ESMAP
Energy Sector Management Assistance Program

GOING GLOBAL

EXPANDING OFFSHORE WIND TO EMERGING MARKETS

OCTOBER 2019

WORLD BANK GROUP
THE WORLD BANK
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ABOUT ESMAP

ESMAP is a partnership between the World Bank and 21 development partners and private non-profits to help low- and middle-income countries reduce poverty and boost prosperity through environmentally sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated into the World Bank Group's strategies, country financing and policy dialogue in the energy sector, through which it works to accelerate the energy transition required to achieve Sustainable Development Goal 7 and the Paris Agreement targets.

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Front cover: Dudgeon Offshore Wind Farm 22 in August of 2017. Photographer: Jan Arne Wold/Woldcam, 2017 ©

Interior: © Danish Wind Industry Association

Back Cover: © MHI Vestas—Blyth Aerial

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Exchange Rate

At the time of publication, 1 United States Dollar ($) = 0.8 Pound Sterling (£)

ABBREVIATIONS AND ACRONYMS

GEBCO	General Bathymetric Chart of the Oceans
GW	gigawatt
IEA	International Energy Agency
IFC	International Finance Corporation
IPP	independent power producer
IRENA	International Renewable Energy Agency
km	kilometer
kV	kilovolts
LCOE	levelized cost of energy
m/s	meters per second
MNRE	Indian Ministry of New and Renewable Energy
MW	megawatt
MWh	megawatt hour
NGOs	Nongovernmental organizations
nm	nautical mile
OECD	Organisation for Economic Co-operation and Development
PPA	power purchase agreement
WBG	World Bank Group

EXECUTIVE SUMMARY

For many years, offshore wind was the expensive cousin of onshore wind with generation costs in the range of $150 to $200 per megawatt hour (MWh). This changed dramatically between 2016 and 2017 when a series of competitive tenders in Europe witnessed strike prices fall below $100/MWh, culminating in projects that bid into merchant markets with no subsidy at all. As of September 2019, the lowest bid price is just below $50/MWh in the United Kingdom (UK) Contract for Differences Allocation Round 3 including the cost of transmission.[1]

Prices have continued to drop thanks to technological improvements, economies of scale, maturation of supply chains, better procurement strategies, and the efforts of large and sophisticated project developers, including several from the utility and oil and gas sectors. However, to date the offshore wind industry has remained largely confined to Europe and China.

As prices continue to drop, offshore wind is increasingly gaining traction in emerging markets. Projections suggest that offshore wind will add between 7 to 11 gigawatts (GW) per year from 2019 to 2024, reaching between 15 to 21 GW/year from 2025 to 2030.[2] While much of the growth is expected in Europe, China, and new Organisation for Economic Co-operation and Development (OECD) markets including Japan, South Korea, and the United States, there is ample potential for developing countries to ride on this momentum and ramp up their local offshore markets.

This report presents eight case studies on the technical potential for offshore wind in Brazil, India, Morocco, the Philippines, South Africa, Sri Lanka, Turkey, and Vietnam (here, technical potential is calculated on the basis of wind speed and water depth). Considering offshore areas within 200 kilometers (km) of the coast,[3] these eight countries have a total technical potential of approximately 3.1 terawatts, including 1,016 GW of fixed capacity and 2,066 GW of floating capacity (See Table 1).[4]

For most of these countries, offshore wind estimates represent a multiple of their currently installed total generation capacity. This suggests that offshore wind can play a transformational role in meeting national goals ranging from expanding electricity access to increasing the mix of renewable resources in the energy mix, all while contributing to the Sustainable Development Goals and commitments made under the Paris Agreement.

Converting this potential into actual deployment must take into account country-specific technical, economic, social, and environmental considerations. To effectively harness their offshore wind opportunity, countries must take a "big picture" approach to their grid and port infrastructure development, adopt innovative approaches to financing, establish stable policy frameworks, and cooperate on sensible supply chain development. Further analysis is necessary to develop a complete understanding of potential at the country level, looking at challenges with regards to grid capacity and integration issues, shipping lanes, migratory patterns, impacts on fisheries, and various logistical considerations.

TABLE 1: SUMMARY TECHNICAL POTENTIAL FOR OFFSHORE WIND IN SELECT EMERGING MARKETS WITHIN 200 KM OF COAST

Country	Fixed (GW)	Floating (GW)	Total (GW)
Brazil	480	748	1,228
India	112	83	195
Morocco	22	178	200
Philippines	18	160	178
South Africa	57	589	646
Sri Lanka	55	37	92
Turkey	12	57	70
Vietnam	261	214	475
Total	**1,016**	**2,066**	**3,082**

Source: Authors, 2019.

To assist in this effort, the Energy Sector Management Assistance Program (ESMAP), in partnership with the International Finance Corporation (IFC), launched a new World Bank Group (WBG) initiative in March 2019 to support the inclusion of offshore wind into the energy sector policies and strategies of WBG client countries and the technical work needed to build a pipeline of bankable projects. This report is the first in a series of planned knowledge products to be published by ESMAP, and we hope that it will help to increase awareness of the huge technical potential that exists in key emerging markets.[5]

THE DEVELOPMENT OF OFFSHORE WIND MARKETS

INTRODUCTION

Thanks to rapid advances in technology and dramatic reductions in cost, offshore wind has come into the mainstream. Since 2016, the cost of generation from offshore wind in its European birthplace has rapidly declined to the point where projects are now bidding subsidy-free into competitive tenders. In China, the only non-European market with significant offshore wind development, the sector is seen as a key element of the country's plans to reduce the carbon intensity of its grid at a competitive cost. Just like its predecessors—onshore wind and solar PV—it is only a matter of time before offshore wind truly 'goes global'.

As offshore wind technology spreads across new geopolitical landscapes and into promising new markets, it will evolve from what is seen in Europe to accommodate local conditions. Fortunately, there is a deep well of lessons learned that can serve to accelerate this transition, allowing emerging markets to achieve cost-competitive, international standard offshore wind projects in a shorter time frame. As a first step toward this goal, the present report looks at the challenges and opportunities faced by offshore wind with a focus on case studies of eight promising markets: Brazil, India, Morocco, the Philippines, South Africa, Sri Lanka, Turkey, and Vietnam. Each case study includes an assessment of the country's technical potential, proximity to demand centers, relevant policies and targets, and how it fits within current and future regional offshore wind markets.

Understanding these specific circumstances can help contribute to broader knowledge, influencing the sustainable and functional expansion of offshore wind to emerging markets. It is important to note that further research and active stakeholder engagement are required to achieve a comprehensive understanding of the true opportunities within each market. As such, this report serves as a starting point for policy makers and stakeholders at the local level.

HISTORY

When considering offshore wind's future, it is important to understand where, how, and why the technology first became viable. Europe has been at the forefront of the offshore wind industry since the first offshore wind farm was installed in 1991 at Vindeby in Eastern Denmark. Vindeby consisted of 11 'marinized' onshore turbines, each generating 450 kilowatts (kW) for a total capacity of 5 megawatts (MW). Dismantled in 2017, Vindeby paved the way for offshore wind farms across Europe.

Throughout the 2000s, offshore wind continued to expand in the southern North Sea, Irish Sea, and Baltic Sea.[6] These areas feature ideal conditions for offshore wind, with strong winds, average wind speeds over 8 meters per second (m/s) and relatively shallow water depths, less than 50 meters (m). Sixteen years later, the UK is now home to the world's largest offshore wind industry, with a cumulative capacity of 8.5 GW[7] and the lowest costs in the world. As shown in Figure 1, Belgium, Denmark, Germany, and the Netherlands, have also contributed to the considerable growth of the European offshore wind

FIRST COMMERCIAL WIND FARM LOCATED IN VINDEBY, DENMARK. DECOMMISSIONED IN 2017.

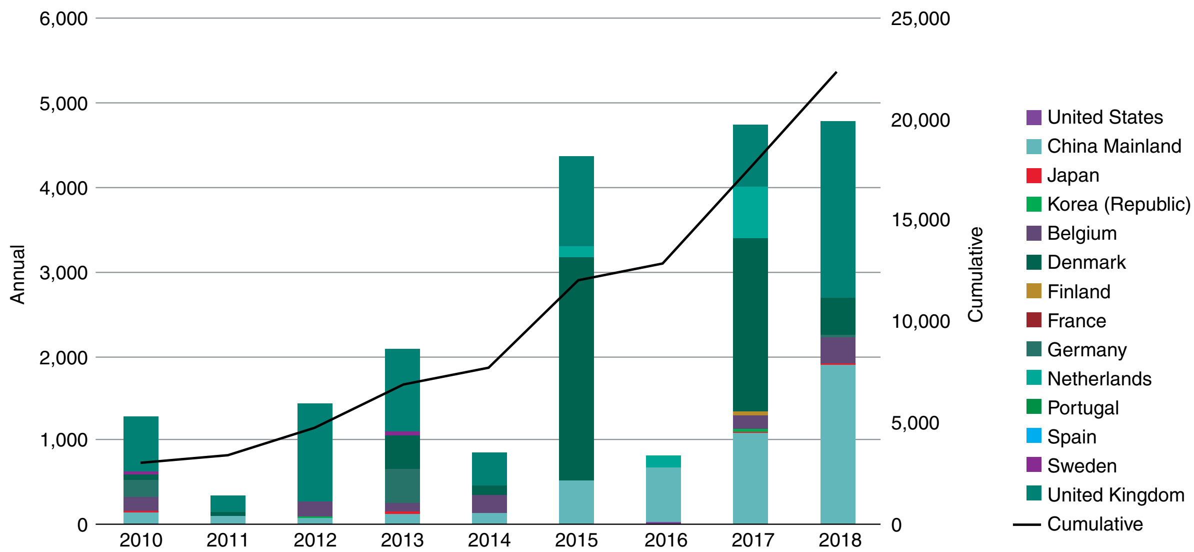
Photo credit: Danish Wind Industry Association, https://www.thegwpf.com/content/uploads/2017/10/Screenshot-2017-10-18-16.49.20.png

market, which remains home to the lion's share of global installed capacity.[8] Outside of Europe, China has steadily been building its offshore wind industry, adding 1.6 GW in 2018 (the most of any country) to bring its total up to 4.4 GW. As of September 2019, global offshore wind capacity stands at around 25 GW,[9] representing around $26 billion in annual investments. However, the International Renewable Energy Agency (IRENA) notes that offshore wind would need to increase tenfold by 2030 (to 228 GW) to support the transformation of the power sector necessary to achieve the Paris Agreement goals.[10]

