Offshore Wind

SUBSEA ENGINEERING OPPORTUNITY
International Market Insights Report Series

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Scottish Enterprise

Contents

1. Introduction

This report is the first in a series of reports considering the opportunities for the Scottish oil and gas (O&G) subsea supply chain in other subsea and related markets. The report is a desk review considering the international activity of each of the sectors including where there is current activity and where there is the potential for activity based on published targets and available resource and opportunity. The report also considers the particular synergies of the given sector and the subsea oil and gas supply chain. These opportunities cover where there is a direct cross over and also where there are opportunities for collaboration to provide innovative solutions.

Offshore wind (OW) is an interesting prospect for the O&G subsea supply chain as there are many potential synergies across the depth and breadth of the supply chain, many of which are already being exploited. Offshore wind also enjoys a global reach in terms of potential and ambition. Currently Europe is the main offshore wind market with 90 percent of the installed capacity (12.6 GW out of 14.4 GW). China is the only other country with significant capacity installed at present. The potential and ambition for growing the OW market exists in: Europe, expanding the current capacity five-fold by 2030; Asia with approximately 46 GW targeted to 2030 and beyond and the Americas with the USA targeting 22 GW by 2030. This is summarised in Table 1 below.

Table 1: The potential offshore wind capacity and country/continent targets for offshore wind globally. Source: various

Country	Installed Capacity (end 2016)	Potential	Target
Europe	*12,631 MW*	*Technical potential: 2,919 GW of offshore wind in European waters.* *The economically attractive (as defined in Unleashing Europe's offshore wind potential) is 1,350 GW.*	*24.6 GW (assumed capacity by 2020, based on projects currently under construction and consented.)* *Central scenario for 2030 is 70 GW of offshore wind (low - 49 GW and high - 99 GW).*
United Kingdom	5,156 MW		10 GW to 2020 20 GW by 2030
Germany	4,108 MW		6.5 GW by 2020 15 GW by 2030
Denmark	1,271 MW		No specified target
Netherlands	1,118 MW		4.5 GW by 2023 Proposal for 1 GW per year 2023 - 2030
Belgium	712 MW		
Sweden	202 MW		
Finland	32 MW		
Ireland	25 MW		
Spain	5 MW		
Norway	2 MW		
France	-		3 GW by 2023 3 GW post-2023

Africa	-		600 MW project proposed in Tanzania (concept stage)
Asia & Pacific	*1,730 MW*		
China	1,627 MW	500 GW (0-50 m water depth)	10.5 GW by 2020 30 GW overall Pipeline: 3.5 GW to start construction in 2015
India	-	502 GW	Plan to 2032 is currently being Devised
Japan	60 MW	600 GW (realistically exploitable)	700 MW by 2020 10 GW by 2030
South Korea	35 MW	Theoretical potential 88 GW, practical potential 33 GW	900 MW by 2016 1.5 GW by 2019 Pipeline (Q1-2014) 90 MW
Taiwan	8 MW		600 MW by 2020 1800 MW by 2025 3 GW by 2030
Australia	-		2 GW project proposed (feasibility stage)
Americas	*30 MW*		
USA	30 MW	2,058 GW	3 GW by 2020 22 GW by 2030 86 GW by 2050 (Wind Vision)
Brazil	-		Potential pipeline up to 11.2 GW

Table 1 above shows the currently installed operational capacity (as of end 2016), the potential resource available in the countries studied (or supranational potential) as well as any stated targets and potential pipelines. The data collected for this (further elaboration and references in Section 4) show that there is a huge appetite for offshore wind globally with a target of over 41 GW by 2020. Not all of the projects are on a trajectory to be commissioned by 2020, but work is progressing and there is a pipeline of projects reaching far beyond 2020 as well. As a rough guide, based on current European project prices, 41 GW would equate to an investment of £127bn.

The opportunities for the Scottish O&G subsea supply chain to diversify into the offshore wind market exist both in Europe where there is a significant pace to the industry, and cost reduction emphasis is creating opportunities for innovation and collaboration from outwith the sector as well as in the rest of the world where countries are taking their first steps into OW. The opportunities are particularly from countries where there is an ambition to harness OW, such as Taiwan, Japan, etc. but the market is still immature, they are therefore looking to partner with companies from mature markets to benefit from their experience. The opportunity in these emerging markets is likely to be greatest in countries that do not have an indigenous oil and gas market.

The subsea engineering needs of offshore wind have the greatest synergies with subsea oil and gas around: surveys (such as environmental, geophysical, geotechnical & meteorological required for site selection, project design and EIAs including their analysis and interpretation); design and installation (particularly for floating offshore wind foundations and moorings); and O&M (particular strengths include IRM and offshore logistics).

2. Sector overview

The offshore wind (OW) sector harnesses the energy of the wind in an offshore environment. The sector primarily uses horizontal-axis three-bladed turbines, although innovations in turbine design have been demonstrated e.g. vertical axis turbines; two-bladed designs and kites. A growing area in offshore wind, of particular interest to subsea engineering, is the development of floating turbines. For floating OW the technology on the topside is the same (or similar) to fixed structures but instead of jackets or monopiles, semi-submersibles; tension leg platforms or spar buoys are used and moored to the seabed.

Offshore wind benefits from a greater availability of resource and less constraints than onshore wind, this allows larger turbines to be deployed and from this there is a resulting increase in the load factor, illustrated by the average load factor for UK offshore wind is 36.9% (with new projects averaging 44%) compared to 27.3% for the UK onshore.[1,2] Offshore wind, combining abundant resource and increased load factors, is therefore an important growth area in renewable energy.

Current focus in the sector is on cost reduction, this is being achieved through learning (with 14.4 GW installed worldwide[3]); increased rotor size (turbines rated at 8.3MW have been installed in UK projects and new turbines rated at 9.5 MW have been selected for UK projects[4,5]) and reduced cost of capital. Within UK projects there has been a 32% reduction in cost of energy from 2012 to 2016.[6] The role of subsea technologies and processes is an area of interest in continuing the cost reduction trends. A current innovation challenge is looking for solutions in areas such as internal structural monitoring; subsurface structural inspection; offshore heavy lifting and high quality offshore service with focus on automation, communication and sensor technology (more detail in Section 3 below). Many European countries now operate and auction for support, such as the Contract for Difference (CfD) in the UK, and tender systems in Germany, the Netherlands and Denmark. OW developers either compete for a fixed amount of capacity based on the level of support they would need to receive to build the project (Netherlands and Denmark) or they bid for the level of support they require for a project they are developing (UK and Germany) both within allocated rounds. This competition has also led to a reduction in prices with the latest UK CfD round (Sept 2017) awarding projects at £57.50/MWh, well below the anticipated £70-90/MWh, the most recent German round (April 2017) resulted in the award of three tenders with zero subsidy. The zero subsidy windfarms will rely on the wholesale proce of electricity for the income over the lifetime of the project. However, these farms are yet to be built and therefore prove that these cost predictions are achievable.[7]

Key considerations for offshore wind include – availability of resource, water depth, seabed conditions, distance from shore and access to ports for installation and service as well as local support for offshore wind development such as supportive planning/permitting policies and financial support such as R&D funding or subsidies.

Although there are similarities between the O&G industry and offshore wind, particularly

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[1] RenewableUK / Digest of UK Energy Statistics (DUKES) 2017
[2] The Crown Estate, Offshore wind operational report, January to December 2017, 2018
[3] Global Wind Energy Council, Global Offshore Wind Capacity Reaches 14.4GW in 2016, 2017
[4] Wind Power Monthly, Ten of the biggest turbines, 2017
[5] OffshoreWind.biz, First Turbine Installed at Blyth, 2017
[6] Offshore Wind Programme Board, Third Cost Reduction Monitoring Framework Report, 2016
[7] ICIS, Falling offshore wind costs may lead to increased capacity targets for North Sea countries, 2017

floating turbines, it should be noted that there are differences in terms of the industries such as contractual arrangements; type of installations, e.g. small numbers of rigs per oil field versus tens and hundreds of WTGs per wind farm; and classifications e.g. definitions of deep water >50m in offshore wind versus 500 - 1499m in O&G (ultra deep >1500m).

There are already a number of companies that have expanded into offshore wind from oil & gas, some examples include:

- Subsea 7 who were awarded the EPCI contract for the Beatrice Offshore Windfarm in 2016.
  This contract is Subsea 7's largest North Sea project worth in excess of US$1bn.[8]
- Ecosse Subsea Systems who have been awarded the contract for seabed clearance for Hornsea Project One's export cables, amongst other projects.[9]
- Xodus Group who carried out the Environmental Impact Assessment (EIA) for the Statoil Hywind Floating Offshore Wind Farm.[10]
- Wood who acquired Sgurr Energy in 2010 as a further move into the clean energy markets.[11]

[8] Subsea7, Press Release, Subsea7 Awarded Wind Farm Contract, 2016
[9] Ecosse Subsea Systems, Ecosse Subsea Systems Scoop Seabed Project on World's Largest Offshore Wind Farm, 2017
[10] Xodus Group, Xodus Group to carry out environmental study for potential offshore wind pilot park, 2011
[11] Renewable Energy Focus, Wood Group acquires stake in renewable specialist SgurrEnergy, 20110

3. Subsea Engineering Needs

The development of an offshore wind project can be broken down into a series of steps, for the purposes of this document these are an overview of the process and do not include finance, etc. related activities. These steps include the full offshore wind farm which will include multiple wind turbines (WTGs) per project, from tens to hundreds, and, depending on distance to shore and size of windfarm, one or more offshore substations. The steps are:

- Site identification and characterisation
- Design of the windfarm
- Construction and Commissioning
- Operation, Monitoring and Maintenance
- Repowering / Decommissioning

The figure below shows the lifetime cost of an example floating and an example fixed 400 MW wind farm. Highlighted in each section is an estimation of areas of offshore wind development that have a subsea focus or activity. The key areas for subsea engineering are balance of plant (BoP) - all aspects of the windfarm aside from the turbine; installation and commissioning; operations and maintenance and project management. Balance of plant is a slightly larger for subsea in the floating wind example as the floating foundations are more expensive currently and the O&M costs are slightly reduced as it is assumed that any large maintenance and repair activities can be done at a quayside rather than out at the wind farm. Installation is also assumed to be easier as the turbines can be towed to site already assembled (as seen in the HyWind project off Peterhead). Through the sections below examples of subsea technology requirements will cover both fixed and floating wind.

