sub)national governments, port authorities, and offshore wind developers must collaborate closely to create and implement a detailed, value-chain-backed roadmap for the selected offshore wind ports. This roadmap should specify required infrastructure upgrades, investment timelines, and align infrastructure development closely with the offshore wind project pipeline. Such coordinated planning ensures timely availability of critical infrastructure, minimizing risks to offshore wind deployment timelines and maximizing regional economic benefits. Crucially, this planning process should include meaningful engagement with local communities and stakeholders from the outset. By incorporating land use impacts, environmental sensitivities, and socio-economic concerns into the roadmap, governments can foster public support, reduce development risks, and ensure offshore wind brings shared and sustainable benefits.

4 MARSHALLING PORTS: ALIGN PORT DEVELOPMENT PLANNING WITH MARINE SPATIAL PLANNING

To efficiently develop offshore wind regions, marine spatial planning must be closely integrated with port infrastructure development. Governments and port authorities should jointly designate offshore wind zones within feasible operational distances of marshalling ports. This alignment optimizes logistical efficiency, reduces environmental impacts, and prevents infrastructure bottlenecks by concentrating projects strategically around existing or planned marshalling ports.

5 MANUFACTURING PORTS: DEVELOP A LONG-TERM STRATEGIC VISION FOR OFFSHORE WIND COMPONENT MANUFACTURING, COMBINED WITH SUPPORTIVE POLICIES AND SECTOR ENGAGEMENT

Governments should establish a clear and strategic vision for local offshore wind manufacturing, explicitly identifying whether local production of components will be pursued. This vision needs to incorporate the country's current manufacturing capabilities, the market opportunity and wider economic benefits of local component manufacturing. A clear strategic vision, combined with supportive industrial policies and coordinated with offshore wind value chain stakeholders, can enable focused investment decisions and targeted capacity-building, ensuring that local manufacturing aligns effectively with regional economic goals.

GLOSSARY

Capacity Factor – the ratio of actual energy produced by a power plant over a given period to the maximum possible energy it could have produced if it operated at full capacity continuously during that period. It is expressed as a percentage and reflects the efficiency and utilization of a power plant.

Crew Transfer Vessel (CTV) – a small vessel used to transport maintenance crews to and from offshore wind farms. CTVs are typically used for wind farms located relatively close to shore (50–75 km)

Emerging Markets and Developing Economies (EMDEs) – countries or regions with lower income levels and less developed infrastructure and institutions, often characterized by rapid growth potential, expanding energy needs, and limited access to low-carbon technologies.

Export Cable – a high-voltage cable that transmits electricity from offshore wind turbines to shore, either for connection to the national grid or for direct industrial use.

Fixed-bottom Foundations – support structures for offshore wind turbines anchored directly to the seabed, such as monopiles, jackets, or gravity-based foundations. Suitable for shallow waters, typically less than 60 meters deep.

Floating Offshore Wind – a technology where wind turbines are mounted on buoyant platforms anchored to the seabed with mooring lines, allowing deployment in deeper waters where fixed-bottom foundations are not feasible.

Levelized Cost of Energy (LCOE) – the average cost of producing one megawatt-hour (MWh) of electricity over the entire lifetime of a power plant, including capital and operational costs. It enables cost comparisons across different energy technologies.

Manufacturing Port – a port with industrial infrastructure for producing offshore wind components such as towers, blades, and foundations.

Marshalling Port – a port where offshore wind components are received, stored, and partially assembled before being loaded onto vessels for transport to offshore installation sites.

Marine Spatial Planning (MSP) – a process for organizing human activities in marine areas to achieve ecological, economic, and social objectives. In offshore wind, MSP ensures optimal placement of wind farms relative to other uses and infrastructure.

Original Equipment Manufacturers (OEMs) – (in this context) companies that design and manufacture key offshore wind components, such as wind turbines, blades, nacelles, or other major systems.

Operations and Maintenance (O&M) Port – a port that serves as a base for the long-term servicing of offshore wind farms. These ports support maintenance crews and house vessels such as CTVs and SOVs to ensure ongoing turbine performance.