COSTS

Until recently, cost has been the key barrier to offshore wind's growth. Just four years ago in 2015, the levelized cost of energy (LCOE) for offshore wind projects ranged from $150 to $200 per MWh, roughly three to four times that of onshore wind. The situation changed dramatically between 2016 and 2017 when a series of competitive tenders in Europe delivered strike prices below $100/MWh, culminating in projects which bid into the merchant market without any form of subsidy, starting in the Netherlands. In 2017, bids in the United States—which had only 30 MW installed offshore wind capacity—fell as low as $65/MWh. In late September 2019, the UK's third contract-for-difference (CfD)[11] delivered the lowest strike price in history, £39.65/MWh ($49.6/MWh),[12] a 30 percent reduction compared to the previous auction held in 2017.[13] Figure 2 illustrates the continuing

FIGURE 1: ANNUAL OFFSHORE WIND INSTALLATIONS BY COUNTRY AND CUMULATIVE CAPACITY, 2008–2018 (MW)



Source: Data from BNEF. 2018. *2H 2018 Offshore Wind Market Outlook*. Available at: https://www.bnef.com/core/insights/19859

FIGURE 2: LEVELIZED OFFSHORE WIND TARIFFS, 2005–2030 (2018 $/MWh)

Source: BNEF. 2019. *Offshore Wind Roundtable Tokyo: Global trends & local opportunities*. Available at: https://www.bnef.com/core/insights/20553

Note: Figures refer to an estimated levelized price, taking into account tariff price and length, inflation, a merchant tail assumption and a 25-year lifetime. Prices above $150/MWh were omitted. The full cost of transmission to shore is included in some but not others.

trend in cost reduction for new offshore projects with commissioning dates up to 2025. With these declines in LCOE, offshore wind is within the competitive range of new coal ($60–$143/MWh), nuclear ($112–$183/MWh), and even combined cycle gas ($42–$78/MWh) projects.[14]

The speed and magnitude of offshore wind cost declines have led some observers to conclude that in certain European markets offshore wind will become the cheapest form of new generation as early as 2022. Falling prices are driven by a series of factors, including larger and more efficient turbines, bigger wind farms, access to better offshore wind resources, lower cost financing, more developed supply chains, price pressure from competitive tenders, and the emergence of larger, more sophisticated project developers.

TECHNOLOGY

The offshore wind sector was built on expertise collected from related industries. In the early 2000s, the UK adopted the then-largest onshore turbines (2 MW) and marinized them for the offshore environment. Installation vessels, specifically jack-up barges, were brought in from the offshore oil industry but had limited capability both in terms of lift capacity and reach. Early projects tended to be very expensive and took longer to build than expected, as developers were unfamiliar with the relatively complex logistical requirements of planning and executing projects in the ocean.

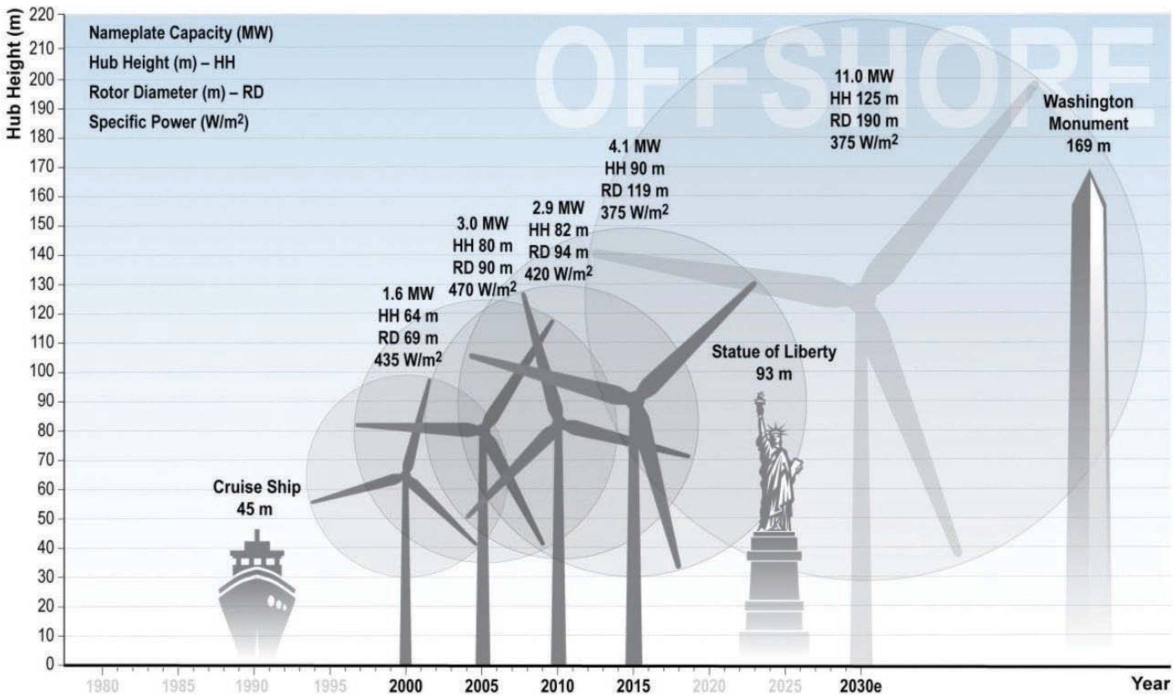
Over time, offshore wind evolved into a distinct, specialized technology. Offshore turbines are now specifically designed to reduce maintenance requirements given the relatively high cost of marine access. At the same time, offshore wind farms are subject to fewer limitations faced by onshore wind, including land use pressures, concerns about views, and transportation/infrastructure constraints. As such, they have evolved to become the largest pieces of rotating machinery on the planet (See Figure 3), capable of generating much higher capacity factors than their onshore cousins.[15]

As of September 2019, the MHI Vestas 9.5 MW turbine was the largest installed turbine in the world, with blades longer than an Airbus A380 airplane is wide. In October 2019, General Electric completed installation of its Haliade-X 12 MW prototype in the Port of Rotterdam as part of a three to five year $400 million testing program.[16] Designs in the 13 to 15 MW range are expected to be commercial by the mid-2020s. Equipment of this size and scale would be extremely difficult to site onshore.

But innovation has not stopped there. New 'floating wind' technologies (see Figure 4) are considered by many in the industry as the next leap forward. While still in its infancy, floating wind has excellent potential, namely because it can be installed in waters between 50 m and 1,000 m in depth, unlocking deep-water sites unsuitable for the fixed foundation technology that has dominated so far.

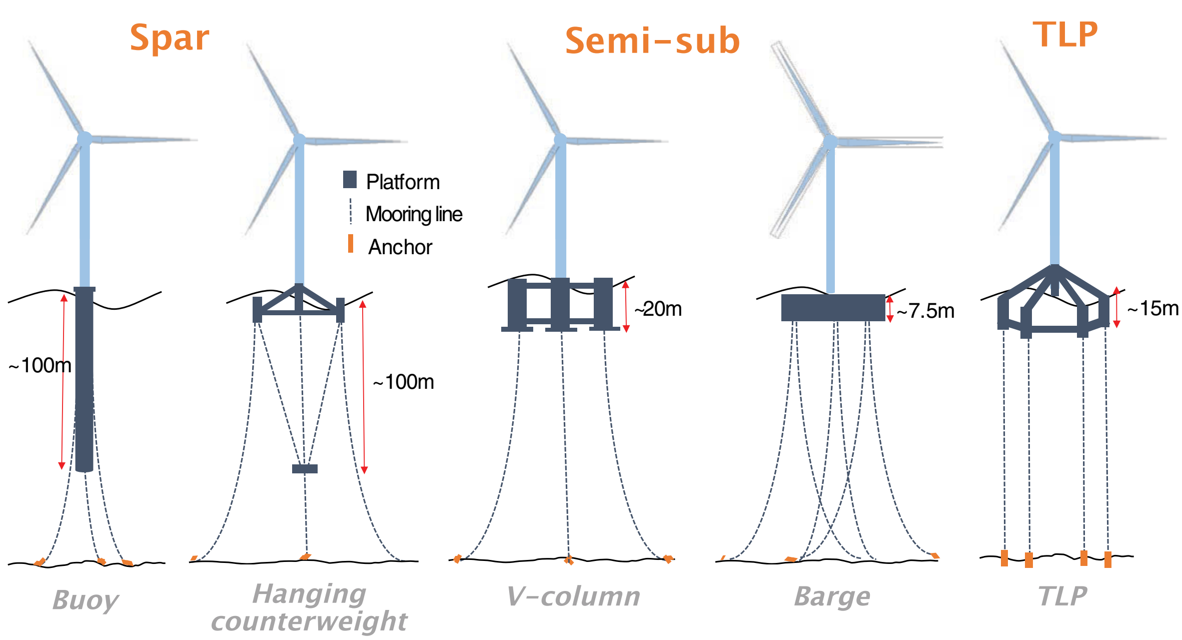
While floating turbine capital costs are more than double that of fixed foundations, they are expected to drop substantially over the next decade. Since 2009, the cost of floating turbines has fallen 86 percent as projects move from single to multiple turbine demonstrations.[17] While more than 30 floating foundation designs exist, none have yet been deployed at full commercial scale. The world's first multi-turbine floating wind farm, the 30 MW Hywind Scotland project, was installed nearly 30 km off Scotland's northwest coast in 2017 and recorded an impressive 57 percent capacity factor in its first full year of operation.

FIGURE 3: EXPECTED GROWTH IN OFFSHORE WIND TURBINE SIZE, 1980–2030 (M)



Source: Berkeley Lab. 2016. *Reducing Wind Energy Costs through Increased Turbine Size: Is the Sky the Limit?* Available at: https://emp.lbl.gov/sites/all/files/scaling_turbines.pdf

FIGURE 4: EXAMPLE FLOATING OFFSHORE WIND DESIGNS



Source: BNEF. 2019. "Offshore Wind Roundtable Tokyo: Global trends & local opportunities." Available at: https://www.bnef.com/core/insights/20553/view

Note: TLP = tension leg platform, m = meters. Based on current design announcements.

PROJECTIONS

2018 saw the addition of 4.8 GW of new offshore wind capacity worldwide. While the majority (60%) was in Europe, the continent's grip on the market is loosening, with high capacity additions in China. Projections suggest that offshore wind will add between 7 to 11 GW per year from 2019 to 2024 at which time it will accelerate, adding between 15 GW and 21 GW per year between 2025 and 2030. Altogether, annual growth from 2019 to 2027 will average 11 GW per year, a fivefold increase over annual installations from the preceding eight-year period.

By 2030, cumulative installations will reach 190 GW and an estimated $700 billion in investment.[18] Estimates indicate that European markets will continue steady growth, but Asia will accelerate and see the majority of installations over the next decade, while the United States will account for around 10 percent of the global market.