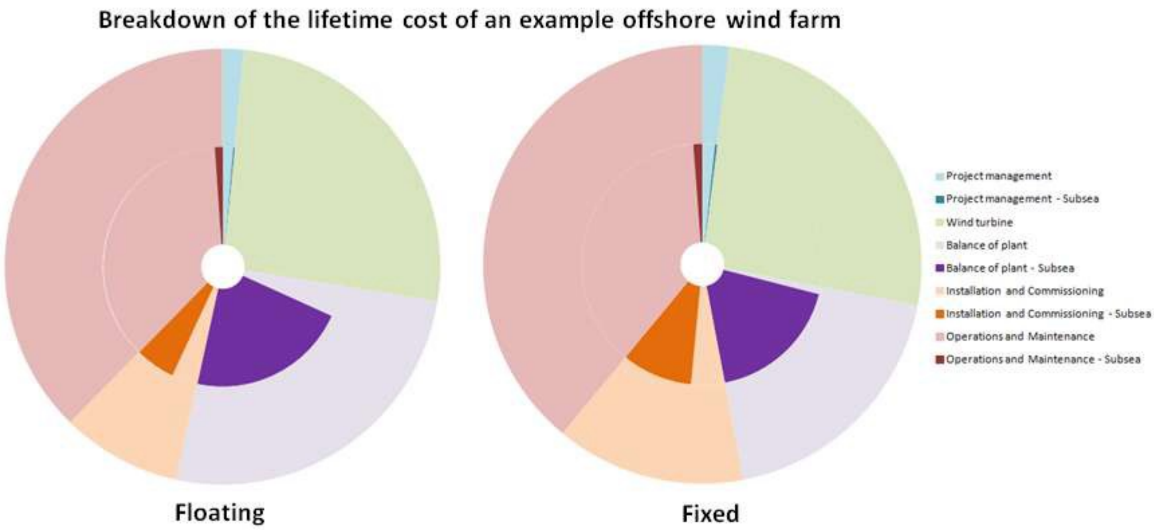

Figure 1: Pie charts showing the breakdown of the cost of an offshore windfarm, the darker segments denote those that are wholly or mostly subsea activities. The graphs are based on an example (fictional) 500 MW (fixed) and 400 MW (floating) wind farm. Source: BVG supply chain reports produced for SE 2014 (fixed) and 2015 (floating).

Taking each of these phases, the cross-over technologies and technology themes from the oil and gas subsector have been identified including challenges that need addressing in the OW sector.

3.1. Site identification and characterisation

Scotland's subsea engineering expertise can provide support across these areas for this first project stage:

- Offshore wind strategy development

In new markets where offshore wind is just emerging, one of the first impacts Scotland can have is on experience of developing a permitting structure, including EIA and surveys – we have skills in this area and sharing this experience will speed the development of new markets as they don't have to take as long as first movers. Our skill sets from developing a permitting structure through Marine Scotland, The Crown Estate and the companies that have first gone through the process will be an asset for this.

- Project management and development

Scotland has significant expertise in the development and management of offshore projects. Although many of these are focused on the O&G sector, the understanding of the offshore environment, managing risk and a challenging environment will be a useful cross over. There are of course differences in terms of serial production of components and repeatable activities in terms of installation compared to the more bespoke nature of O&G.

- Environmental surveys

Environmental surveys are required to be undertaken at an early stage in project planning as part of the Environmental Impact Assessment (EIA) required for the consenting process; these include the benthic environment as well as, marine mammals and bird surveys. Scotland has at least 5 Survey equipment companies including, service providers; manufacturers and suppliers.

- Geophysical, geotechnical & meteorological surveys

There are two levels of survey that are particularly relevant to offshore wind, firstly the seabed environment through geophysical surveys to understand the bathymetry, seabed conditions and characteristics. Then geotechnical surveys penetrate deeper to understand the changes in the seabed strata and specific formations, these are important for macro- and micro-siting of WTG foundations as well as minimising installation risk. Scotland has at least 15 geoscience survey companies including service providers, consultants, suppliers and technology providers.
Meteorological studies are also required to ensure detailed wind data is obtained, although this is not obviously subsea related, this data will be collected either through a met mast or fixed LiDAR system which will require a foundation and therefore the associated surveys and installation. There is also a move towards floating LiDAR systems, which can save a factor of 5-10 in cost associated with a fixed system, which will require the associated survey and mooring system which has direct crossover to offshore O&G. Metocean data is also required to understand currents and the oceanographic environment, this is done through additional sensors on the met mast and seabed based ADCPs.

3.2. Design of the windfarm

- Front End Engineering Design (FEED)

Scotland has a number of companies that specialise in FEED, these skills will be transferable to the offshore wind industry. This stage is relevant to subsea in particular for foundation type decisions and wind farm layout. Examples of these companies include DNV GL, Atkins, TNEI, Sgurr.

- Site and environmental surveys

Scotland has at least 43 companies that are involved in the survey and positioning of pipelines and subsea infrastructure, including manufacturing, suppliers and technology provision. Although not dealing with pipelines specifically, survey and positioning of monopiles, pin piles and anchors will be required for offshore wind as well as the siting of inter-array and export cables to transfer power from the WTGs

3.3. Construction and Commissioning

From the Company Capability Analysis there are 254 Scottish companies in the Oil and Gas subsea construction sub-sector, this includes: subsea civil engineering including design, sea bed platforms, subsea excavation, foundations, pipes, manufacture and laying cables, cable connections/tiebacks and striping. Operations and planning and FEED Studies, project management and demolition services.

- Foundations – fixed

Foundations are the biggest cost element of the balance of plant (BoP), specific costs are very dependent on the water depth that the windfarm is deployed in, fixed foundations include predominately monopiles, but jackets are also deployed particularly in deeper water windfarms (40 m). Monopiles are mostly piled into the seabed, and jackets use pin-piles, however examples can be seen of suction bucket foundations and gravity base foundations.

Foundation manufacturing is carried out at fabrication yards such as Bifab, but Scotland is not dominant in the steel rolling and forming that is seen for a lot of the monopiles. The largest crossover is anticipated to be in the preparation of the seabed and installation.

The Neart na Goithe Offshore Windfarm, developed by mainstream renewable power, is looking to employ a new jacket design for its 448 MW project. The jacket is a six-legged steel lattice structure, pictured below in Figure 2, and will also be used for the twin offshore transformer modules.[12]

Figure 2: The proposed six-legged jacket for the Neart na Goithe offshore wind farm. Source: Mainstream Renewable Power

- Foundations – floating

For deeper water windfarms, >50m, floating foundations are required. There are three key types of floating foundation: semi-submersibles; spar buoys and tension leg platforms (TLP). There is huge crossover with the O&G supply chain for these foundations as they are technology that is currently deployed. For example TLPs are analogous to mid water arches, spar platforms and semi-subs are well used within the industry. Alongside the foundations the moorings are O&G related technology including the ropes, cables and chains and the anchors.

There are at least 37 Scottish companies providing services within moorings and foundations including in particular, manufacturers and suppliers of this equipment.[13,14]

- Cables

Cables, both inter-array and export, are a vital part of an offshore wind farm, moving the power generated by the WTGs to the offshore transformer and then to shore. Opportunities

[12] Mainstream Renewable Power, Neart na Gaoithe Offshore Wind Farm, Scoping Report, 2017
[13] Scottish Enterprise, Subsea Company Capability Assessment, 2017
[14] tbr, Scotland's Upstream Oil & Gas Supply Chain, 2016

exist in the supply of array cable as well as the laying of cables, the preparation of the seabed, e.g. trenching and boulder clearance as well as the protection of cables are all O&G supply chain related activities. For floating windfarms, depending on the depth, inter-array cables (in particular) are likely to be floating rather than dropped to the seabed and brought back up between WTGs. Knowledge and technology around risers may assist in the development of these farms. There is also a likely crossover in knowledge around cable arrays and connectors.

- Installation

A key crossover point for OW installation with O&G is port and port facility logistics, learning can be sought on this area in particular. Although not entirely subsea related this area, alongside vessel management is an important area.

Underwater services, such as ROVs, trenching, boulder removal and support activities around piling- or the installation of other types of foundation such as suction buckets – will all be highly relevant here.

It is also interesting to look at technology developments in both directions, a replacement for typical sacrificial anodes (used to prevent corrosion) is being trialled at the under construction Arkona windfarm in the German Baltic Sea, the innovative solution is 'Thermalius' a thermally-sprayed aluminium solution.[15]

Offshore wind vessel requirements include differ from oil and gas in that they need smaller vessels due to the smaller devices, although bespoke turbine carrying vessels are being used. The vessels also need to contend with working in potentially high tidal flow areas, therefore a requirement for dynamic positioning, and with a maximum speed greater than the tidal velocity.[16]

3.4. Operation, Monitoring and Maintenance

Although a significant part of the lifetime cost of an offshore windfarm is the operation and maintenance (O&M) phase, the subsea activity in this area is fairly limited. Figure 3 below shows a break down of offshore wind O&M activities. Subsea activities are largely related to underwater survey and repair activities.

The Scottish O&G supply chain has particular strengths in inspection, repair and maintenance (IRM), the CCA shows 192 companies working in this subsector, a third of the companies in the oil and gas supply chain having skills or activities in this area.

For both onshore and offshore wind the global wind services market revenue increased by 10.5% in 2016 when compared to 2015. Market revenue is estimated to reach $14.3 billion (£10.8bn) in 2020, at a CAGR of 12.3%.[17] Currently, approximately 3% of wind capacity is offshore (although this is expected to grow dramatically) and based on a conservative 3% of OMS being subsea related, this is a conservative global market of $13m (£9.9m) for subsea O&M by 2020. As seen in Figure 3 the subsea elements of O&M have excluded vessel and e.g. offshore accommodation. Some of these activities will have a subsea aspect, so it is worth noting that the figure stated above is likely to be a minimum figure in terms of the market.