Power-to-X (PtX) – a group of technologies that convert renewable electricity into other energy carriers or fuels, such as hydrogen, ammonia, or synthetic hydrocarbons, for use in energy storage, transportation, or industrial processes.

Service Operation Vessel (SOV) – a specialized vessel that provides offshore accommodation and workspaces for technicians performing maintenance on offshore wind turbines. SOVs are typically used for offshore wind farms further from the shore (>75 km), as they are designed for multi-day missions and can operate in rough weather conditions.

Substation (Offshore) – a platform at sea that collects electricity from multiple turbines, increases the voltage via transformers, and transmits the power to shore through export cables. It is a key component in offshore wind power transmission.

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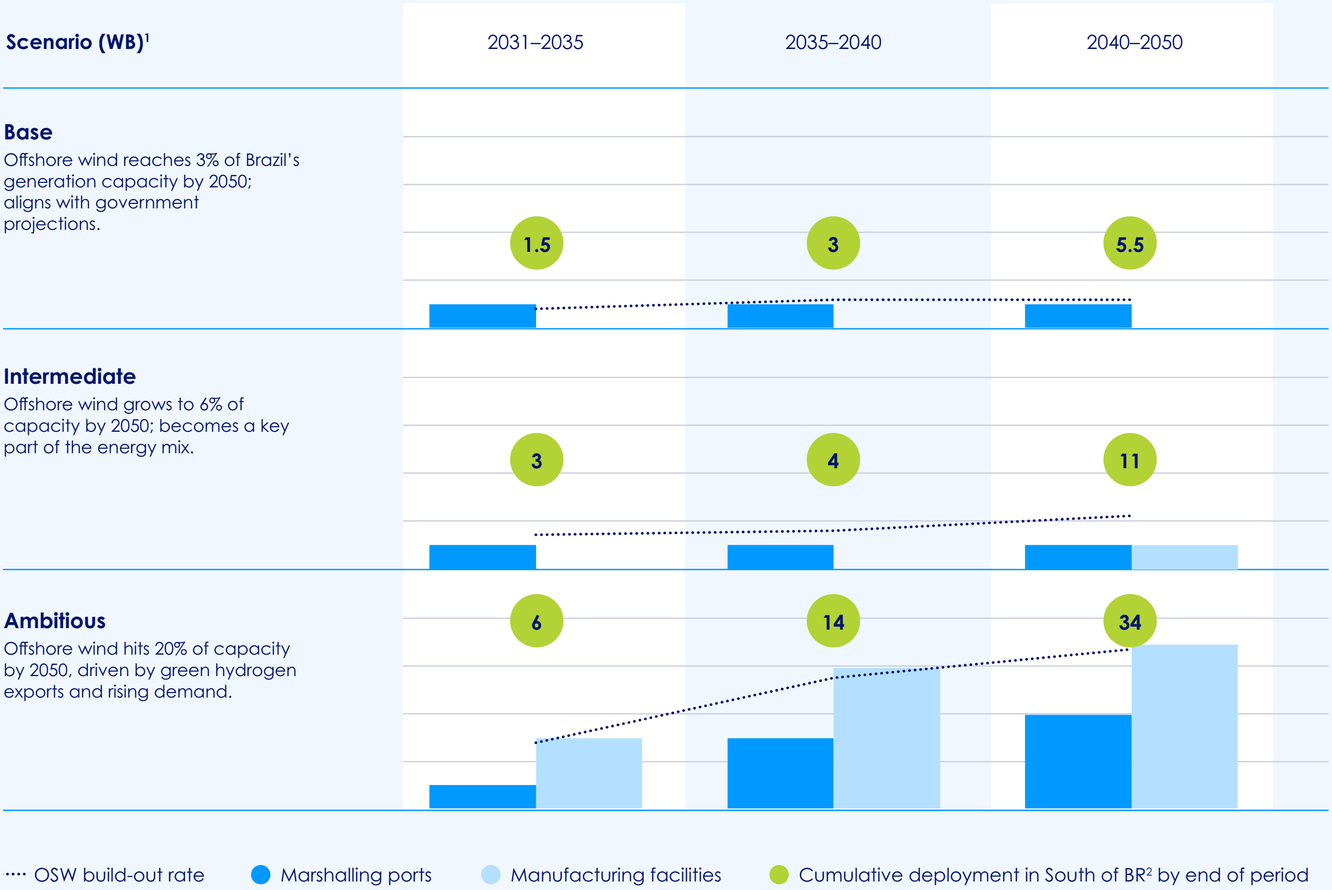
APPENDIX