Floating wind will become important for many developing countries, particularly states with deeper waters, seismic activity, and/or significant extreme weather risk.[19] By 2030, Bloomberg estimates a cumulative installed capacity of 1.2 GW of floating wind across seven countries and 19 different sites.[20]

While global emerging markets have ample wind resources and the need for clean, cost-competitive power, significant barriers to offshore wind investment remain. According to International Energy Agency (IEA), if offshore wind is to become a mainstay of the global clean energy transition, more work is required by governments and industry, including the development of long-term visions and work to promote investment and spur innovation.[21] Fortunately, emerging markets have an opportunity to harness lessons learned from more developed markets to aid them in 'jumping the queue' and more rapidly scaling offshore wind.

LESSONS LEARNED

Development of the European offshore wind sector yields several useful lessons learned for emerging markets:

1. **There is a steep learning curve for offshore wind.** Initially, offshore wind projects in emerging markets will require concessional financing or other forms of public support, as they will be more expensive than both conventional generation and onshore renewables (both wind and solar PV). It is likely that countries with existing strong port infrastructure and experience in oil and gas will be early movers. By starting on the right foot with top-quality projects, subsequent offshore wind projects will see rapid cost declines, becoming a cost-competitive part of the energy mix within a shorter time frame than was the case in European markets.
2. **Offshore wind construction is much more complex and time-consuming than onshore construction.** Onshore wind development typically takes two to three years from inception to commissioning with development costs ranging from $1 to 2 million per project. In contrast, an offshore wind farm typically takes five to ten years to develop, requiring $10 to $50 million in development costs. Grid connection, grid reinforcement, transformers, and export cabling are critical long lead items.
3. **Financing offshore wind is very complex and requires innovative structuring to reduce risks and ensure bankability.** Offshore wind projects have high capital expenditures (often more than $2 billion) and risks due to the complexity of offshore construction. As a result, innovation will be required for both financing (involving many different structures and financing consortia) and project

management (handling multiple contracts and associated interface risks), including the potential use of guarantees and concessional financing.

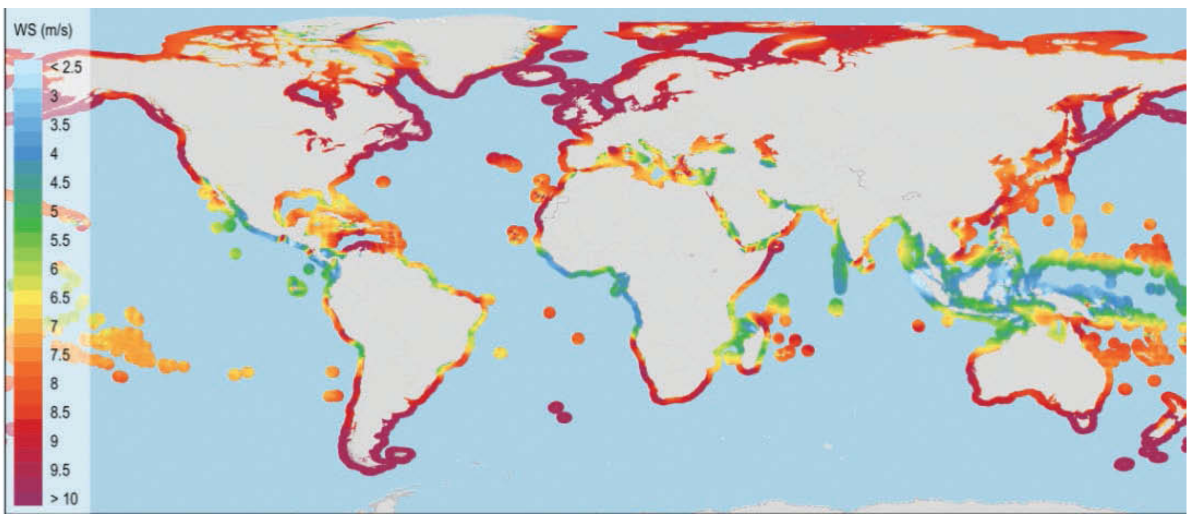
4. **Offshore wind development is driven by policy, requiring stable frameworks and phased procurement to draw competition and spur industrial development.** The sector is politically attractive, being a scalable technology with high public acceptance and high potential for job creation, direct investment, and local economic development. To be successful, a stable policy environment is critical, with a logical progression of procurement approaches (e.g., moving from set tariff demonstration projects to competitively auctioned commercial scale projects once the market has matured).
5. **Offshore wind development must be adaptable to new market contexts.** Offshore wind in emerging markets is not going to look exactly as it has in Europe. From a technical perspective, the industry must adapt to more challenging water depths, less robust grids, extreme weather events (typhoons, high waves) and increased seismic activity. From an environmental perspective, new approaches may be required to mitigate impacts on marine and avian wildlife as well as income generating activities like fishing and aquaculture. From a financing perspective, bankability will be a challenge in the context of utility off-takers who do not have a long history of independent power producers (IPPs) development and have some difficulty in putting forward bankable power purchase agreements (PPAs).
6. **Regional cooperation is key to achieving economies of scale.** To achieve competitive pricing and drive supply chain development, a regional approach is required to generate sufficient scale (over 5 GW yearly). Without regional cooperation, individual governments might be more inclined to attempt to create markets independently, building supply and value chains where they do not necessarily make sense.


DOW OS

ESTIMATING OFFSHORE WIND POTENTIAL IN EMERGING MARKETS

Figure 5 represents a global overview of offshore wind speeds up to 200 km from shore, at 100 m hub height. Offshore wind projects are potentially viable with wind speeds over 7 m/s (although most European development has occurred in areas with wind speeds over 8 to 9 m/s); these areas are marked in orange and red. The map clearly illustrates significant proximate opportunities to many developing countries, particularly in Asia and the Americas. However, wind speed is only one consideration in determining where offshore wind may be viable.

FIGURE 5: MAP OF GLOBAL OFFSHORE WIND SPEEDS (100 M)



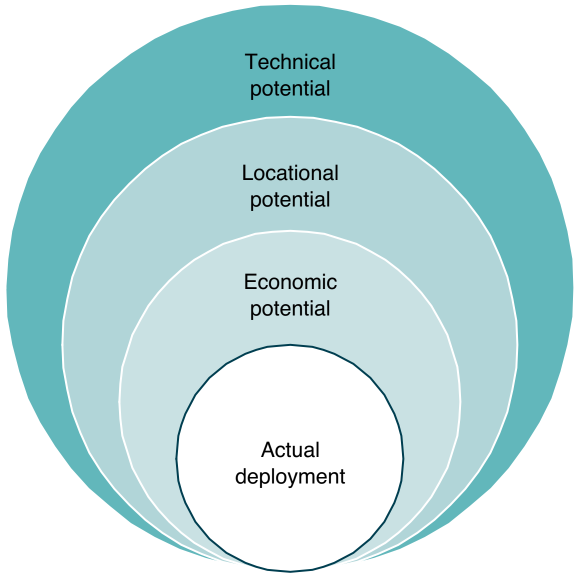
Source: Data obtained from the Global Wind Atlas (version 3.0), a free, web-based application developed, owned, and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided by ESMAP. Available at: https://globalwindatlas.info

METHODOLOGY AND EARLY FINDINGS

To date, relatively little research has been undertaken on the potential for offshore wind in emerging markets. Any assessment of this kind must start with an estimate of *technical potential*, that is, the maximum possible installed capacity as determined by wind speed and water depth. This is the focus of the present report. As illustrated in Figure 6, the *locational potential*, *economic potential* and finally, *actual deployment* represent increasingly restrictive amounts:

1. **Technical potential:**[22] As indicated in Table 2, fixed foundation is considered technically viable in areas with water depth less than 50 m and average wind speeds over 7 m/s. Floating wind is considered technically viable with water depths from 50 m up to 1,000 m. The input data is sourced from the Global Wind Atlas,[23] which provides wind speeds up to 200 km offshore, and bathymetry surveys from the General Bathymetric Chart of the Oceans (GEBCO).[24, 25]

FIGURE 6: PROGRESSION TOWARD ACTUAL DEPLOYMENT



Source: Authors, 2019.

TABLE 2: TECHNICAL VIABILITY REQUIREMENTS OF OFFSHORE WIND BY TECHNOLOGY

Types of Offshore Wind	Wind Speed (meters/second)	Water Depth (meters)
Fixed foundation	>7	<50
Floating	>7	50<1,000

Source: Authors, 2019.

2. **Locational potential:** Only a portion of the technical potential will translate into locational potential, represented by the physical area where developers can obtain consent to build. This is restricted to areas of the seabed that are available and suitable for offshore wind development.
3. **Economic potential:** This represents areas of the locational potential where offshore wind can be developed at a competitive tariff.
4. **Actual deployment** is the final subset, restricted to areas where a country's energy policies can support offshore wind development, including constraints and restrictions pertaining to shipping corridors, migratory pathways, and other logistical concerns. Altogether, actual deployment potential is a small fraction of the overall technical potential.

To assess locational and economic potential, detailed country-specific work is required involving stakeholder engagements, assessment of the regulatory environment, analysis of supply chain capabilities, and so on. While this level of analysis goes beyond the scope of this report, the World Bank Group is prepared to assist emerging markets as they progress through subsequent stages, leading ultimately to bankable, international-standard projects.

CASE STUDIES

The following analysis focuses on the technical potential for offshore wind in eight emerging markets: Brazil, India, Morocco, Philippines, South Africa, Sri Lanka, Turkey, and Vietnam. Table 3 provides a summary of the results, split between fixed foundation and floating wind. The table also includes the country's RISE (Regulatory Indicators for Sustainable Energy) score[26] which accounts for seven metrics (legal, planning, incentives, financial, network connection, counterparty risk, and carbon pricing) to indicate attractiveness and maturity of the renewable energy market.

Looking at offshore areas within 200 km of the coast, there is a total technical potential of 3.1 terawatts in these eight countries, including 1,016 GW of fixed and 2,066 GW of floating.

For most countries, the amounts represent a multiple of their total installed generation capacity. Fixed foundations represent the bulk of the opportunity in India, Sri Lanka, and Turkey. Other countries such as the Philippines and South Africa will require floating foundations, for which commercial scale is currently a barrier to deployment. Brazil, Morocco, and Vietnam can benefit from both technologies. Additionally, the magnitude of technical potential in these three countries is significantly higher than in all the other markets considered, with the exception of South Africa.

The Appendix provides a breakdown of these figures by water depth and wind speed for each country.