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[15] Renews, Monopiles get hi-tech corrosion protection upgrade at Arkona, **361**, 2017
[16] SubseaUK, Subsea Technology and Engineering, 2014
[17] Frost and Sullivan, Wind Power Market Outlook, 2017

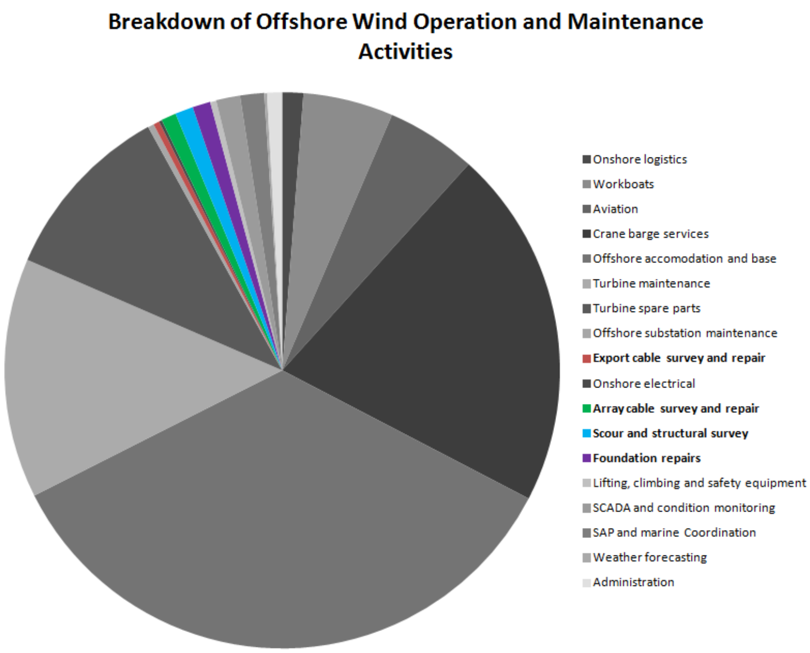

Figure 3: Breakdown of offshore wind operations and maintenance activities. The coloured segments (also in bold in the legend) denote activities that are wholly or mostly involved in subsea. Source: Adapted from The Crown Estate Guide to offshore wind O&M, this is based on a 500MW wind farm.

The Offshore Renewable Energy Catapult (ORECat) and the Knowledge Transfer Network (KTN) are working on a joint innovation challenge looking specifically to engage out-of-sector companies. Solutions for part of the challenge or turnkey solutions are both welcome. Innovation Challenge 2 – ‘subsurface structural inspection’ is of particular interest here and is looking for solutions in the following areas: Robotics; Multitasking unmanned aerial vehicles (UAVs); Sensors and advanced imaging; Communications technology; Non-destructive inspection techniques; Data processing and analysis; Artificial intelligence and Satellite imaging.[18]

3.5. Repowering / Decommissioning

Offshore wind farms are expected to have a lifetime of approximately 20 – 25 years. All offshore windfarms must have a decommissioning plan as part of their consent. Guidance on the decommissioning can be found is available from the government[19]

Windfarms may be repowered in that the turbine may be replaced (or components of) for a newer more efficient model, however this will depend on the suitability of the foundations for increased life and the new turbine (weight, size, etc.)

Where a windfarm is decommissioned it is likely that the rotors will be removed and the foundations will be cut off at the seabed. Cables will also have to be removed. This subsea activity will have direct crossover with O&G subsea companies.

The first offshore wind farms are starting to be decommissioned in Europe, including the Danish Vindeby windfarm – the world’s first – whose 11 turbines have seen 25 years of

[18] InnovateUK, Innovation Challenge 02 Subsurface Structural Inspection, 2017
[19] Department of Energy and Climate Change, Decommissioning of offshore renewable energy installations under the Energy Act 2004

operation since 1991[20] and the first decommissioning of an offshore wind farm, the Swedish Yttre Stengrund windfarm which operated from 2001 to 2015, decommissioning was decided upon as it was not technically and financial viable to repower this windfarm.[21]

Given that at the end of 2016 there were 3,589 grid connected WTGs installed in Europe, and there is a huge global ambition for offshore wind, the decommissioning market will be a significant prize, although only in the medium term.

3.6. Cost Reduction in Offshore Wind

One of the key reasons that the LCOE of offshore wind has dropped so dramatically is the rapid take up of new technology in terms of larger capacity nacelles. Developers, keen to reduce costs, have been quick on the uptake of new technology. Larger turbines mean a reduction in number of installations, and therefore time and money. The technology has been rapidly developed and available to the market and projects appear to be willing to take risks with new technology in order to benefit from the savings. By their nature offshore wind farms allow a rapid deployment of a number of turbines within one farm, rather than the bespoke one-offs traditionally seen in the oil and gas industry.

The offshore wind industry is working collaboratively on a number of industry challenges in a bid to further reduce costs in the sector. Examples of such projects include:

- Reducing the cost of jacket foundations, led by offshoreenergy.dk and the Danish Wind Energy Association, 50 companies from across the supply chain are involved in the four workstreams: standardising designs for transition pieces, improvements to modularisation and industrialisation; improvements to knuckles and pipework plus a steering group tasked with “formulating and agreeing on overall harmonisation of standards for jackets”.[22]

[20] OffshoreWind.biz, Second Offshore Wind Farm Decommissioning on the Way, 2016
[21] OffshoreWind.biz, Vattenfall Wraps Up First Ever Offshore Wind Farm Decommissioning, 2016
[22] ReNews, In Brief, **359**, 2017

4. Global Markets

The Global Wind Energy Council's (GWEC) *Global Wind Report: Annual Market Update* states that in 2016 there is a total of 486.8 GW of wind installed globally, of this 14.4 GW is offshore. Wind is installed in more than 90 countries globally of which 45 have offshore wind installations or activities/investigations in this area.[23]

Offshore wind deployment has, to date, been mostly in European waters, with the UK leading the world with 5.4 GW of operational windfarms[24]. Over 90% of installed offshore wind capacity is in the North Sea, Baltic Sea, Irish Sea and Atlantic Ocean[25]. Although this dominance also highlights where the expertise are situated in offshore wind, there are other global players who are making significant progress in the market, including: China, Japan, South Korea, Taiwan, Vietnam and the USA.

Figure 4 below shows the wind power data across the global oceans. Wind power density is only part of the equation for offshore wind as distance to shore, water depth and seabed conditions are all critical factors in where offshore wind can be installed.

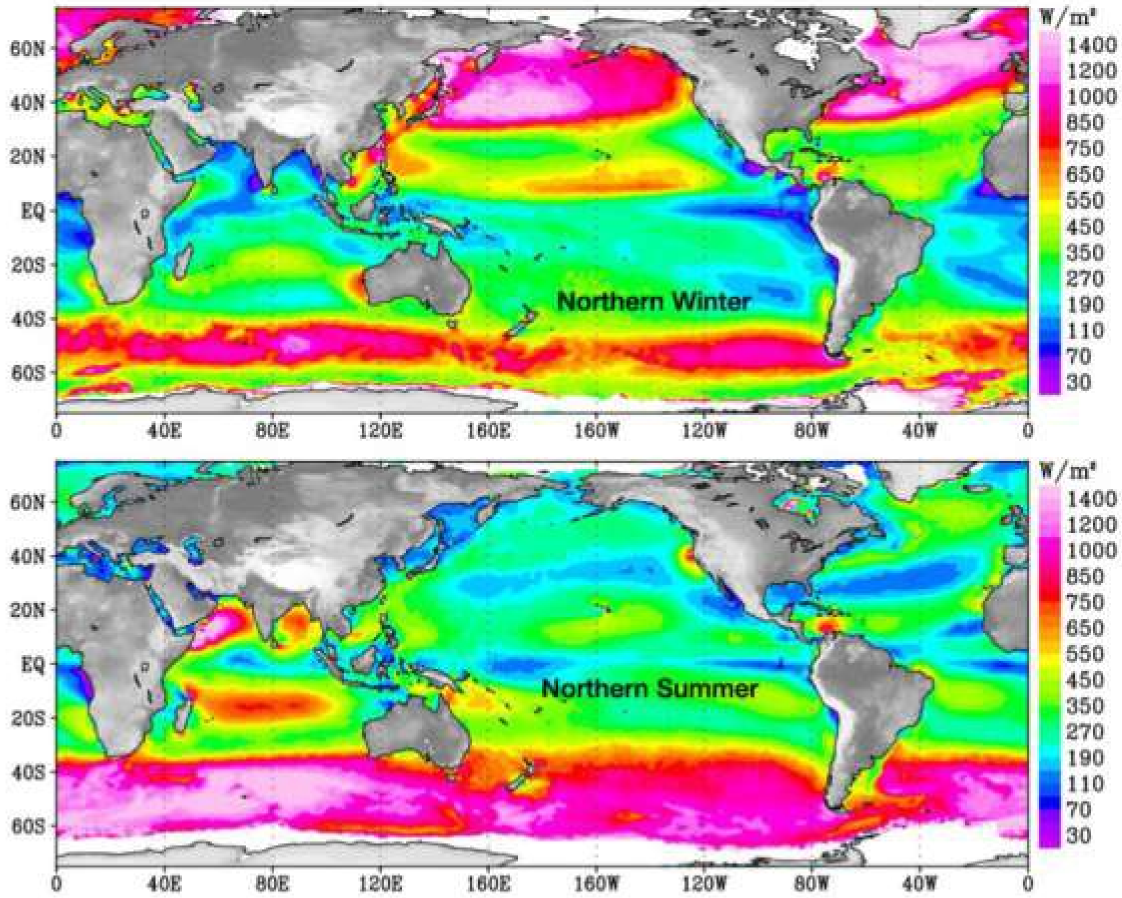

Figure 4: Wind power data over global oceans. Source NASA Jet Propulsion Laboratory

23 4c Offshore website, accessed October 2017
24 RenewableUK, UK Wind Energy Database, Wind Energy Statistics, Accessed October 2017
25 FOWIND, Offshore Wind Policy and Market Assessment - A Global Outlook, 2014

4.1. Europe, Middle East and Africa

In 2016 offshore wind counted for more than half of new clean energy investments in Europe totalling €18.2bn (£15.6bn) out of €27.7bn (£23.8bn).[26]

Europe has a total installed capacity of 12.6 GW from 3,589 grid-connected offshore wind turbines, across 81 offshore windfarms, in 10 countries in 2016. There are a further 11 projects under construction which will add an additional 4.8 GW of capacity, bringing the cumulative total to 17.4 GW. By 2020, it is anticipated that the cumulative installed capacity will be 24.6 GW. Projects that are consented; under consideration and in the planning process represent a further 96.8 GW of capacity.[27] Based on current capex of ~£3.1m/MW, the pipeline of projects up to 2020 (7.2 GW), not including those that are operational or already under construction, is potentially worth up to £22.3bn.