APPENDIX 1 SCENARIOS USED FOR THE SOUTH OF BRAZIL CASE STUDY

The pace of offshore wind development in the South of Brazil will be shaped by multiple factors, including electricity demand, government support, and infrastructure readiness. The case study in this paper evaluates port infrastructure requirements across three distinct scenarios defined in the World Bank's *Scenarios for Offshore Wind Development in Brazil*, **see Figure 11**.

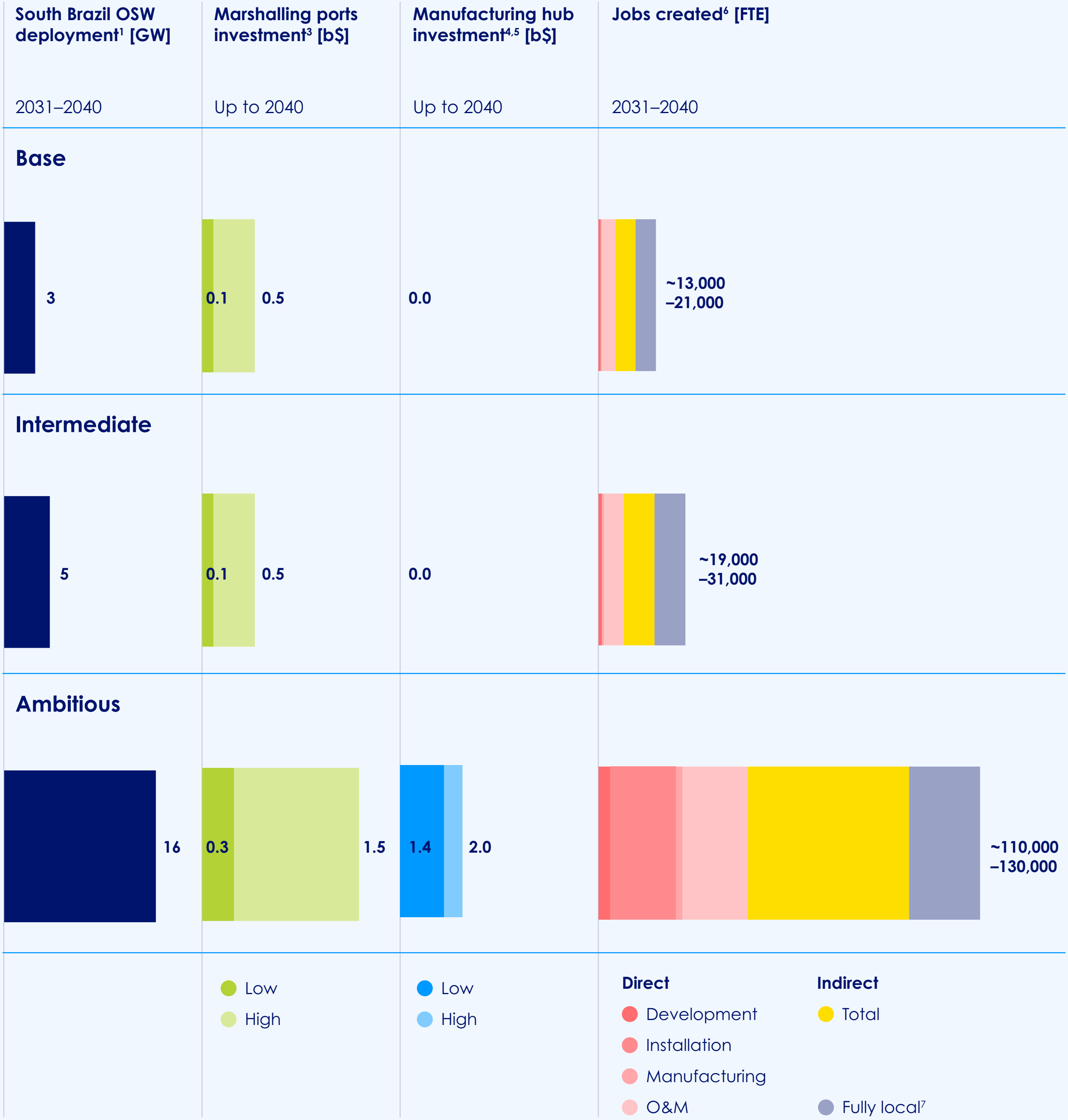
In all three scenarios, port infrastructure needs to be upgraded to accommodate the deployment of offshore wind. However, the scale of infrastructure and number of ports required varies depending on the project pipeline. Figure 11 summarizes the projected offshore wind deployment in the South of Brazil and required ports per scenario, as per the discussion on regional coordination in the previous chapter.