TABLE 3: COUNTRY RISE SCORE AND FIXED AND FLOATING POTENTIAL WITHIN 200 KM OF COAST

Country	RISE Score	Potential GW		Observations
		Fixed	Floating	
Brazil	71	480	748	Brazil has excellent potential with shallow waters close to demand centers and a strong supply chain potential.
India	87	112	83	Set an offshore wind target of 5 GW by 2022 and 30 GW by 2030. Best opportunities are in Tamil Nadu and Gujarat.
Morocco	67	22	178	Excellent wind speeds and suitable depths along the Atlantic Coast; regional synergy possible with Spain and Portugal.
Philippines	62	18	160	Best potential in the north and central areas; potentially synergies with regional development (Taiwan, Vietnam).
South Africa	76	57	589	High wind speeds but deep waters will favor floating foundations. Few regional development synergies likely.
Sri Lanka	55	55	37	Strong winds and shallow waters suggest potential for fixed foundation. But limited power demand affects scalability.
Turkey	75	12	57	Good winds but deeper waters may favor floating; key issues around shipping and proximity to demand.
Vietnam	67	261	214	Excellent resource off southwest coast; existing nearshore development; strong potential for floating and fixed.
Totals		**1,016**	**2,066**	**Grand Total = 3,082 GW**

Source: Authors, 2019.

BRAZIL

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	*Fixed*	*Floating*
71	480 GW	748 GW

- Offshore wind development may occur after or alongside further development of the sizeable unexploited onshore resource capacity, which can be scaled at a lower cost in the short term.
- When offshore wind enters the market, it will likely be fixed foundation.
- Brazil's coast has three broad shelves <50 m deep which have average wind speeds >7 m/s:
    1. The northeast coast (São Luis to Natal) has wind speeds up to 9 m/s, with a technical potential of 237 GW for fixed foundations. The shelf falls away rapidly, leaving little scope for floating foundations.
    2. The southeast coast (south of Vitória) has wind speeds up to 8.5 m/s with technical potential for 67 GW of fixed and 227 GW of floating foundations.
    3. The southern coast (from Florianopolis to the Uruguayan border) has the best wind resources of over 9 m/s, with a potential of 173 GW for fixed foundations and 430 GW for floating.

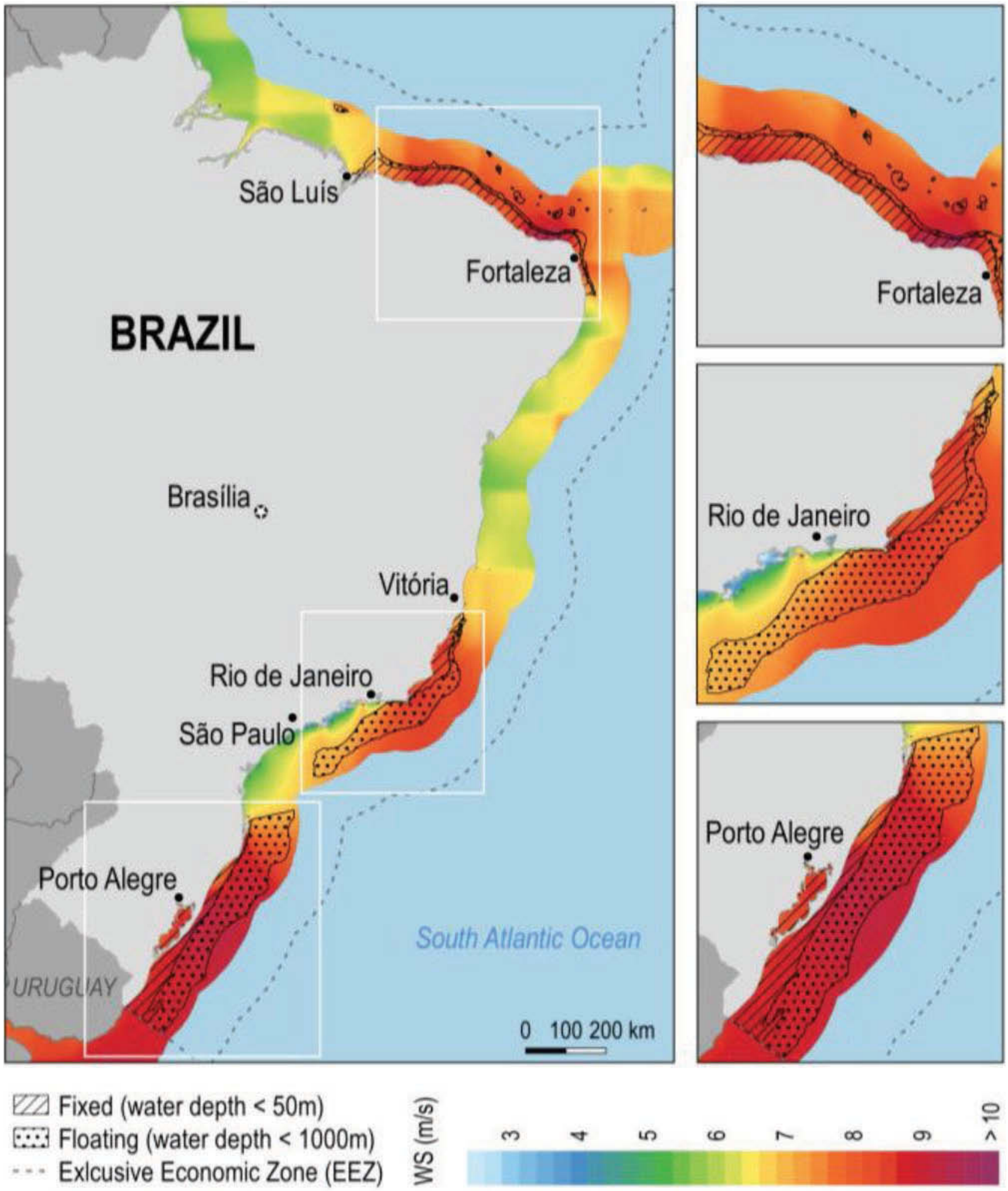
Transmission to demand centers[27]

- Power demand is concentrated in the southern and eastern regions, and major electricity generation assets (primarily hydropower) are in the northern and western regions. As a result, the main transmission lines have developed as a central spine running from north to south.
- Extensions from the central grid run to the coasts and could service all three offshore wind zones, but they are of lower voltage and would require substantial upgrades to evacuate substantial levels of offshore wind capacity.
- The southern and southeast wind areas are located closer to demand centers.

Relevant policies and targets: In 2018, Brazil announced it aims to source 45 percent of its energy from renewable by 2030, with 23 percent derived from wind, solar, and biomass.[28]

Fit with regional offshore wind market: There are potential synergies with Southern Cone countries (Argentina, Chile, and Uruguay).

Map 1: Brazil



São Luís
Fortaleza
BRAZIL
Brasília
Vitória
Rio de Janeiro
São Paulo
Porto Alegre
URUGUAY
South Atlantic Ocean
0 100 200 km
Fortaleza
Rio de Janeiro
Porto Alegre
Fixed (water depth < 50m)
Floating (water depth < 1000m)
Exlcusive Economic Zone (EEZ)
WS (m/s)
3
4
5
6
7
8
9
> 10

INDIA

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
87	112 GW	83 GW

- The best offshore wind resources are at the southern tip of India in Tamil Nadu. There is a sizeable shallow area which has a technical potential of 54 GW.
- In the northwest, off Gujarat in the Gulf of Khambhat, there is an area with weak winds between 7 and 7.25 m/s in waters less than 50 m deep. The technical potential is estimated to be 36 GW.
- India's first 1 GW of offshore wind development is planned for the Gujarat zone, with 35 developers having registered for an upcoming auction.[29]
- A third wind area is north in the Gulf of Kutch with wind speeds of 7 to 7.25 m/s and shallow water. The technical potential for this area is 5 GW.

Transmission to demand centers[30]

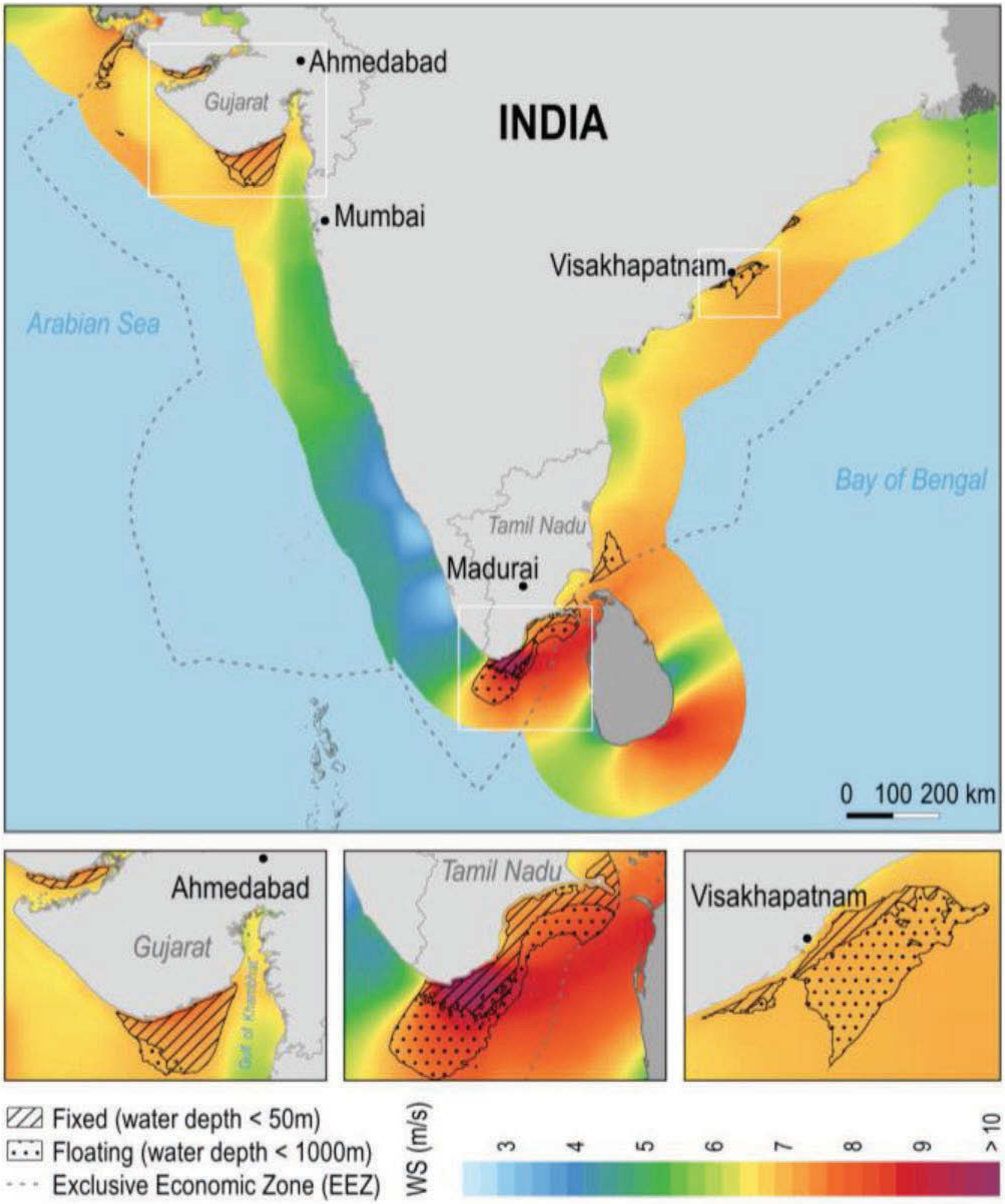
- The grid near the southern tip of Tamil Nadu is 400 kilovolts (kV), suitable for large-scale offshore wind. There are plans to extend the nearby 765 kV line to Bangalore, creating a connection with a substantial demand center.
- Gujarat's grid is less robust near the coast, though it is understood that the Gujarat Energy Transmission Corporation has planned reinforcement to 400 kV to facilitate the initial 1 GW offshore wind project.