Figure 5 shows the water depth, distance to shore and capacity of European offshore wind farms at various stages of development. The trend in the figure shows that there is a push for larger, deeper and further from shore (in a small number of cases >200 km) in those projects consented and deeper, and further from shore (>150m) for those at the application submitted stage.

A big impact in Europe is the rapid development of larger turbines, with 8+ MW turbines being installed in projects at the moment and a desire by the industry to go even bigger (there is discussion of 12 MW turbines being developed).

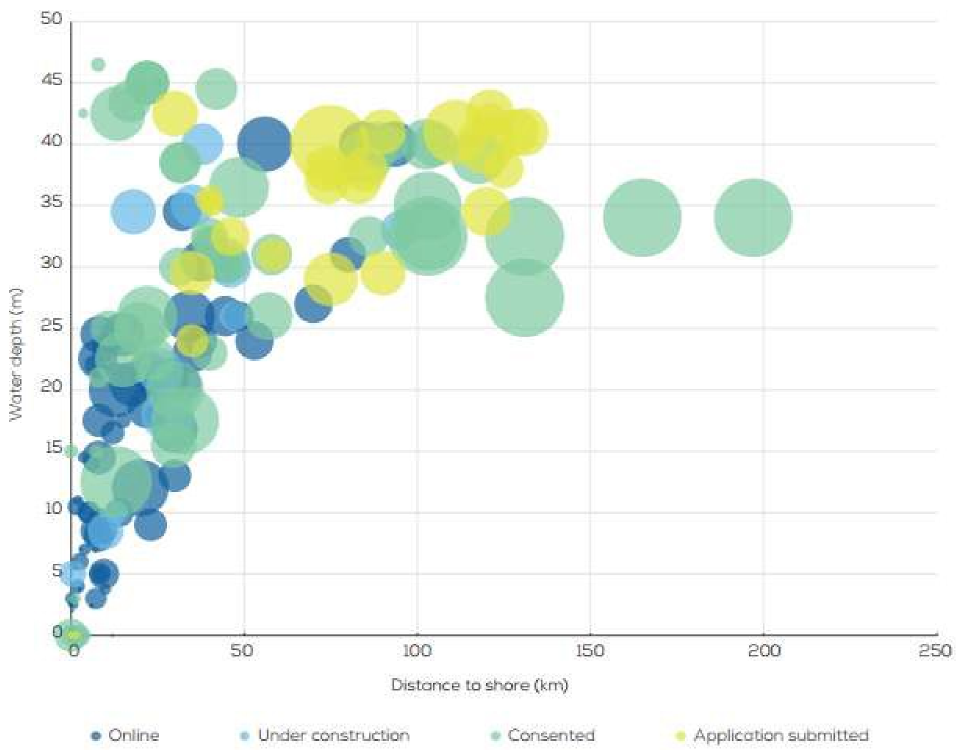

Figure 5: Average water depth, distance to shore of bottom-fixed, offshore wind farms by development status. The size of the bubble indicates the overall capacity of the site. Source: WindEurope

[26] WindEurope, Annual Statistics 2016
[27] WindEurope, Offshore Wind Statistics 2016

Ten European countries have operational offshore wind capacity, Portugal, also had a floating offshore wind turbine installed from 2011 – 2016, which has been decommissioned as planned so they do not currently have any installed capacity, but the 25 MW Windfloat Atlantic project is consented and planned to be operational by 2018[28]. Figure 6 shows the cumulative total of offshore wind installations in Europe at the end of 2016. The figure highlights the UKs lead with 40.8% of installed capacity followed by Germany and Denmark with 32.5% and 10% respectively.

Some examples of European projects include:
- The commissioning of the HyWind floating wind farm off Scotland's North East Coast in October 2017
- A demonstration project in Le Croisic, France, is progressing with the Floatgen floating wind turbine being towed to site, the 2 MW Vestas turbine is scheduled to be installed before the end of 2017.[29]

Figure 7 shows the breakdown of consented capacity (24.8 GW) across the European sea basins.

The figure illustrates that activity will still be predominately in the North Sea (78%) however, there is anticipated to be more activity in the Atlantic Ocean once French projects receive full consent (an additional 3 GW). Although the figure shows that there are consented projects in the Mediterranean Sea this is not anticipated to be realised until after 2020.[27]

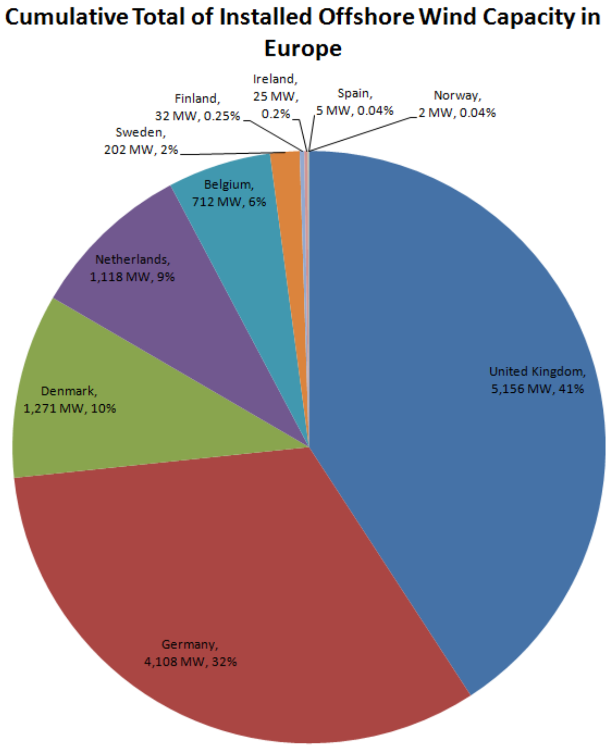

Figure 6: Cumulative total of operational offshore wind capacity in Europe by Country, source: Wind Europe.

[28] OffshoreWind.biz, Portugal Okays 25MW WindFloat Atlantic, 2016
[29] ReNews, AWAE Offshore Windpower - Preview Edition, 2017

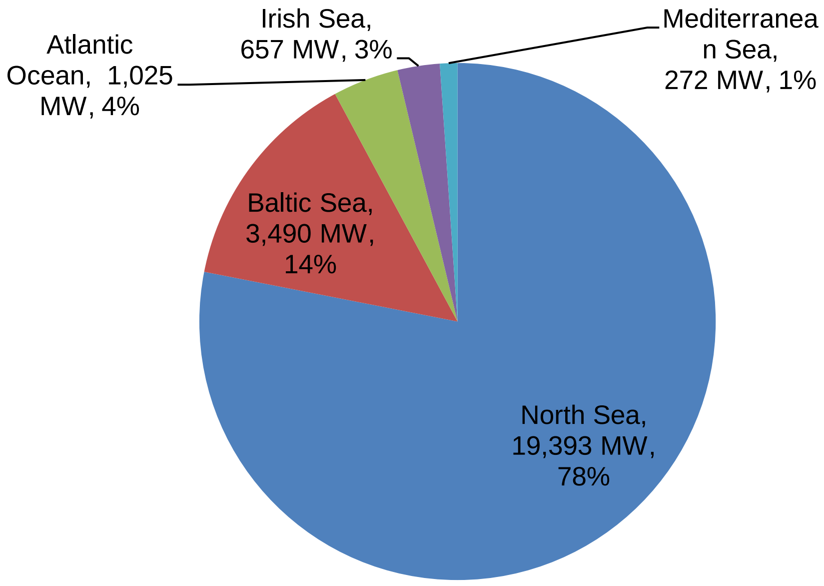

Figure 7: Consented wind turbine capacity by sea basin, Source: Wind Europe

Most European countries with an offshore wind market, or the ambition for one, operate on a capacity tender. The auction is for a tariff/power purchase agreement available for the sale of electricity of the wind farm for varying lengths e.g. 15 years in the UK, 25 years in the Netherlands, but they also come with e.g. guarantee of electrical connection.
The upcoming auctions are as follows:

- UK: Contract for Difference (CfD) next round April 2019 with £557m available for renewable energy projects (not just offshore wind).[30]
- Germany: Next round 01 April 2018, 1.61 GW will be available in the auction, of which at least 500 MW must be tendered.[31]
- Netherlands: Next round 15 December 2017, 700 MW available across two sites. The government amended the rules to allow for subsidy free bidding.[32]
- France: negotiations are currently ongoing on the French Round 3 offshore wind auction for sites, they are expected to be announced in early 2018.[33]

In June 2017, Energy Ministers from Germany, Belgium and Denmark, along with 25 companies from industry, jointly declared that they would deliver 60 GW of offshore wind, or at least 4 GW a year during the 2020s. This ambitious pledge comes on the back of continued cost reduction, and is a further statement of intent by the industry, on top of national and supranational targets.[34]

Offshore wind development is untapped as yet in **AFRICA**, although it is on the radar. The African Development Bank Group has previously done some work in this area, considering the opportunities. They note that offshore wind is behind onshore wind, in part due to the difficulties around permitting in the ocean environment, which is typically a lengthy and complex process. There is available resource however, as shown in Figure 8, with the key areas of resource in the north west, east and south of the continent.

[30] OffshoreWind.biz, UK: Next CfD Round Scheduled for Spring 2019, GBP 557 Million Earmarked for Renewables, 2017
[31] OffshoreWind.biz, Germany Accepts First Subsidy-Free Offshore Wind Auction Bid, 2017
[32] Bloomberg, Subsidy-Free Wind Power Possible in $2.7 Billion Dutch Auction, 2017
[33] OffshoreWind.biz, France Pre-Selects 10 Dunkerque Offshore Wind Bidders, 2017
[34] Reuters, Germany, Belgium, Denmark and industry pledge huge EU offshore wind expansion, 2017

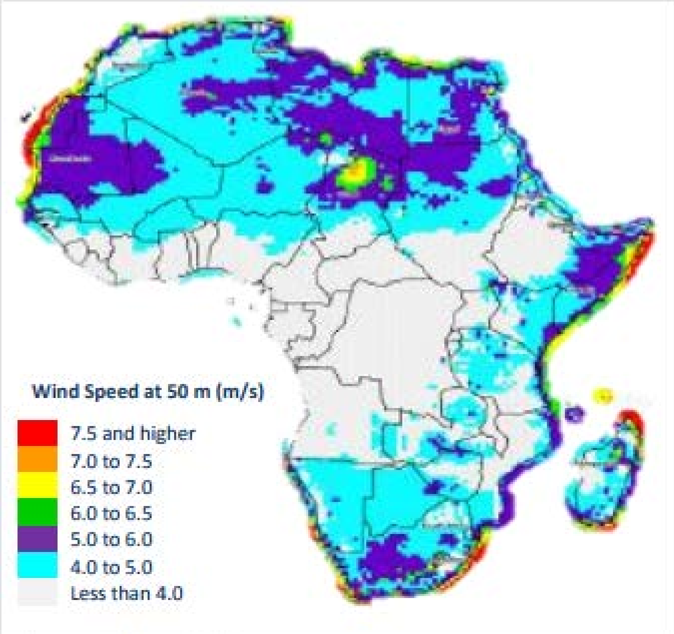

Figure 8: Wind resource in Africa modelled at 50 meters height and a resolution of 50 km. Source African Development Bank Group.