FIGURE 11 SCENARIOS FOR OFFSHORE WIND DEPLOYMENT AND ASSOCIATED PORTS IN THE SOUTH OF BRAZIL



Source: World Bank (2024) Scenarios for offshore wind development in Brazil
Notes: The projected scale of hydrogen production and export in the ambitious scenario is likely overstated, given recent shifts in global sentiment toward hydrogen.[74,75] However, there are opportunities in Brazil for growth in demand for green power and hydrogen, for example through the production of green steel or sustainable aviation fuel. **1.** OSW deployment scenarios based on World Bank scenarios. **2.** Based on World Bank scenarios for offshore wind in Brazil; South region deployment estimated by ratio of suitable area for bottom-fixed offshore wind in the South to national total. **3.** Assumes one marshalling port can serve 1 GW OSW deployment p.a. **4.** Base and intermediate scenario: no local manufacturing due to low build rate; ambitious scenario: local manufacturing of monopiles, towers and subsea cables, ~1.5 GW per year per facility per component.

FIGURE 12 JOBS AND INVESTMENT ASSOCIATED WITH OFFSHORE WIND DEPLOYMENT IN THE SOUTH OF BRAZIL UP TO 2040



Source: World Bank (2024) Scenarios for offshore wind development in Brazil; NREL (2023) A Supply Chain Road Map for Offshore wind Energy in the United States; Parkinson et al. (2022) Marshalling ports required to meet US policy targets for offshore wind power; WindEurope (2024) Investments in European manufacturing facilities

Notes: 1. Based on World Bank scenarios for offshore wind in Brazil; South region deployment estimated by ratio of suitable area for bottom-fixed offshore wind in the South to national total. **2.** Assumes one marshalling port can serve 1 GW OSW deployment p.a. **3.** Low scenario: port upgrade cost of $100M; high scenario: $500M per port. Actual investments depend on current port readiness. **4.** Base and intermediate scenario: no local manufacturing due to low build rate; ambitious scenario: local manufacturing of monopiles, towers and subsea cables, ~1.5 GW per year per component per year per facility. **5.** Investment total for coastal manufacturing facility (includes storage, quays etc. for sea transport). Low scenario: $235M per facility, average for towers, monopiles and subsea cables (based on WindEurope Investments in EU facilities); high scenario: $335M per facility, average for towers, monopiles and subsea cables (based on NREL Supply Chain Road Map) **6.** Assumes 50% of (in)direct development FTEs is local, 20% of (in)direct installation FTEs is local, 80% of (in)direct O&M FTE is local. Base and intermediate scenario assume 0% of manufacturing FTEs is local, ambitious scenario assumes 20% of manufacturing FTEs is local. **7.** Fully local bar illustrates employment effect if all (in)direct development, installation, and O&M is local, plus 20% of manufacturing in the Ambitious scenario.