Relevant policies and targets:

- In June 2018, the Ministry of New and Renewable Energy (MNRE) set an offshore wind energy target of 5 GW by 2022 and 30 GW by 2030. It will be challenging to meet the 2022 target given the long development cycle for offshore wind.[31]
- The FOWIND studies look at project feasibility in the areas off Tamil Nadu and Gujarat.[32, 33]

Fit with regional offshore wind market: Opportunity in Tamil Nadu has potential synergies with regional development in the northwest of Sri Lanka.

Map 2: India



Ahmedabad
Gujarat
INDIA
Mumbai
Visakhapatnam
Arabian Sea
Bay of Bengal
Tamil Nadu
Madurai
0 100 200 km
Ahmedabad
Gujarat
Tamil Nadu
Visakhapatnam
Fixed (water depth < 50m)
Floating (water depth < 1000m)
Exclusive Economic Zone (EEZ)
WS (m/s)
3
4
5
6
7
8
9
> 10

MOROCCO

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
67	22 GW	178 GW

- Morocco's western coast along the Atlantic Ocean has excellent wind speeds in shallow and deeper waters suitable for offshore wind.
- There are two areas well-suited for fixed foundations in the southern and central regions of the country, with technical potentials of 11 GW for the southernmost area, and 10 GW for the middle.
- Further from shore, there is a band of waters up to 1,000 m deep with wind speeds reaching over 9 m/s which would be suitable for floating offshore wind with a total technical potential of 135 GW.
- On the northern coast there is another band of waters with 43 GW of floating wind potential.

Transmission to demand centers

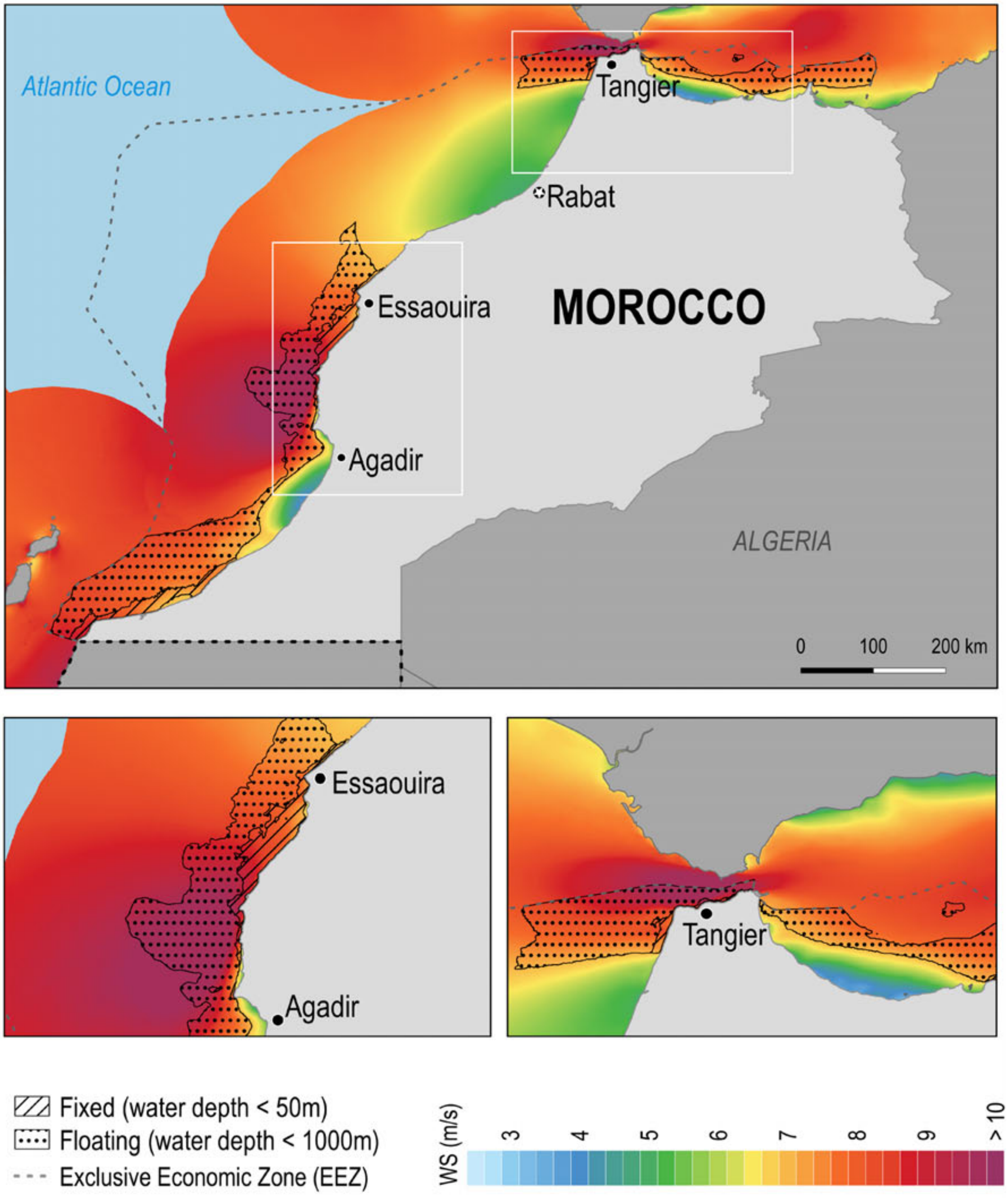
- Grid access points exist near the potential development areas though substantial reinforcement will be needed to transmit power to the main demand centers of Rabat and Casablanca.
- Solar and onshore wind generation in Morocco have recently expanded but still have some way to go. As such, offshore wind must join the queue for renewable energy deployment.

Relevant policies and targets

- As of 2014, Morocco imported approximately 90% of its energy needs.[34] Morocco's national strategic objective is to improve security of supply by reducing dependence on energy imports, including increasing use of renewable sources for electricity production.
- By 2030, renewable energy sources are planned to provide 52% (10 GW) of the total installed capacity.[35]

Fit with regional offshore wind market: Morocco's market could potentially sell energy into Europe's market, specifically Spain and Portugal, as they have yet to deploy offshore wind themselves. That said, these two countries have plans to do so in the future (particularly in floating foundations).

Map 3: Morocco



PHILIPPINES

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
62	18 GW	160 GW

- There are reasonable wind resource areas in the northern and central areas of the Philippine archipelago, some of which are in waters shallow enough for fixed foundation offshore wind.
- There is one area suitable for fixed foundations in the Guimaras Strait with 7 GW of technical potential.
- Three main areas suitable for floating offshore wind are north of Luzon and to the north and south of the Mindoro Island. The largest of these areas is off the south coast of Mindoro with a technical potential of 53 GW.
- There are also numerous pockets around the archipelago with areas suitable for floating turbines but with comparatively low wind speeds.