There are reports of a Swedish company proposing a 600 MW offshore wind farm in Kenya, which was not approved by the Kenyan government, due to the scale of the project and the lack of necessary infrastructure for a project of this scale. A 310 MW project in Lake Turkana in Northern Kenya is cited as being constructed but not operational as it does not have the transmission lines to distribute the power. The proposed 600 MW project is reportedly being moved to Tanzania.[35]

4.2. Asia and Pacific

CHINA is targeting 10.5GW of offshore wind by 2020 with their national offshore wind development plan, there is a further national development pipeline with total offshore wind ambitions of 30GW. Although China failed to meet earlier (ambitious) targets of 5 GW by 2015, they have been making progress and at the end of 2016 they have commissioned 1,627 MW of OW capacity, as well as a pipeline of 3.5 GW starting construction in 2015.[3,25,36]

Support for offshore wind is increasing with Feed-in Tariffs (FiT) for offshore wind at CNY 0.85/kWh (£0.10) and CNY 0.75/kWh (£0.09) for the inter-tidal zone, this support level came into place on 01 January 2017, and an acceleration of activity is expected to be seen.[37,38] There is also a strong emphasis being put on local tendering for support in the market, across all renewable energy sources. [39]

[35] ESI Africa, Kenya loses offshore wind farm to Tanzania, 2017
[36] BVG, Offshore Wind in China: Opportunities for UK companies in a growing market, 2014
[37] IEA, Feed-in tariff for onshore and offshore wind, China. Accessed 17 January 2017.
[38] Bloomberg News, China Can Expect a Surge in Offshore Wind Farms, Goldwind Says, 2017
[39] National Development and Reform Commission on adjusting photovoltaic power generation, 2016 (translated by google)

Figure 9: Figure showing increase in offshore wind deployment in China. Source: Bloomberg

Earlier analysis by the IEA[40] in 2011 shows that there is an assumption of decreasing costs, particularly in the far offshore developments, for both the capital investment and the operation and maintenance, which is to be expected as learning and volume increases. The current FiT as shown in the previous paragraph is in-line with the predictions, although no reference has yet been found to a 'far offshore' tariff.

Table 2: Expected investment costs and Feed-in Tariff prices for Chinese offshore wind out to 2050. Source IEA 2011

		2010	2020	2030	2050
Unit Investment	Near offshore	¥14m-19m/MW *(£1.6m-2.2m/MW)*	¥14m/MW *(£1.6m/MW)*	¥12m/MW *(£1.4m/MW)*	¥10m/MW *(£1.1m/MW)*
	Far offshore	-	¥50m/MWh *(£5.7m/MWh)*	¥40m/MWh *(£4.5m/MWh)*	¥20m/MWh *(£2.3m/MWh)*
O&M cost	Near offshore	¥150/MWh *(£17/MWh)*	¥150/MWh *(£17/MWh)*	¥100/MWh *(£11.4/MWh)*	¥100/MWh *(£11.4/MWh)*
	Far offshore	-	¥300/MWh *(£34.1/MWh)*	¥200/MWh *(£22.7/MWh)*	¥100/MWh *(£11.4/MWh)*
Projected average tariff	Near offshore	¥0.77-0.98/kWh *(£0.09-0.11/kWh)*	¥0.77/kWh *(£0.09/kWh)*	¥0.60/kWh *(£0.07/kWh)*	¥0.54/kWh *(£0.06/kWh)*
	Far offshore	-	>¥2.00/kWh *>(£0.23/kWh)*	¥2.00/kWh *(£0.23/kWh)*	¥1.00/kWh *(£0.11/kWh)*

Offshore wind costs in China could fall to £75/MWh by 2020, an 8-10% reduction on 2015 costs. There are opportunities for UK companies to help develop the Chinese offshore wind market particularly where learning and experience can be used to help reduce costs.[36] Current capex costs are lower in China as current farms tends to be within 15 km of the shore, many even within the inter-tidal zone less than a one mile (1.6 km) from the coast. As the industry grows and Chinese windfarms move further offshore costs are likely to increase as has been seen in Europe with the move from early e.g. UK Round 1 windfarms (average £1.6m/MW) to the more operationally challenging conditions offshore in later rounds (average £3.1m/MW). These costs have then been shown to be reduced through the use of larger rotor WTGs.[41]

[40] NOTE: the IEA did not define the boundary between 'near offshore' and 'far offshore' in the roadmap.
[41] Carbon Trust, Detailed appraisal of the offshore wind industry in China, 2014

Work still needs to be done to establish the actual commercial potential of China's offshore wind resource at a wind farm level as estimates of the potential are currently at a macro level. It is understood though that the potential off China's east coast has been estimated at 200 GW within a water depth of less than 25 m, an additional 300 GW of potential is available in water depths of 25-50 m.[41]

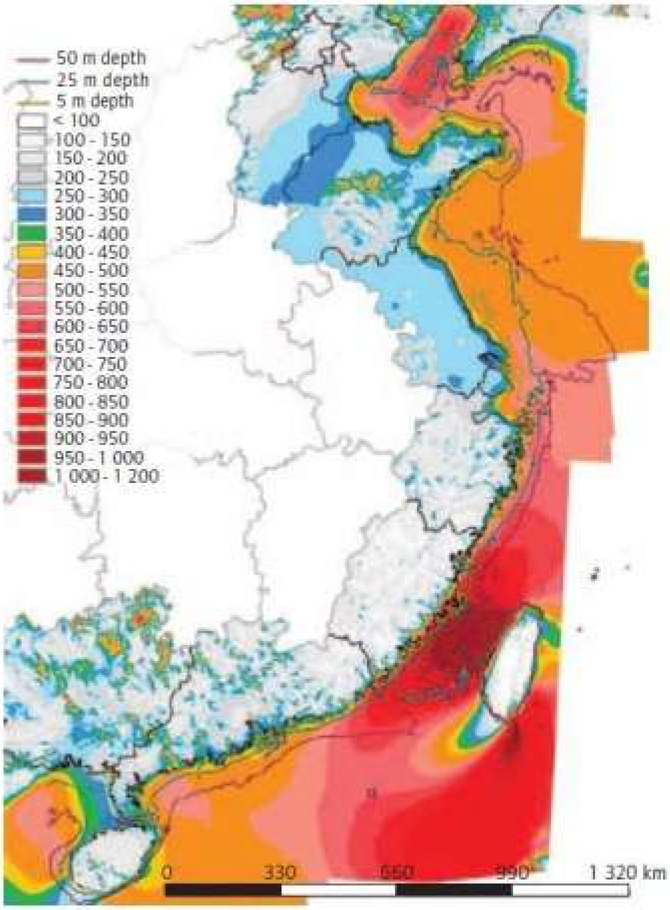

Figure 10: Map showing the water depth and annual average wind density (at 100 m height) in W/m^2 off China's east coast and surrounding area. Source: IEA 2011

A potential issue for offshore wind in China is the risk of typhoons, however, the Chinese Meteorological Association has performed research which shows that there are only a few isolated areas which are subject to wind speeds in excess of 70 m/s (the upper limit for IEC Class 1 turbines) – for example, the east coast of Fujian and Hainan Island. North of the Yangtze River sees limited typhoon risk, but still sufficient wind resource for harnessing.[41,42]

Within 5-30 m water depth off China's east coast the seabed is largely soft and silty soils, these are different to the seabed conditions in Europe and will require different foundation solutions to those deployed in European waters.[41] *This is an area for potential subsea engineering R&D.*

Other areas for potential engagement with the subsea engineering industry include OW installation techniques and bespoke vessels for installation as lack of experience in this area is adding cost to Chinese projects.[41]

[42] World Bank Group, Open Knowledge Repository, China - Meeting the Challenges of Offshore and Large-Scale Wind Power: Strategic Guidance, 2010

There are not yet any specific studies on offshore wind potential in **INDIA**, however, the Xi Lu et al. Global wind energy potential study in 2009 suggests that India's long coastline has a potential for 502 GW of offshore wind energy. Coupled with this potential, relatively low construction costs make India and interesting emerging market for OW.[43, 44]

A current project, Facilitating Offshore Wind in India (FOWIND[45]) 2013 - 2018, established through the Indo-European cooperation on Renewable Energy Programme, and funded €4m by the European Union, is focusing on the states of Gujarat and Tamil Nadu. The project includes preliminary resource assessment and techno-commercial analysis. As part of the resource assessment an offshore LiDAR platform was deployed in early 2017 off the Gujarat coast.[46] An offshore wind plan to 2032 will be developed. FOWIND will also facilitate knowledge sharing between the EU and India particularly on offshore wind technology, policy, regulation, industry and HR as well as promoting related R&D activities in India[47] – *this could provide opportunities for the subsea engineering sector to get involved in this emerging market*.

JAPAN'S drive for renewable energy exploitation has been progressed following the Fukushima disaster after the Great East Japan Earthquake in 2011. Japan is a nation with a plentiful offshore wind resource, estimated at 1600 GW, however 80% of this is in waters deeper than 50 m, which start close to the shore. At 80 m above sea level wind speeds average 7.5 m/s [48]. In 2016 Japan added 7 MW of new OW capacity, which brings its operational capacity to 60 MW.[3]

Of the estimated resource, approximately 600 GW is seen as realistically exploitable. Of particular interest to the subsea sector is that it is estimated that 50-85% of this OW resource would be accessed by floating technology. Table 3 below shows the opportunity for the build out for offshore wind in Japan.[49,50]

Table 3: Proposed market build-out of wind power in Japan Source: JPWA

Year	Total installed offshore wind power	of which is Floating Offshore
2013	0.05 GW	0.004 GW
2020	0.7 GW	0.1 GW
2030	10 GW	4 GW
2050	37 GW	18 GW

RD&D activity for floating offshore wind has been promoted and funded at government level through the Ministry of Economy, Trade and Industry (METI) and the Ministry of the Environment (MOE).