FIGURE 13 ASSESSMENT OF POTENTIAL MARSHALLING AND MANUFACTURING PORTS FOR OFFSHORE WIND DEVELOPMENT IN THE SOUTH OF BRAZIL

Suitability for OSW role

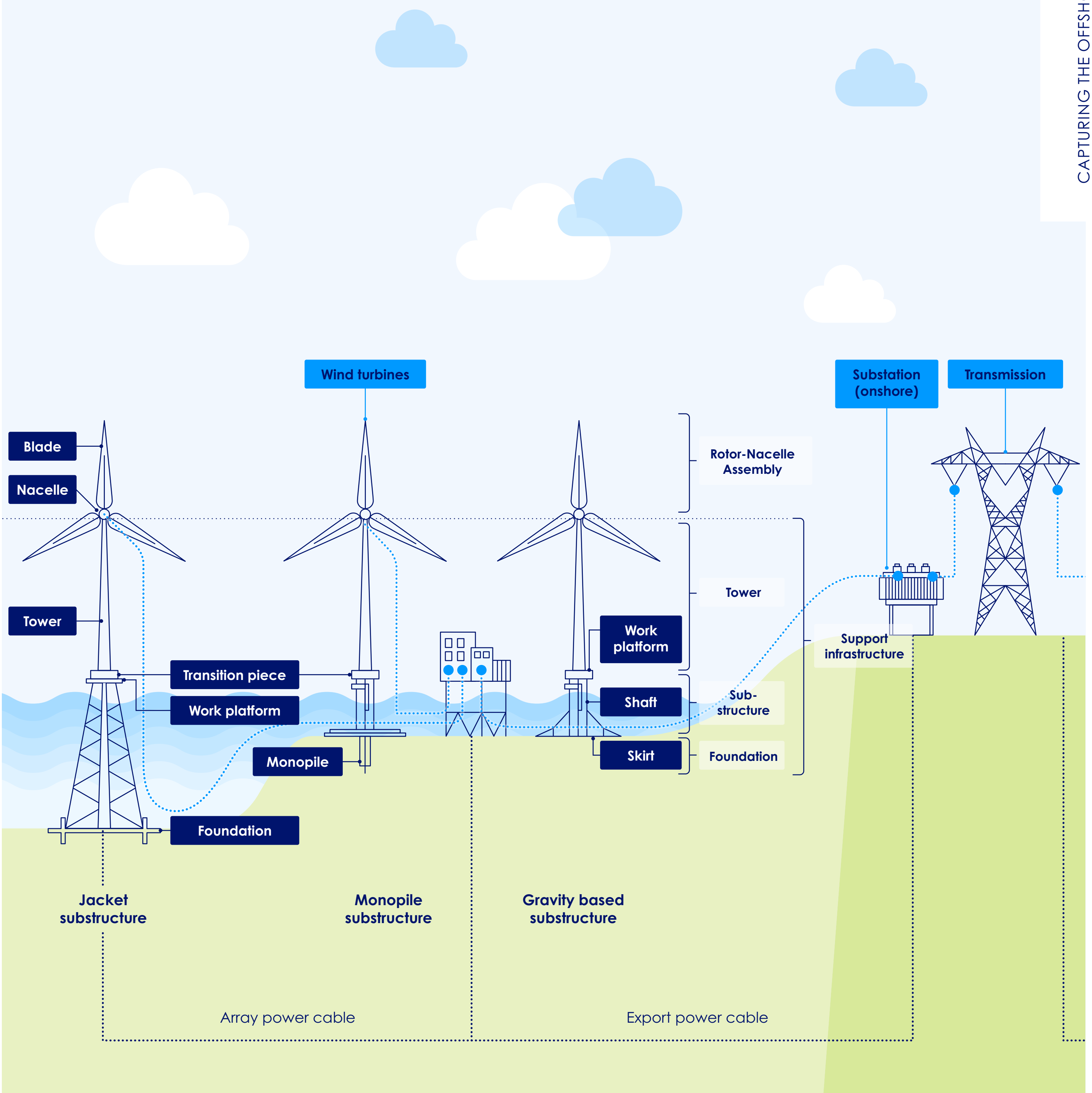
Yes · Partial · No

Port	Distance to OSW zone	Marshalling			Manufacturing			Port characteristics
		Distance	Space	Access	Space	Access	Hinterland	
Tramandai (BR)	5 km	Yes	No	Partial	No	Partial	Partial	Small offshore terminal supporting O&G industry. Port access sufficient for marshalling but likely limited space as port is located within city. Port entrance width not available.
Porto de Rio Grande (BR)	15 km	Yes	Yes	Yes	Yes	Yes	Yes	Brazil's second busiest port, housing a large industrial complex. State-owned port with 3 terminals in a lagoon.
Itajaí (BR)	120 km	Yes	Partial	Partial	Partial	Partial	Partial	One of Brazil's top container ports, focused on exports of food, textiles and wood. The port entrance width may be too narrow at 170 m.
São Francisco (BR)	210 km	Yes	No	Partial	No	Partial	Partial	Small port focused on transport of steel and agricultural products. Likely limited space as port is surrounded by dense urban development and located in hills, with few flat areas. The port entrance width may be too narrow at 150 m.
Paranagua (BR)	290 km	Yes	Partial	Partial	Partial	Partial	Partial	One of Brazil's top container ports, focused on agricultural products. The port entrance width may be too narrow at 150 m.
Montevideo (UR)	475 km	No	No	Yes	No	Yes	Yes	Medium-sized port in the capital of Uruguay. Three docks, used for containers. One dock can accommodate roll-on/roll-off vessels. Located next to large city, available space likely restricted.
Port of Santos (BR)	500 km	No	Partial	Yes	Partial	Partial	Partial	Large container terminal with roll-on/off facilities, may be suitable for manufacturing if space is available.
La Plata (AR)	600 km	No	Partial	No	Partial	No	Yes	Medium-sized port with better sea access than Buenos Aires. Not accessible for large offshore wind installation vessels: width of 60 meters and depth of 8.5 meters.
Buenos Aires (AR)	700 km	No	No	Partial	No	Partial	Yes	Large port, Argentina's primary port. Located in the capital city and next to a nature reserve, space is likely restricted.