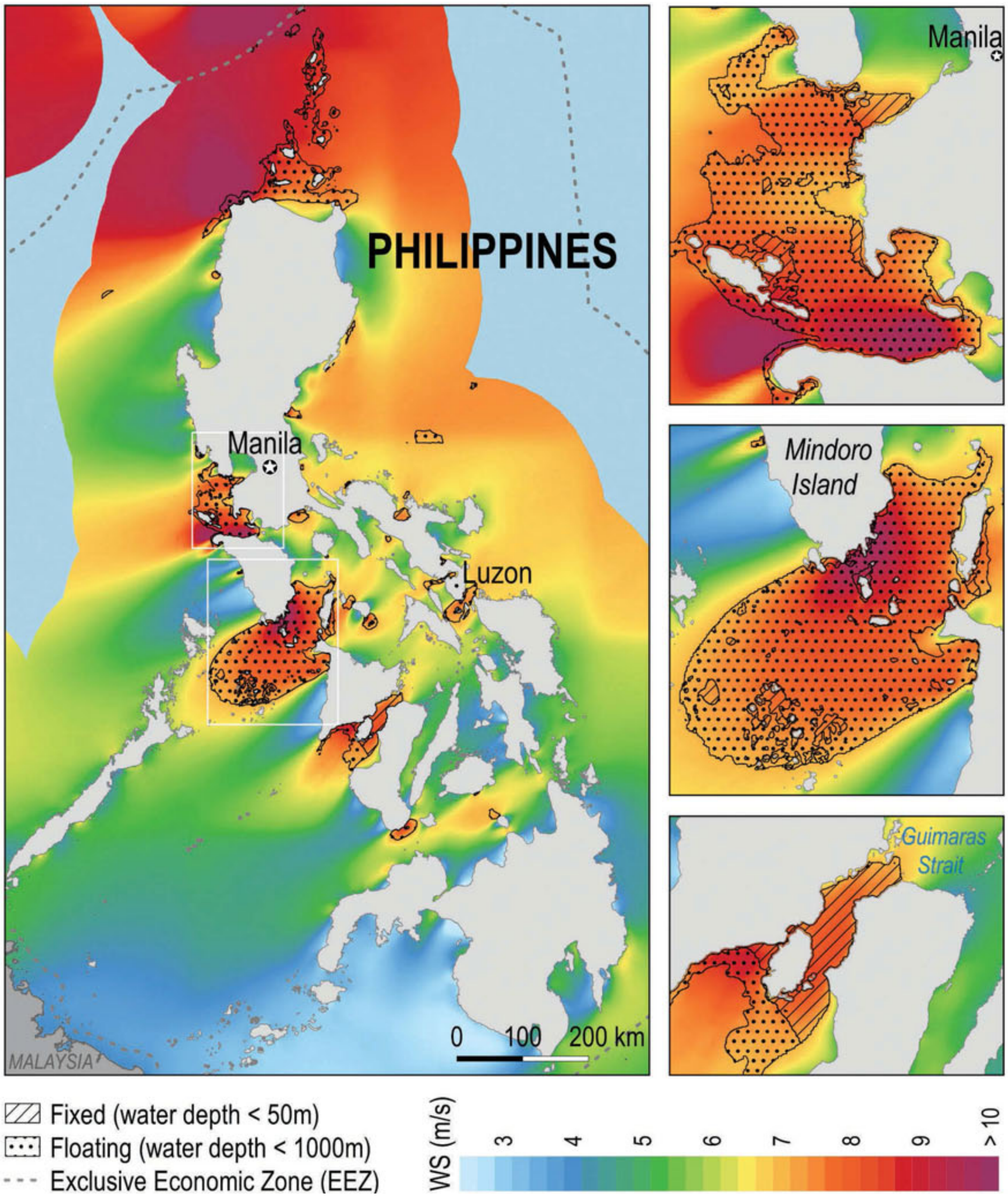
Transmission to demand centers

- The Philippines includes over 7,000 islands, with the bulk of the 100 million population located on just eight.
- The major islands are connected by a transmission grid, but the extremities, for example north of Luzon and the fixed foundation opportunity in the Guimaras Strait, have very limited connectivity.
- Perhaps the most promising area for floating wind is to the north of Mindoro which is near the demand center around Manila.

Relevant policies and targets: Electricity prices are among the highest in Southeast Asia, due in large part to dependence on expensive imported diesel, oil, and coal. The government renewable energy target is 50% by 2030, with the majority coming from hydro (8.7 GW) and geothermal (3.5 GW), followed by wind (2.4 GW).[36]

Fit with regional offshore wind market: With Taiwan as a leading market for offshore wind, and Vietnam and Indonesia showing promise, there are potential synergies in the region.

Map 4: Philippines



SOUTH AFRICA

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
76	57 GW	589 GW

- South Africa's entire 2,500 km coastline has wind speeds over 7 m/s; however the waters are deep (>50 m) and the currents on the southern and eastern coasts are some of the strongest in the world which will present a significant challenge, particularly for floating wind.
- On the eastern coast around Durban, there is a small area of less than 50 m water depth which has a technical potential for 18 GW of fixed foundation offshore wind.
- Moving clockwise along the coast west from Durban up to the Namibian border, there is a strip of water between 50 m and 1,000 m off the coastline that has a technical potential of 567 GW for floating wind.
- If the government applies restrictions on the minimum required distance from shore, the area's economic potential would decrease. However, there is a 200 m deep plateau directly below the southernmost tip of Africa which stretches 200 km from shore, which might be suitable for early stage floating wind, and alone has a technical potential of 204 GW.

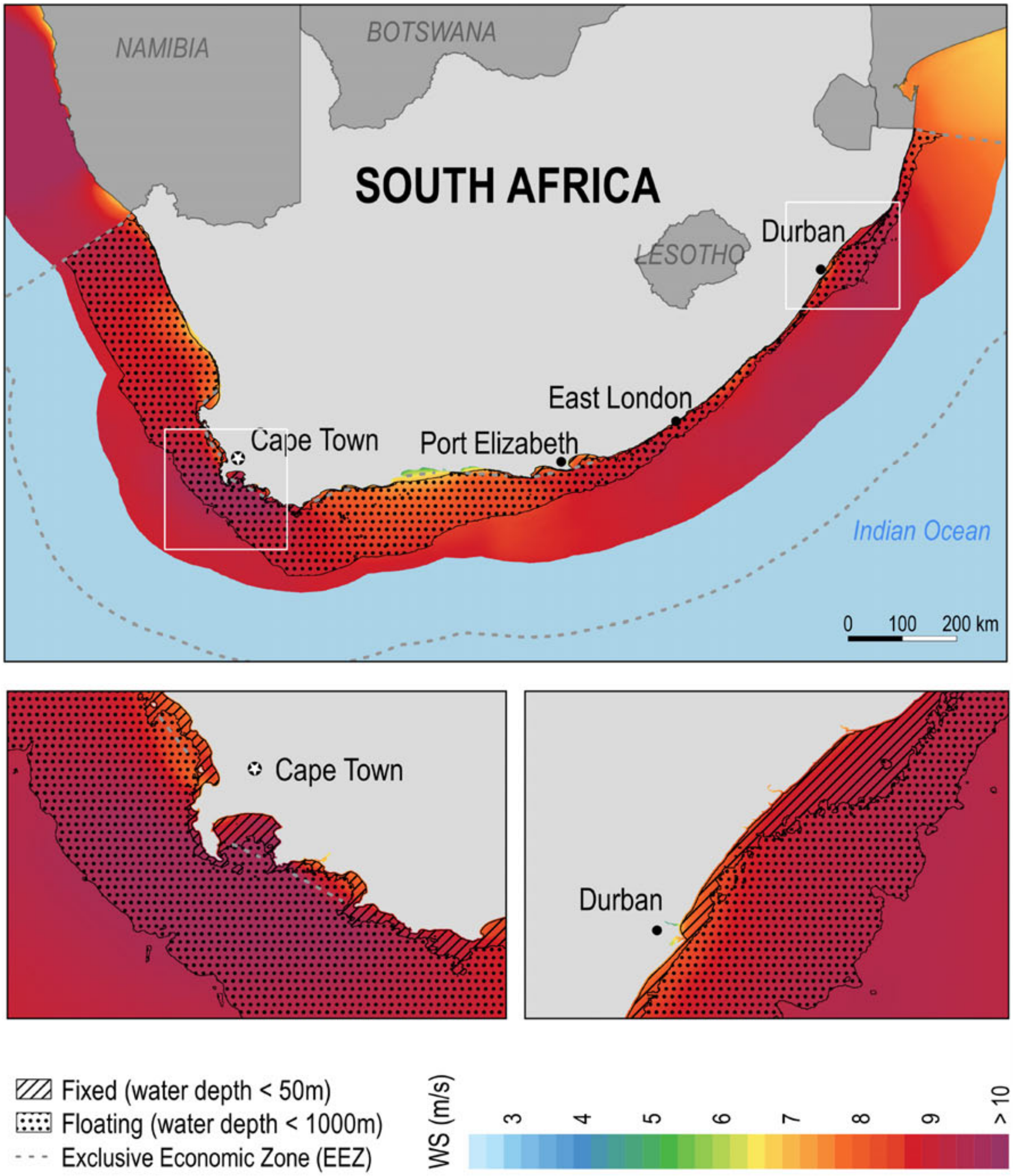
Transmission to demand centers[37]

- Power demand is concentrated in the northeast of South Africa, with major demand being in the southwest around Cape Town.
- Floating wind resources around Cape Town are particularly good. There is a 765 kV grid connection with plans for reinforcement which could transfer power to the north. Similarly, Durban has a 765 kV grid connection.
- Growth in renewables will shift the balance of generation to the southeast requiring substantial investment in grid infrastructure, which would assist offshore wind power evacuation.

Relevant policies and targets: A draft of the Integrated Resource Plan was updated in March 2019 and shows a substantial increase in renewables with wind power rising to 15.1 percent of generation by 2030. However, there is no mention of offshore wind.[38]

Fit with regional offshore wind market: The offshore wind potential is of such a size that it would not need to depend on regional demand. While Namibia has some potential, power demand is relatively low such that it is unlikely to yield synergies.

Map 5: South Africa



SRI LANKA

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
55	55 GW	37 GW

- Windspeeds northwest of Sri Lanka range from 7.5 to over 9 m/s with water depths below 50 m deep. The total area has an offshore wind technical potential of 45 GW. The seabed falls away rapidly to 2,000 m leaving little potential for near-term floating turbines but to 1,000 m there is a resource with 27 GW technical potential.
- However, given the shallow water in the straits, there may be substantial fishing activity and bird populations, which could substantially reduce the area's consentable potential.
- Southeast of the island, windspeeds are 7 to 9.5 m/s in water depths up to 50 m. This area is close to the shore and approximately 200 km long with an offshore wind technical potential of 6 GW. Further from shore, the seabed deepens to 1,000 m, viable for floating wind and adding 10 GW of potential.
- If the government applies restrictions on the minimum required distance from shore, the area's economic potential would dramatically decrease.

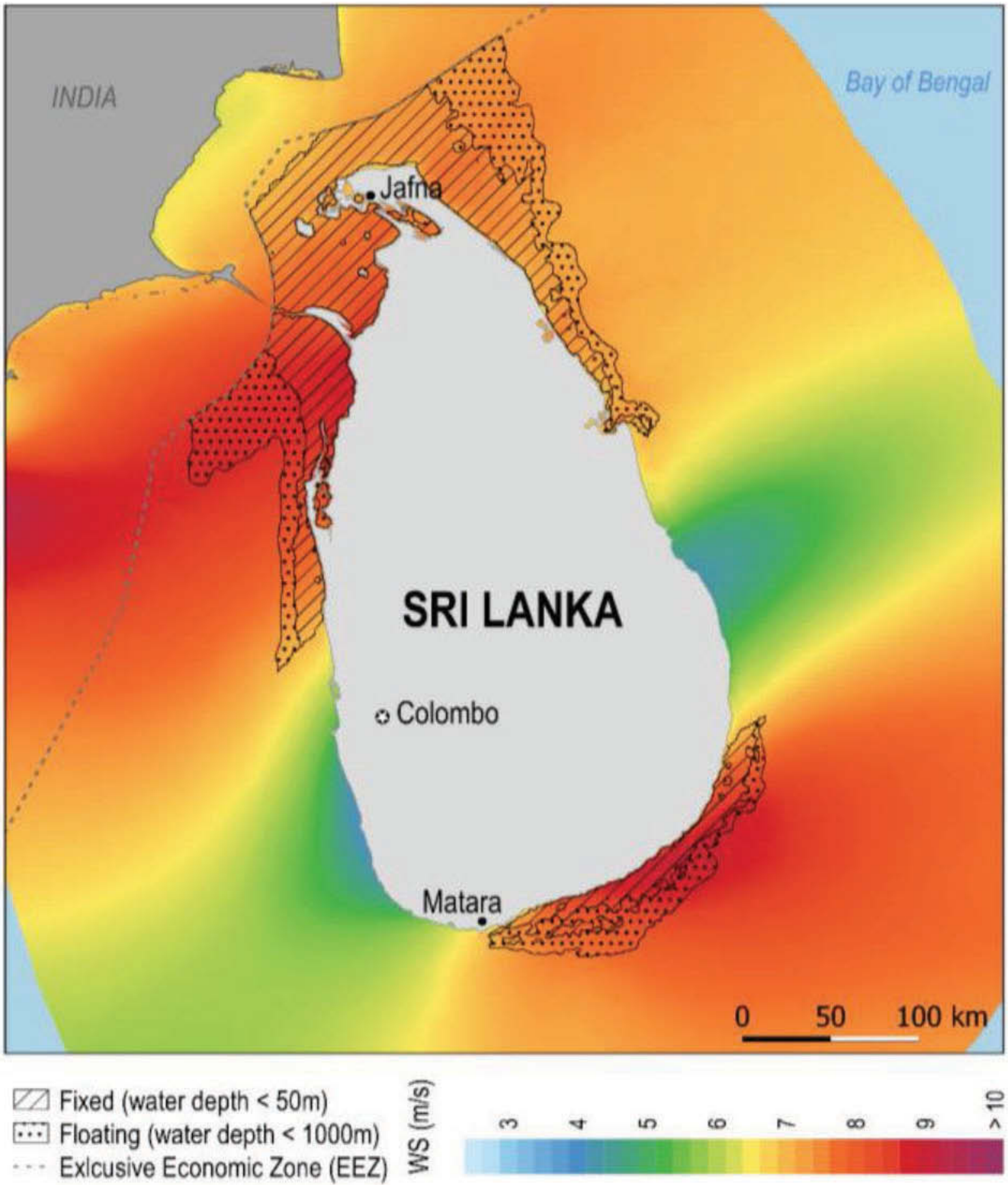
Transmission to demand centers[39]