Offshore wind in Japan is predicted to be more expensive to deploy than elsewhere in the world. A METI commissioned study estimated that the deployment of a large fixed

[43] WWF, The Energy Report– India 100% Renewable Energy by 2050, 2013

[44] Global Wind Energy Council, India Wind Energy Outlook 2011

[45] NOTE: The FOWIND consortium is led by Global Wind Energy Council (GWEC) and the other consortium partners include the Centre for Study of Science, Technology and Policy (CSTEP), DNV GL, the Gujarat Power Corporation Limited (GPCL), National Institute of Wind Energy (NIWE) (who joined in June 2015) and the World Institute of Sustainable Energy (WISE).

[46] OffshoreWind.biz, India Set to Install First Offshore Wind LiDAR off Gujarat, 2017

[47] FOWIND website, accessed November 2017

[48] Main(e) International Consulting LLC, *Floating Offshore Wind Foundations: Industry Consortia and Projects in the United States, Europe and Japan: An Overview*, 2013

[49] Japanese Wind Power Association, *Target & Roadmap for Japanese Wind Power*, 2014.

[50] The Carbon Trust, *Appraisal of the Offshore Wind Industry in Japan*, 2014.

offshore wind farm would be ¥1.07-1.12b/MW, or approximately £6-6.5m/MW. This is double the average cost for a European fixed offshore windfarm (at £3.1m/MW). The Japanese farm would also expect to see higher O&M costs.[51] It is possible that these increased costs are due to the early state of the offshore wind industry in Japan[50], where the supply chain is currently undeveloped compared to Europe, and so cost would be expected to fall over time.

In 2016 **SOUTH KOREA** commissioned 30 MW of offshore wind capacity, the Tamra project, increasing their cumulative total to 35 MW.[3, 52] This follows the inception of South Korean offshore wind which began in 2013 with the installation of a two turbine 5 MW demonstration project also off Jeju Island.[25] These wind farms form part of an overall plan, for semi-autonomous Jeju Island, to become carbon free by 2030. These carbon free plans, announced at the Paris Climate Conference, include 1 GW of offshore wind by 2020 and 2 GW of wind by 2030.[53]

The Korea Institute of Energy Research (KIER) predicts a theoretical potential offshore wind resource of 88 GW.[54] From which KIER has calculated a technical potential of 33 GW.[55] Developments in larger monopiles, jackets and floating foundations that have happened in Europe and elsewhere may have an impact on this potential as the assumptions used by KIER include a maximum water depth of 30 m. Korea has shallow waters around its shores (the southwest offshore wind project will be in 8-10 m water depth), however, the seabed is muddy which will have an impact on the foundations that are suitable for these conditions. This is an area where subsea engineering may provide answers, although these conditions are different to the North Sea.[56]

There is a real drive for renewable energy development in South Korea as a nation which currently imports almost 96% of its energy requirements, due to low natural resources and energy intensive industries. Offshore Wind, however, is a plentiful natural resource for Korea, and would thus increase energy security as well as the carbon reduction benefits. Korea is already implementing a reduction in coal plants, in 2016 coal represented approximately 40% of electricity generation, and there are plans to reduce nuclear power as well.[57] The plans submitted to the UNFCCC target reducing Korea's greenhouse gas emissions by 37% from Business as Usual (BAU) level by year 2030. New and renewable energy supply has increased with a CAGR of 14% from 2009-15.[58]

South Korea in a supportive move for renewable energy has implemented a Renewable Portfolio Standard (RPS) which requires producers who generate more than 500 MW of power (both state owned and private) to generate an annually increasing percentage from renewable energy sources. This impacts 18 Korean energy companies. The percentage has increased from 2.0% in 2012 to 4.0% in 2017 and will increase to 10% by 2023. Renewable Energy Certificates (RECs) are awarded for generation from renewable energy supplies and are weighted for technologies. Offshore wind less than 5 km from shore receives 1.5 REC per MWh generated and wind projects greater than 5 km from shore receive 2 REC per MWh.[58,59]

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[51] Wind Power Offshore, *Japan plays long game with floating technology*, 2014
[52] OffshoreWind.biz, South Korea Becomes Offshore Wind Energy Producer, 2016
[53] Renforus, Carbon-Free Island Jeju by 2030
[54] KIER, New and Renewable Energy Data Centre, Energy Data, Wind, accessed October 2017
[55] KIER, New and Renewable Energy Data Centre, About RES-Map, About Wind, accessed October 2017
[56] Wind Power Monthly, Tide turns in South Korea, 2016
[57] OffshoreWind.biz, Korea Readies for Wind Expansion, 2017
[58] Export.gov, Korea - Energy New and Renewable, accessed October 2017
[59] Korea Energy Agency, Renewable Portfolio Standards (RPS), accessed October 2017

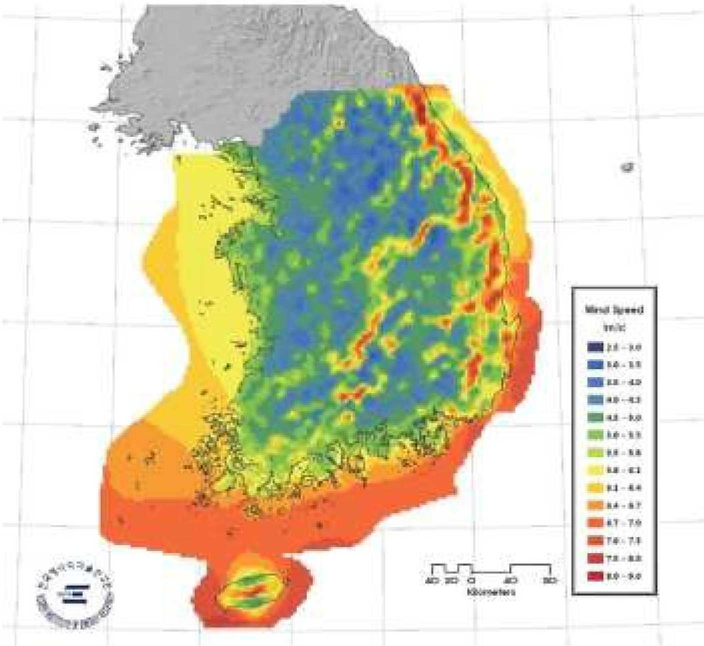

Figure 11: wind speed map of South Korea source. KIER

The Korean state-owned company, Korean Offshore Wind Power (KOWP), has plans to make South Korea one of the top three offshore wind energy countries by 2020. KOWP have entered into a cooperation agreement with Dutch company Wind Minds, to realise their ambitions of a 2.5 GW wind farm the "Southwest Offshore Wind Project".[60] The Korean's have entered into this agreement as they want to draw on the experience of the Dutch in developing their OW industry as they have great ambitions. The Southwest offshore wind project is located to the southwest of Seoul and off the coast of Jeollabuk-do Province. It is a three-phase project with an aim to build out 60-80 MW by 2018, followed by 400 MW by 2020 and the final approx. 2 GW in the proceeding decade (although there are no firm plans for how phase 3 will be implemented yet).[58]

In addition to the Southwest OW project there is the 96.8 MW Saemangeum Offshore Wind Farm which is currently in development, due to be completed in mid-2018, the 100 MW Hallym Offshore Wind Power Demonstrator has consent and over 450 MW of capacity across four wind farms in the permitting process at present[61]

The west coast of South Korea has predominately shallow water, with most of the proposed sites in less than 10 m water depth, although further offshore the depth increases to approximately 70 m. On the east coast of the country, the water depth increases rapidly close to shore to a depth in excess of 2000 m in the Ulleung Basin.[62] The west coast will have challenges associated with the muddy seabed and the development of appropriate foundations. Development on the east coast will be linked to the progress of floating offshore wind. It is expected that the lower cost sites, in shallower waters, will be developed initially.

[60] OffshoreWind.biz, Wind Minds to Engage in 2.5GW Korean Offshore Wind Project, 2016
[61] 4cOffshore, Hallym Offshore Wind Power Demonstration, accessed 26 October 2017.
[62] Korea Hydrographic and Oceanographic Centre, Basic Maps of the Sea, accessed October 2017

The South Korean government has invested approximately $200m (£151m) in a variety of projects, examples of R&D initiatives include floating wind foundations, suction bucket foundation types, carbon-fibre wind turbine blades and projects related to grid and transmission.[56]

TAIWAN has big ambitions for harnessing its wind power resource, which it has articulated through the "Thousand Wind Turbines Project" looking at development both on an offshore. There is a government target to have 20% of energy from renewable resources, with and expectation that wind will play a significant role in this (at least 33%). The Thousand Wind Turbines Project is backed by the Bureau of Energy (BOE) and Ministry of Economic Affairs (MOEA) and a 'promotion office' to lead the project was opened in 2012. Taiwan aims to have 600 MW offshore wind capacity installed by 2020, increasing to 3 GW by 2030. The offshore wind potential is shown in Table 4 below.