Rio de Janeiro (BR)	800 km	No	No	Yes	No	Yes	Yes	Large port with modern cargo handling facilities, including roll—on/roll-off vessels. Space availability likely limited because of dense urban development surrounding the port.
Port of Açu (BR)	1000 km	No	Partial	Yes	Yes	Yes	Yes	Privately owned port, specialized in cargo activities across 2 terminals. Committed to the energy transition, with MoUs focusing on sustainability and energy.

Source: World Port Index (2024);Global Energy Monitor (2025) Global Wind Power Tracker, February 2025 release; Global Wind Atlas (2023); Climate Trace (2025); Open Infrastructure Map (2025); World Bank (2024) Scenarios for Offshore Wind Development in Brazil; Port Authority websites ; Systemiq Analysis; Expert interviews

MAIN COMPONENTS OF AN OFFSHORE WIND FARM

FIGURE 14 MAIN COMPONENTS OF AN OFFSHORE WIND FARM



Note: components for floating offshore wind not depicted here.
Source: Based on figure in "Scenarios for Offshore Wind Development in Brazil", World Bank, 2024

ENDNOTES

1 "Oceans, seas and Coasts", UNEP

2 Seabed space generally knows less restrictions than land use, but can also be constrained due to multiple users and stakeholders (shipping, fisheries, nature reserves, military zones etc.

3 "Overcoming Turbulence in the Offshore Wind Sector", Energy Transitions Commission, 2024

4 Note that LCOE can be higher – even today – in regions without careful planning and auctioning

5 "Overcoming Turbulence in the Offshore Wind Sector", Energy Transitions Commission, 2024

6 "Overcoming Turbulence in the Offshore Wind Sector", Energy Transitions Commission, 2024

7 "Overcoming Turbulence in the Offshore Wind Sector", Energy Transitions Commission, 2024

8 "Global Wind Report 2024", GWEC, 2024

9 "Offshore Wind Outlook 2019: World Energy Outlook Special Report", IEA, 2019

10 "Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels", ETC, 2023

11 The largest operational floating wind farm has a capacity of 88 MW (Hywind Tampen)

12 "Global Wind Power Tracker", Global Energy Monitor, February 2025 release.