- Power demand is concentrated in the south and west of Sri Lanka, with Colombo (the capital) about 150 km from a potential landing of offshore wind export cables in the northwest of the island.
- The government is proposing the addition of a high-voltage direct current (HVDC) link with India, which could substantially reduce the cost of necessary grid reinforcement.
- The southeast potential wind area is further from the grid and the planned HVDC link.

Relevant policies and targets: The Sri Lankan government has a target to generate electricity with 100 percent renewable energy by 2050.[40]

Fit with regional offshore wind market: The northwest area overlaps with Tamil Nadu's potential offshore wind area, representing a possibility for collaboration between the Indian and Sri Lankan governments.

Map 6: Sri Lanka



TURKEY

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
75	12 GW	57 GW

- The most attractive areas for offshore wind lie in the north-west in the Aegean Sea where wind speeds rise to 9 m/s; the largest area has a technical offshore wind potential of 6 GW fixed and 19 GW floating.
- The Sea of Marmara and the Black Sea have good wind speeds of 7–8 m/s.
- There are many pockets of opportunity along the western coast and to the southeast.
- In total the areas with water depths less than 50 m have a technical potential of 12 GW and to 1,000 m depth a further 57 GW.
- The areas in the north must account for shipping lanes between the Aegean Sea and the Black Sea, which can be facilitated by careful planning.
- As all the areas are coastal, projects must engage local stakeholders and manage visual impacts, especially their effect on tourism.
- Due to heavy marine traffic in Marmara and the Black Sea coasts, careful navigational planning will be required.
- There are several main reasons limiting access to this offshore opportunity:
    1. Turkey only has six nautical miles (nm) of territorial waters on its western coast (bordering the Aegean Sea), leading to competing uses and strong interplay of environmental and social issues;
    2. Lack of an Exclusive Economic Zone; and
    3. Numerous islands along the western coast further fragment jurisdictional waters.

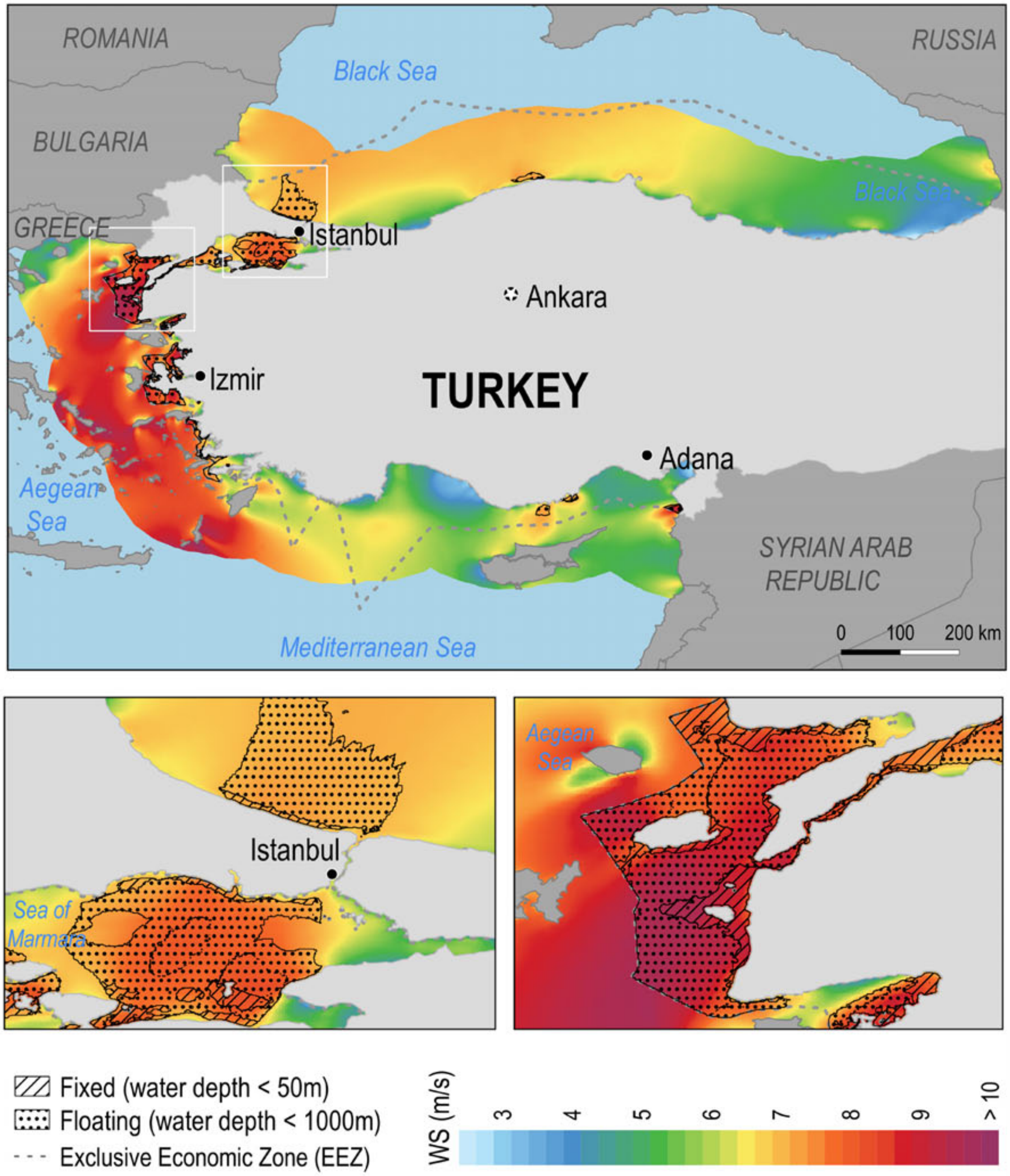
Transmission to demand centers: Transmission networks in the north and west are quite strong with 380 kV and 154 kV lines. However, reinforcement will be needed to accommodate offshore wind, especially for projects more than 1 GW.

Relevant policies and targets:

- Turkey increased its 2012 renewable energy target from 27 percent to 38.8 percent of power generation by 2023, following news that 32.5% renewable generation had been achieved in 2018.[41]
- There was a tender for offshore wind in 2018 which received no bids, reportedly because of high local content requirements.

Fit with regional offshore wind market: Turkey has some synergies with the wider European offshore wind market, but no offshore wind farms have been built in the Mediterranean yet.

Map 7: Turkey


ROMANIA
RUSSIA
Black Sea
BULGARIA
GREECE
Istanbul
Ankara
Izmir
TURKEY
Adana
Aegean Sea
SYRIAN ARAB REPUBLIC
Mediterranean Sea
0 100 200 km
Istanbul
Sea of Marmara
Aegean Sea
Fixed (water depth < 50m)
Floating (water depth < 1000m)
Exclusive Economic Zone (EEZ)
WS (m/s)
3 4 5 6 7 8 9 > 10

VIETNAM

Technical potential for offshore wind

Technical potential for offshore wind within 200 km		
RISE Score	***Fixed***	***Floating***
67	261 GW	214 GW

- World class wind resources lie off the southwest coast of Vietnam in the South China Sea, where average wind speeds exceed 10 m/s off the coast of Binh Thuan and Ninh Thuan provinces, in water depths <50 m. This area then extends south and, with average wind speeds falling to 7 m/s the area extends up to 125 km from shore. This area alone has technical potential for 165 GW of fixed offshore wind.
- Outside this is a very large area below 1,000 m water depth which runs from the south of the country all the way to the Central region south of Hue, with a technical potential of 175 GW for floating wind.
- In the Gulf of Tonkin (northern region), there is a sizeable area with windspeeds of 7 to 8.5 m/s at <50 m, with a technical potential for fixed foundation wind of 88 GW. To the south of the gulf there is also an area <1,000 m with a technical potential of 39 GW for floating wind.