Table 4: Offshore Wind in Taiwan. Source: MOFA

Water Depth (m)	Area (km^2)	Potential (GW)	Feasible (GW)
5-20	1779	9	1.2
20-50	6547	48	5
>50		90	9
Total:	>8326	147	15.2

There is currently 8 MW installed in a demonstration project (two turbines installed in 2016), and plans for 3 demonstration projects c. 100 MW are in place. The demonstration projects are also a trial for how the larger scale offshore wind developments will take place through access to offshore wind zones with 300 MW of capacity being made available each year. All the demonstration projects are in shallow waters on the west coast of the country. Demonstration projects can receive up to 50% support for installation up to a maximum of NT$250m (£6.3m).[63, 64]

There is also a Feed-in Tariff (FiT) for offshore wind as well as a 20-year guaranteed power purchase agreement. The current FiT level is NT$6/kWh (£0.15/kWh) up from the 2014 level of NT$5.6076/kWh (£0.14/kWh). This is an attractively high FiT and has seen interest from a number of European and Canadian developers, resulting in proposals for 11 GW of capacity over 24 projects. The FiT level could be reviewed in the future and is likely to be subject to a 2.5 GW cap.[63,65]

[63] Flanders Trade and Investment, The Offshore Wind Energy Sector in Taiwan, 2014
[64] Thousand Wind Turbines Project, Offshore Wind Power, Demonstration Incentives, accessed October 2017,
[65] Digitimes, Taiwan justifies high feed-in tariff for offshore wind farms, 2017

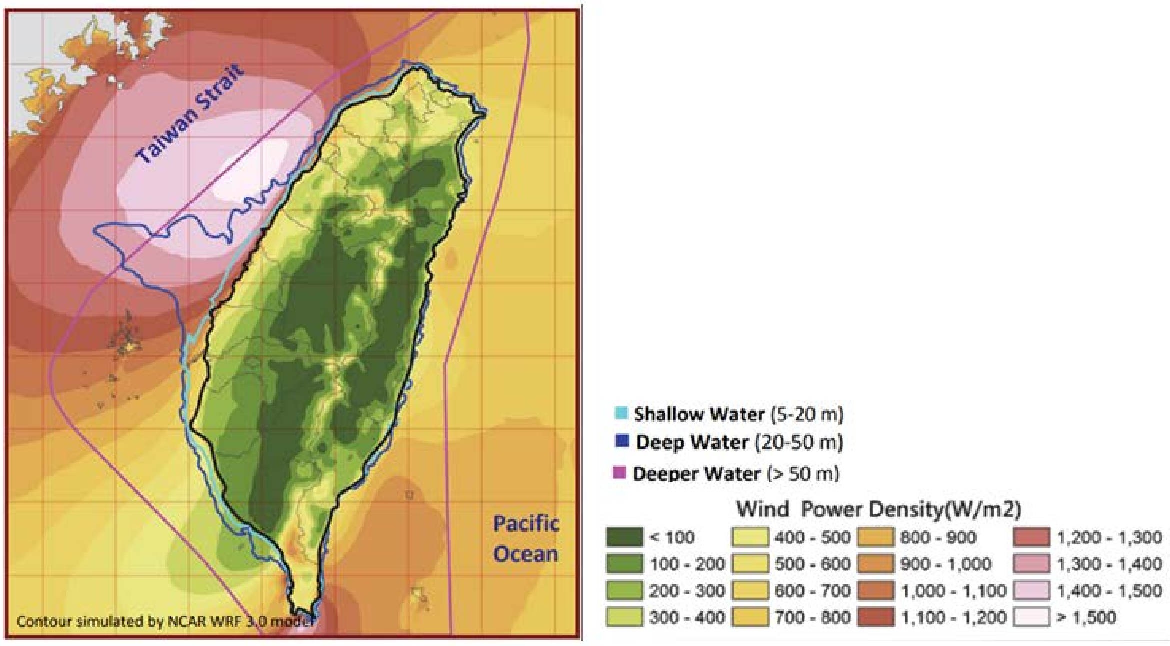

Figure 12: Wind power density map for Taiwan including water depth indications. Source: MOFA

Taiwan also has to consider more extreme environmental conditions then are found in western Europe. Although some sites for offshore wind in Taiwan can boast a capacity factor of 40-50% (similar to new UK projects) there is a need to have infrastructure that will withstand typhoons (turbines) and earthquakes (foundations). The technology deployed must take account of this.

Taiwan has limited expertise in the subsea sector and is therefore looking to learn from other countries. Some particular areas of interest include development of Environmental Impact Assessments (EIAs) for migratory birds and ocean mammals, as well as impacts on local fisheries, navigation and harbour operations. Project management is another area of interest with risk assessment and mitigation; vessel coordination and construction scheduling all highlighted as areas of potential development with European partners.[66] The UK are already forging links with Taiwan, with a delegation of 24 companies visiting with DIT in October 2017.[67] In 2017, Fugro and International Ocean Vessel Technical Consultant, a Taiwanese surveying company, have worked together to deploy a floating lidar system to collect wind data.[29]

AUSTRALIA is a newcomer to offshore wind, but has plans to build it's first OWF in the Bass Strait. The project dubbed 'Star of the South' will be a 250 turbine, 2 GW project covering 574 km^2. The developer, Offshore Energy, has an aim to start generation in 2024.[68] The project is at an early stage and has applied for an exploration licence to be able to carry out a feasibility assessment including seabed conditions, a two-year wind measurement campaign using two fixed meteorological masts and up to two floating LiDARs as well as two land based LiDAR systems.[69,70]

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[66] Industrial Technology Research Centre, Policy and Promotion of Offshore Wind Power in Taiwan, 2013
[67] OffshoreWind.biz, UK Supply Chain Companies Explore Offshore Wind Links with Taiwan, 2017
[68] Sydney Morning Herald, Australia's first offshore wind farm wins international funding, 2017
[69] Star of the South Energy Project Website, accessed October 2017
[70] Australian Government, Department of the Environment and Energy, Proposal to conduct offshore wind farm exploration activities, 2017

Australia has a Renewable Energy Target (RET) which aims for 33 TWh of renewable electricity federally, the RET however, expires in 2020 and there is currently no replacement as the government have not taken up the recommendation for a proposed replacement the clean energy target (CET). Both schemes are technology neutral.[71]

4.3. The Americas

The **UNITED STATES OF AMERICA** has a large offshore wind resource, including the Great Lakes, and they are targeting to have, by 2030, 20% of electricity production from wind, of which approximately 17% is expected to be from offshore sources.[72] Offshore wind is of particular interest in the US, not just due to the resource, but also that 80% of the electricity demand is from the coastal states.

The National Offshore Wind Strategy 2016, updating a previous assessment by NREL in 2010, estimates that the total theoretical OW resource is approximately 10,800 GW. This is based across the whole US EEZ (out to 200 nm) at 100m elevation and a capacity density of 3 MW/km^2. When technical constraints are included such as >7m/s wind speed, the technical potential is estimated as 2,058 GW[73]

As well as federal targets for offshore wind, including the Wind Vision of 86 GW by 2050, individual states also have targets. Most ambitious is New York State, where Governor Cuomo set a goal to develop 2,400 MW of offshore wind projects by 2030. A bill was also passed in summer 2016 that requires New York State utilities to purchase 1,600 MW of electricity from offshore wind farms by 2027.[74] Maryland, Massachusetts, New York and New Jersey are all states with policies in place that will drive significant development of offshore wind capacity.[75]

As can be seen in Figure 13 below both the east and west coasts of the US have favourable wind speeds for offshore wind. The east coast is seeing the majority of the current development as the Atlantic has shallower water closer to the shore to allow for deployment of current technology. The deeper water of the Pacific Coast has resource that will require the development of floating technology to be harnessed.

[71] Wind Power Monthly, Australia scraps plans for clean energy target, 2017
[72] US Department of Energy, National Renewable Energy Laboratory, *20% Wind Energy by 2030 increasing wind energy's contribution to US electricity supply*, 2008.
[73] National Offshore Wind Strategy, DOE and DOI, 2016
[74] Gizmodo, New York State approves largest Americas offshore wind farm, 2017
[75] Windpower Engineering & Development, U.S. offshore wind momentum sparks competition among state leaders & businesses, 2017

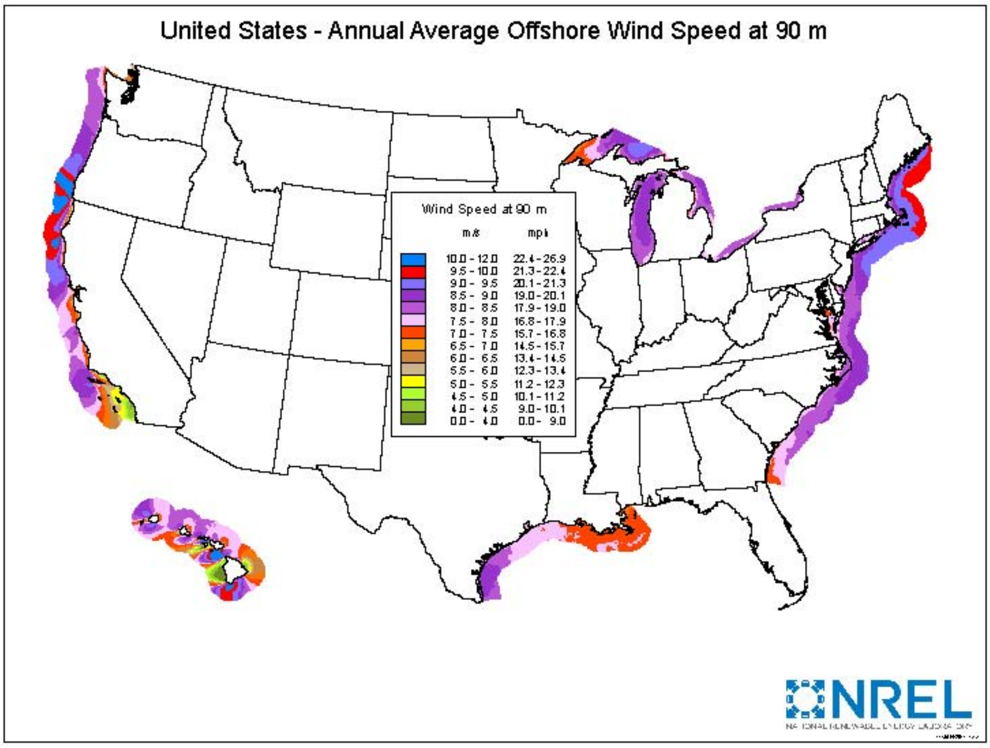

Figure 13: Map of annual average wind speeds off the US coast. Source: NREL

At the end of 2015, the US Department of the Interior had awarded 11 commercial leases for offshore wind developments with a total capacity of 14.6 GW.[76] Development of offshore wind is regulated by BOEM. BOEM have a number of so-called Wind Energy Areas (WEA), offshore wind development zones, that are in planning. It is also possible for developers to come forward with proposals outwith these areas.