13 "Market Outlook 2024–2033", Global Wind Energy Council, 2024

14 "World Energy Outlook 2024", IEA, 2024

15 EMDE is a broad term for all countries not considered advanced economies. This includes LMICs, but also some higher income countries that are still considered "emerging".

16 The attractiveness of the offhore wind electricity will depend heavily on the price of generated electricity and thus on local power system and regulatory regime.

17 Note that estimates for offshore wind jobs are sometimes difficult to compare like-for-like across sources, because there are differences in scope considered (e.g., direct versus indirect jobs, local versus global jobs, and scope of value chain considered).

18 "Global Wind Power Tracker", Global Energy Monitor, February 2025 release.

19 "The European offshore wind industry – key trends and statistics 2015", European Wind Energy Association, 2016

20 Ports in Denmark, the Netherlands, Germany, France, the United Kingdom, Belgium and Ireland.

21 "Investments in ports for offshore wind", 2024, European Commission

22 "Streamlining planning and permitting to accelerate wind and solar deployment", ETC, 2023

23 These timelines are highly dependent on planning and permitting: construction itself can happen in 1–2 years

24 "Offshore wind co-location: integrating offshore wind with flexibility", RenewableUK, 2025

25 "Dutch Offshore Wind Innovation Guide", Wind & water works, 2024

26 For example, in recent offshore wind auctions in the Netherlands, investments into energy system integration were included as one of the tender criteria. Winning developers included plans for electrolysers and co-developing floating solar energy and battery systems.

27 For example: https://www.tno.nl/en/sustainable/energy-supply/energy-systems-transition/energy-islands-conversion-transport/

28 "Full clarity and route forward for all Strategic Investment Model (SIM) projects", Offshore Wind Scotland, 2024

29 As the process is still ongoing, no investment has been made into the selected projects so far

30 Confirmed by several expert interviews

31 "Marshalling ports required to meet US policy targets for offshore wind power", Parkison et al., 2022

32 If a marshalling port's storage capacity is limited, operations are sometimes split over two ports.

33 For example, Vestas shipped 156 blades from China to Spain in 2019, and Dajin Heavy Industry shipped towers for the Moray offshore wind farm from China to Scotland last year.

34 "Record Vestas wind blade cargo on giant boat from China", Recharge, 2019

35 "Dajin Ships First Bath of Wind Turbine Towers for Moray West", OffshoreWIND.biz, 2024

36 Statista https://www.statista.com/statistics/1385431/global-offshore-manufacturing-shares-by-region-and-component/

37 "Public debate on the Baltic LNG terminal", RKK ICDS, 2012

38 "LNG Projects in Latvia and Lithuania can be mutually compatible", The Jamestown foundation, 2011

39 "The Baltic-Nordic Region and the Future European LNG Market", RKK ICDS, 2015

40 "Kipeto Wind Energy Project: A case study on best practice in community engagement in energy projects"; Business & Human Rights Resource Centre, 2018

41 "Kipeto Wind Power Project", Infrahub.Africa, 2025

42 "Winds of Change", The Nature Conservancy, 2023

43 "Kipeto Wind Power Project, Kenya", Power Technology, 2021

44 This paper focuses only on the types of ports with the most pressing infrastructure needs. Operations & maintenance (O&M) ports require much less infrastructure, and decommissioning ports only become relevant ~25 years after offshore wind commissioning.

45 "2030 Vision for European Offshore Wind Ports", Wind Europe, 2021

46 Based on industry examples (e.g., Siemens Gamesa facility in Le Havre, Vestas blades factory in Szczecin)

47 Exact timelines for port, manufacturing facility and offshore wind development are highly dependent on existing infrastructure and local characteristics. Depicted timelines are indicative and based on historical cases.

48 "California Floating Offshore Wind Regional Ports Feasibility Analysis", BOEM, 2023

49 Higher end of the range based on marshalling ports for floating offshore wind. Exact investments highly dependent on existing port infrastructure.