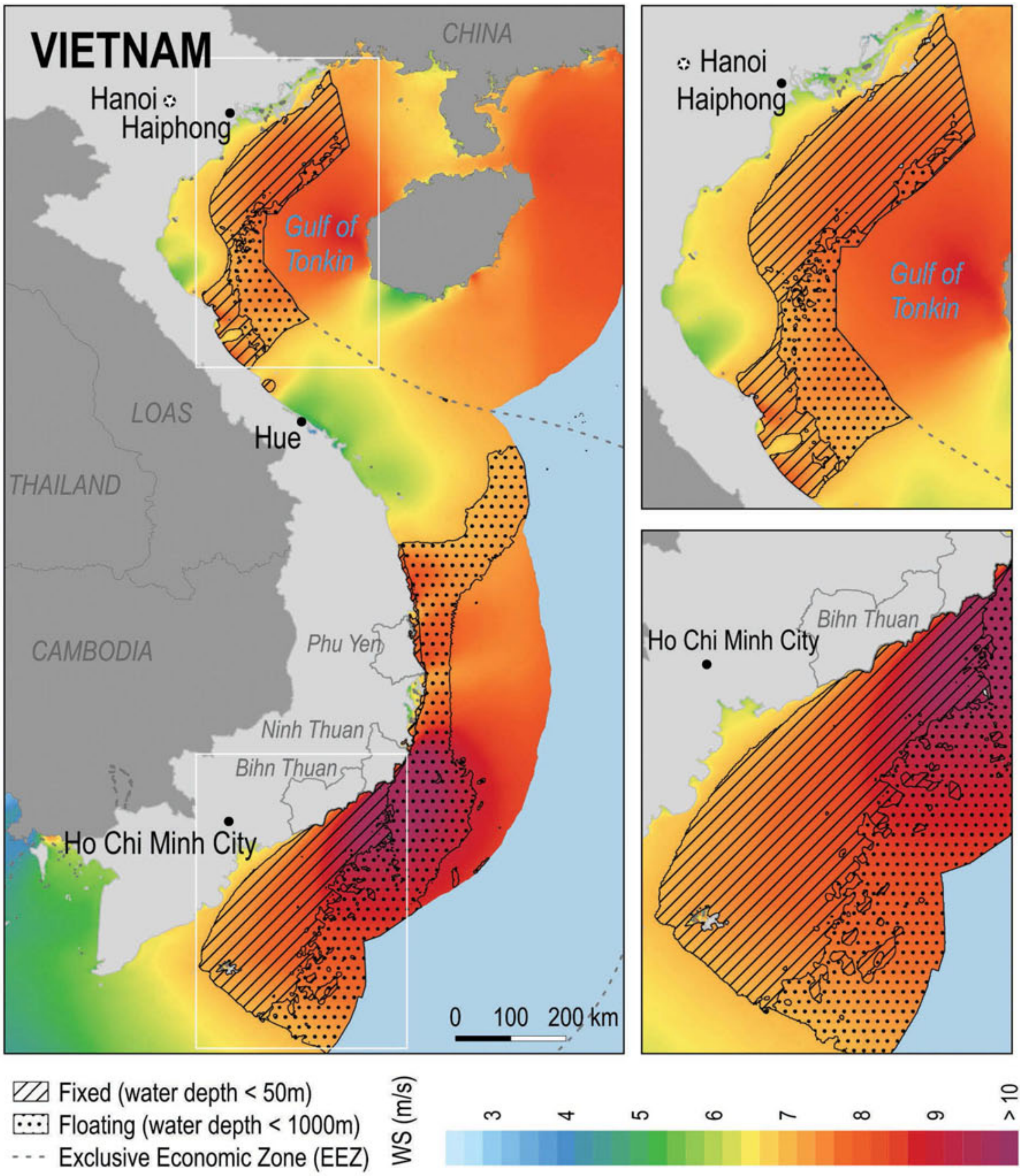
Transmission to demand centers[42]

- The southwest area is approximately 200 km from Ho Chi Minh City. The government has plans for 500 kV reinforcement of the grid to the city by 2025 in the proximity of landfall for offshore wind, but additional grid reinforcement may still be needed.
- The Gulf of Tonkin could supply demand in the Hanoi area, where grid reinforcement is planned as well.

Relevant policies and targets: Vietnam's Power Development Plan (Revised No. 7) aims to derive 10 percent of its electricity from renewable energy by 2030, with 6 GW from wind. Power Development Plan No. 8 is expected to increase this target but currently offshore wind potential is not incorporated.[43]

Fit with regional offshore wind market: There is potential synergy with regional development in China and elsewhere in Asia Pacific.

Map 8: Vietnam



NEXT STEPS

Offshore wind is ready to go mainstream. Since the 1990s, nearly all northwest European countries have deployed fixed foundation projects at scale. The recent dramatic fall in offshore wind power prices is actively driving other countries around the world to embrace the technology. This report demonstrates that considerable opportunity also exists in developing countries to capitalize on their natural resources in offshore wind.

While complex, there are common worldwide themes and trends to guide offshore wind deployment. Emerging economies can learn from more established markets, while simultaneously adapting those lessons to their local context to avoid a one-size-fits-all approach. Further analysis is required, particularly related to geopolitical contexts. Regional cooperation and program management to attract supply chain investment and competition will further drive cost reduction. Floating wind will be required to fully realize market prospects in many developing countries. Commercial-scale projects are needed in the next few years, followed by industrial deployment to bring this technology to maturity.

In March 2019, the WBG announced a new initiative, to be led by ESMAP in partnership with IFC, to assist client country governments assess their offshore wind potential and develop a pipeline of bankable, IPP-led projects. To ensure a close connection to industry, ESMAP and IFC will be working with the Global Wind Energy Council (GWEC) and its Offshore Wind Task Force, consisting of world-leading Original Equipment Manufacturers (OEMs), developers, consultants, and supply chain providers. ESMAP and IFC will be drawing on the expertise of national partners, think tanks, financial institutions, and nongovernmental organizations (NGOs) in generating and disseminating global knowledge on offshore wind to support development in emerging markets. ESMAP will also provide funding to WBG country teams for in-country technical assistance activities and technical studies in response to requests from client governments.

APPENDIX: GEOSPATIAL DATA SOURCES AND DETAILED METHODOLOGY

DATA SOURCES

For the presented analysis, the following open source datasets have been used:

Annual mean wind speed: The wind speed at 100 m height, obtained from the Global Wind Atlas has a coverage of up to 200 km offshore

Water depth: The water depth levels were obtained from the GEBCO gridded bathymetric dataset

Economic exclusive zones: The EEZ boundaries were used for the delineation of the focus area for the geospatial analysis

THRESHOLDS

Dataset	Value Threshold	Details
Wind speed	> 7 m/s	Wind speeds above 7 m/s are assumed as optimal resources for offshore wind deployment
Bathymetry	< 50 m	Water depths of up to 50 m are considered suitable for fixed foundations
	50 m–1,000 m	Water depths between 50 and 1,000 m are considered suitable for floating foundations
Resulting areas	> 10 km^2	The resulting areas were further filtered by size, with areas covering a minimum of 10 km^2 considered suitable for the installation of an offshore wind farm

GEOSPATIAL ANALYSIS

The geospatial analysis is comprised of five main operations:

1. **Clipping of all layers to the Economic Exclusive Zones:** The analysis is relevant only within the EEZ borders, so the first step is clipping the Wind Speed and the Water Depth datasets to the maritime territory of each country.
2. **Subset the main datasets per threshold values:** For the potential calculation, it was important to divide the water depth into 2 categories: above 50 meters depth, considered optimal for fixed foundations and 50–1,000 m, where floating wind can be considered. In parallel, the wind speed dataset was filtered for values greater than or equal to 7m/s.
3. **Subtract the wind speed for each water depth category:** Once the water depth categories that correspond to fixed and floating technical potential have been created, these are used as a mask for extracting the wind speed values within two classes of wind speeds (1) wind speeds between

7–8 m/s and (2) wind speeds > 8 m/s. These two classes are important for planning the turbine type as well as power generation potential.

4. **Remove resulting areas smaller than 10 km²:** It has been assumed that each opportunity zone must have a minimum area of 10 km² to be considered suitable for offshore wind deployment; therefore areas smaller than 10 km² have been removed from the analysis.
5. **Compute the technical potential for the suitable zones:** The technical potential for each opportunity zone has been computed by assuming a density of 3 MW per km² for wind speeds between 7–8 m/s and 4 MW per km² for wind speeds greater than 8 m/s.

The following tables provide supplemental calculations illustrating technical potential at varying water depths.

BRAZIL			
Type	**Water Depth (m)**	**Wind Speed (m/s)**	**GW**
Fixed	≤50	7–8	87.3
	≤50	8	392.5
		Total	**480**
Floating	≤250	7–8	118.9
	≤250	8	430.2
	≤500	7–8	23.7
	≤500	8	52.7
	≤1,000	7–8	41.3
	≤1,000	8	81.2
		Total	**748**

INDIA			
Type	**Water Depth (m)**	**Wind Speed (m/s)**	**GW**
Fixed	≤50	7–8	89.8
	≤50	8	22.2
		Total	**112**
Floating	≤250	7–8	15.6
	≤250	8	36.7
	≤500	7–8	6.4
	≤500	8	3.6
	≤1,000	7–8	8.9
	≤1,000	8	11.5
		Total	**83**

MOROCCO (excluding disputed territory)			
Type	**Water Depth (m)**	**Wind Speed (m/s)**	**GW**
Fixed	≤50	7–8	10.9
	≤50	8	11.3
		Total	**22**
Floating	≤250	7–8	41.9
	≤250	8	54.7
	≤500	7–8	12.9
	≤500	8	19.4
	≤1,000	7–8	15.2
	≤1,000	8	33.5
		Total	**178**

PHILIPPINES			
Type	**Water Depth (m)**	**Wind Speed (m/s)**	**GW**
Fixed	≤50	7–8	13.1
	≤50	8	4.7
		Total	**18**
Floating	≤250	7–8	42.8
	≤250	8	16.3
	≤500	7–8	19.6
	≤500	8	24.3
	≤1,000	7–8	23.3
	≤1,000	8	33.8
		Total	**160**

SOUTH AFRICA			
Type	Water Depth (m)	Wind Speed (m/s)	GW
Fixed	≤50	7–8	14.36
	≤50	8	42.1
		Total	**57**
Floating	≤250	7–8	53.4
	≤250	8	536
		Total	**589**
**No further results: WS above 7 beyond 250 m water depths*			

SRI LANKA			
Type	Water Depth (m)	Wind Speed (m/s)	GW
Fixed	≤50	7–8	35.3
	≤50	8	19.4
		Total	**55**
Floating	≤250	7–8	10
	≤250	8	5.9
	≤500	7–8	3.1
	≤500	8	2.8
	≤1,000	7–8	4.3
	≤1,000	8	10.9
		Total	**37**

TURKEY			
Type	Water Depth (m)	Wind Speed (m/s)	GW
Fixed	≤50	7–8	6.6
	≤50	8	5.6
		Total	**12**
Floating	≤250	7–8	21.3
	≤250	8	20.6
	≤500	7–8	5.4
	≤500	8	5.6
	≤1,000	7–8	7.4
	≤1,000	8	2.7
		Total	**57**

VIETNAM			
Type	Water Depth (m)	Wind Speed (m/s)	GW
Fixed	≤50	7–8	176.8
	≤50	8	83.7
		Total	**261**
Floating	≤250	7–8	99.1
	≤250	8	17.5
	≤500	7–8	20.3
	≤500	8	22.9
	≤1,000	7–8	35
	≤1,000	8	19.2
		Total	**214**

FOOTNOTES/REFERENCES

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