The US commissioned its first offshore wind farm, the five-turbine 30 MW Block Island Windfarm off Rhode Island, in December 2016. [3]

As of October 2017 there are currently 17 offshore wind projects in the US various stages of development off the East and West Coasts, as well as the Great Lakes, representing over 9.1 GW of capacity, some of these include:

- Cape wind, 468 MW, Nantucket Sound, along the coast of the state of Massachusetts (the first commercial offshore wind lease) is fully permitted. The project proposal has had strong opposition from fisherman and local residents including both the Koch and Kennedy families.
- South Fork Wind Farm (developed by Deepwater Wind), a proposed 90-megawatt (MW) wind energy project, off the coast of Long Island, was granted a power-purchase contract from the state-run Long Island Power Authority. The proposal is for approx. 15 turbines and is reported to cost about $740 million. Assuming permitting stays on course, construction could start in 2019 and the farm would be operational by 2022. [74]
- The U.S. Department of Energy awarded three grants up to $47 million (£36m) each for offshore wind demonstration projects in May 2014. These awards were to support design and construction of three projects with anticipated completion by the end of 2017. However, two of the projects have been cancelled. The remaining project is targeting installation in 2020:
    - Dominion Virginia Power will install two 8 MW direct-drive WTGs off the coast of

[76] Bureau of Ocean Energy Management, National Offshore Wind Strategy, 2016

Virginia Beach a step-up from the 6 MW turbines originally envisaged. [77] The project will also install and test a hurricane-resilient design due to the US's hurricane-prone waters. Orsted has also come into the project as a partner and the developer

- The $126m Icebreaker Demonstration project on Lake Eerie is a 20.7 MW freshwater project developed by Fred Olsen and the recipient of $40.7m of funding from the DOE. Tenders are currently out for the onshore substation, as well as a preliminary tender for the installation works. It has been noted that there a number of bids are being looked at by US-EU partnerships to make the most of the learning in OW in Europe.[78]
- There are four parties interested in developing floating offshore wind projects in the lease area around Hawaii. One is currently unnamed and joins Statoil, Progression Energy (400 MW project) and Alpha Wind Energy (two 408 MW projects). [29,79] The Alpha Wind Energy projects have applied for an outer continental shelf lease from BOEM and anticipate building by 2020, with a lifetime cost of energy at $200/MWh (£135/MWh).[80]

The US is also looking to maximize the size of their turbines, confidence in the market is being felt through announcements such as MHI Vestas investing $35m to test their V164-9.5 MW offshore wind turbine at Clemson University, South Carolina. All testing and verification of the wind turbine's gearbox and main bearings will be carried out at Clemson University's 15 MW test bench.[81]

The American O&G industry is already starting to take an interest in the developing offshore wind market with the steel foundations for the Block Island Wind Farm, made in America by Gulf Island Fabrication. Zentech Inc., a Gulf Coast based company, have announced plans to build a Jones Act compliant (see below), four legged, self-propelled dynamically-positioned level 2, jack-up vessel based on a US-built barge.[82]

American-specific issues:

- Activities in the US are subject to The Jones Act, which originating from the Merchant Marine Act of 1920, which "restricts the transportation of merchandise between points in the U.S. to qualified Jones Act vessels. For a vessel to qualify, it must be registered in the U.S., built in the U.S., and owned and operated – absent an exception – by U.S. citizens. A U.S.-flag vessel, in turn, must consist entirely of U.S. citizen officers and crew members, with a limited exception for permanent resident aliens." This definition would include the transport of items or crew out to an offshore wind farm within 3nm of shore.[83]

SOUTH AMERICA has a high penetration of renewable energy largely due to significant hydroelectric power capacity, but also a developing onshore wind market with growth anticipated to be a 17.1% increase in installed capacity per annum between 2017 and 2020 (Frost and Sullivan). The main markets are Brazil, with significant contributions coming from Mexico, Chile, Argentina, Peru, and Uruguay.[17] These combined, along with

[77] ReNews, *Dominion step up to 8MW kit off Virginia***,** AWEA Offshore Windpower 2017 Preview, 2017.
[78] ReNews, *Supply and installation bids flow in for Icebreaker demo*, AWEA Offshore Windpower 2017 Preview, 2017.
[79] ReNews, *Floater twins pop up in Hawaii deep*, **309**, 2015.
[80] State of Green, Hawaii Floating Offshore Wind, Development of an large scale floating offshore wind energy project near Hawaii, accessed October 2017
[81] MHI Vestas Offshore Wind, U.S. leads the world in offshore wind turbine testing, 2017
[82] Zentech, First US Offshore Wind Installation Vessel to be Built with Oil and Gas Expertise, 2017
[83] North American Wind Power, Clarifying the Jones Act for Offshore Wind, 2011

solar power mean that renewable energy could account for 71% of electricity generation by 2035.[84] High population growth is also expected to increase electricity demand by one third by 2030. Offshore wind has yet to develop in South America, but with a long coast line and a good wind resource, the potential is there. The key countries of interest for OW are: Chile, Brazil, Puerto Rico, Colombia, and the Argentine Patagonia

BRAZIL has one tabled offshore wind project, the 'Asa Branca' which is has an ambitious total capacity of 11.2 GW. The project is staged with a first pilot phase of two 6 MW turbines, followed by a commercial 258 MW phase. There is then subsequent plans for a further three 270 MW phases to be built out that will develop the first 1 GW of this project. The project is off the coast of the Brazilian region of Ceara, and appears to still be in the planning stages.[85]

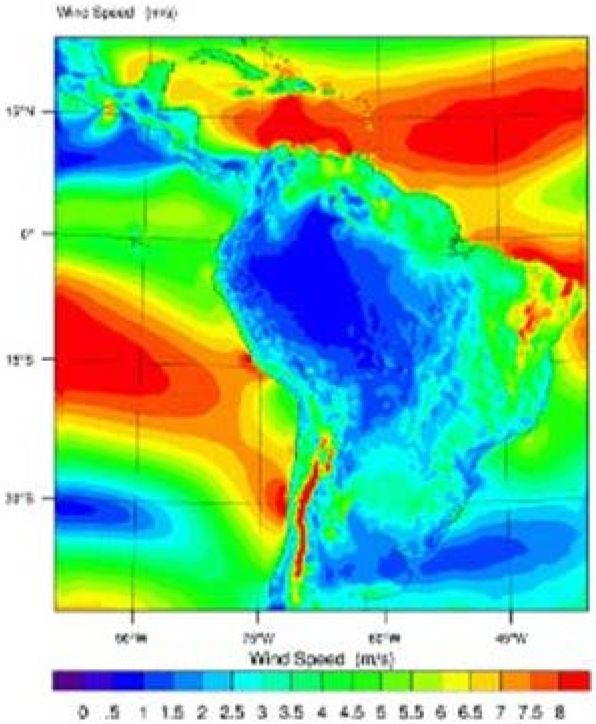

Figure 14: Simulated average wind speeds across South America. Source: Il-Soo, et al.[86]

CHILE has shown some interest in offshore wind, with a macro study of the countries offshore wind resource being done using data from NASA satellites. Deep water close to shore suggests that the Chilean resource is likely to be best suited to floating offshore wind technologies.

Table 5 below shows some statistics about the wind resource available and projected LCOE for development in each studied area. The study[87] based their calculations on an 8 MW turbine (Vestas V164-8.0 MW) and Spar Buoy (HyWind II) foundation. The lowest LCOE is for an area from 45 - 56° S the wind resource here however averages close to

[84] Latin American Science, Latin America: More than 50,000 kilometers of coastline of offshore wind potential, accessed October 2017

[85] Wind Power Offshore, Brazil to enter offshore sector with 12MW project, 2014

[86] Park Il-Soo, Jang Su-Hwan, Jang Yu-Woon, Ha Sang-sub, Chung Kyung-Won, Jeffrey S. Owen, Lee Seung-Woo, Choi Young-Jean. Wind Resource Modelling in Ecuador, *American Journal of Energy and Power Engineering*, **3**(1), 2016, pp. 1-9.

[87] Mattar, C. and Guzm_an-Ibarra, M. C., *A techno-economic assessment of offshore wind energy in Chile*, Energy, **133** (2017) p191-205

the maximum rating for the turbine studied, this is likely to reduce the lifetime of the turbine, so to successfully exploit this resource the turbine specifications will need to be carefully considered.

Table 5: Chilean offshore wind resource estimates. Source: various

Area	Wind resource	LCOE
Far north		>200 USD$/MWh
'North' 30° - 32° S	700-900 W/m^2	100 – 114 USD$/MWh
Central 30 – 45		100 – 140 USD$/MWh
'South' 45° - 56° S	Average wind speeds ~13m/s	72-100 USD$/MWh

Alongside generation of renewable energy, offshore wind could provide a cheap source of power to provide desalination of water in areas of drought such as Puerto Rico and La Guajira in Colombia where water has been rationed due to a lack of supply and two years without rain. Offshore wind has been studied as one of the most promising solutions to providing energy for desalination in coastal areas with an available wind resource.[84,88]

[88] IEA-ETSAP and IRENA, Water Desalination, Using Renewable Energy, Technology Brief, 2012

Appendix: List of Acronyms

ADCP	Acoustic doppler current profiler
BAU	Business as usual
BOE	Bureau of Energy (Taiwan)
BOEM	Bureau of Ocean Energy Management (US)
BoP	Balance of Plant
CAGR	Compound annual growth rate
CCA	Company capability assessment (SE report)
CfD	Contract for Difference (UK)
DIT	Department of International Trade (UK)
EIA	Environmental impact assessment
EPCI	Engineering procurement construction and installation (a type of contracting arrangement)
FEED	Front end engineering design
FIT	Feed-in tariff
FOWIND	Facilitating Offshore Wind in India
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IRM	Inspection, repair and maintenance
KIER	Korea Institute of Energy Research
KOWP	Korean Offshore Wind Power
kW	kilowatt (unit of power)
GW	Gigawatt (unit of power, equal to 1000 MW)
GWEC	Global Wind Energy Council
LCOE	Levelised cost of energy
LiDAR	Light detection and ranging
METI	Ministry of Economy, Trade and Industry (Japan)
MOE	Ministry of the Environment (Japan)
MOEA	Ministry of Economic Affairs (Taiwan)
MW	Megawatt (unit of power, equal to 1000 kW)
NASA	National Aeronautics and Space Administration (US)
NREL	National Renewable Energy Laboratory (NREL)
O&G	Oil and gas
O&M	Operations and maintenance
OW	Offshore wind
R&D	Research and development
REC	Renewable Energy Certificates
ROV	Remotely operated vehicle
RPS	Renewable Portfolio Standard (South Korea)
TLP	Tension leg platform
UAVs	Unmanned aerial vehicles
UNFCCC	United Nations Framework Convention on Climate Change
WEA	Wind Energy Areas (US)
WTG	Wind Turbine Generator