50 "2030 Vision for European Offshore Wind Ports", Wind Europe, 2021

51 The investment case for marshalling ports is often challenging for private investors and can be an area where strategic government support is required.

52 Source: expert interviews

53 "Investments in European manufacturing facilities", Wind Europe, 2024

54 "Offshore wind policies and local content: what can we learn from the UK's experience", Tait et al., 2023

55 Taiwan is planning to drop local content requirements from future offshore wind tender rounds, as a reaction to a challenge from the EU at the World Trade Organization and high costs of the developed offshore wind.

56 "A balancing act: local content and Taiwan's renewable ambitions", Spinergie, 2024

57 "Taiwan's stalled offshore wind sector tied in 'gordian knot' by local content", Recharge, 2024

58 "2024 Offshore Wind Industrial Growth Plan", RenewableUK, 2024

59 While technical potential is a great indicator of offshore wind resource, it only reflects what is theoretically possible and does not mean this scale of development will materialize. Actual project deployment will depend on a range of factors, including the policy regime, infrastructure readiness and investor confidence,

60 "Scenarios for Offshore Wind Development in Brazil", World Bank, 2024

61 "Global Wind Power Tracker", Global Energy Monitor, February 2025 release.

62 Radius of 400 km for marshalling used as there are likely sufficient windows of suitable weather (significant wave height <2 m, wind speed < 12 m/w at 10 m height) available. In 2018–2022, there were 78 suitable weather windows of a 112 hr duration available, giving installation vessels the time to sail 400 km, spend 72 hrs installing, and sail back during good weather. A smaller marshalling radius (~200 km) reduces offshore vessel costs. Source: ERA5 hourly data on wind speed and significant wave height.

63 All these ports are <400 km from the offshore wind zone in the south, and have sufficient channel depth (>9m) and width (>150 m) and no air draft restrictions. Most ports will still need upgrades in quays.

64 The ports of São Francisco and Tramandai are very small and located in dense urban developments with limited space for expansion.

65 "Guide to an offshore wind farm", BVGA, 2019

66 These facilities could be spread along the coastline, or centered around a few manufacturing hubs.

67 Assumes components for 1.5 GW of offshore wind can be supplied per component-specific facility per year. If facilities producing offshore wind components co-locate (which is often the case, such as in Esbjerg or in Jiangsu), this translates to a lower number of manufacturing 'hubs'.

68 The port of Açu is further away and located in the Southeast of Brazil, but for manufacturing distance is of less importance.

69 "Local content for wind industry in Brazil", Aquilon, 2023

70 For Example, GE Vernova's LM Wind Power closed its onshore wind blade plant in Brazil in 2024.

71 "GE Vernova to close wind turbine blades plant in Brazil as demand falls", Reuters, 2024

72 "Governo assina contrato do Plano de Transição Energética Justa e memorandos de entendimento para hidrogênio verde", Governo do Estado Rio Grande do Sul, 2024

73 A good example of a port that could benefit from increased offshore wind activities to transition towards low-carbon employment is the Rio Grande Shipyard in the Port of Rio Grande. This shipyard was newly developed in 2006 and employed ~20,000 workers between 2010–2015. However, after a collapse in global oil prices around 2014- 2015, demand for drilling platforms dropped and activities in the shipyard were brought down to a minimal level. The shipyard is currently exploring new opportunities, including naval construction.

74 Although hydrogen remains integral to decarbonization strategies, initial optimism has been tempered by practical challenges and high production costs. Nevertheless, this scenario illustrates the potential outcomes if Brazil fully commits to offshore wind and effectively utilizes the produced low-carbon electricity, or if the regional pipeline expands following project announcements in Argentina or Uruguay

75 Uruguay has recently announced an initial 3 GW tender. Argentina has not announced offshore wind plans yet, but it has a sizable technical potential of 1870 GW. Source: "Offshore Wind Technical Potential in Argentina", World Bank, 2020. "Uruguay authorizes offshore wind block tender […]", Enerdata, 2024

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