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Offshore Wind Energy

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5.1 Introduction

Offshore wind is the world's most commercially and technologically developed marine renewable energy subsector and is changing fast from being a niche technology into a mainstream supplier of electricity. At the end of 2016, global offshore wind capacity reached over 14.8GW with 12.9GW in Europe and 5.3GW (41%) of this in the UK.[1,2] At the end of 2016, there were 81 operational offshore wind farms spread across the waters of 10 European countries with 11 more projects in construction, totalling an additional 4.8GW. Offshore wind market activity is currently focused in the Atlantic, and Baltic and North Sea basins, which function as a single market. The UK, Germany and Denmark have principally driven the market in the North Sea, Irish Sea and Baltic Sea to date. Future activity in Europe focuses on these areas as well as expanding to the English Channel and the Bay of Biscay.

The countries around these basins have relatively low electricity prices so output from offshore wind farms has been explicitly subsidised. Some subsidy is necessary for all new electrical generating plant, but the cost of energy of offshore wind and subsidies needed continue to fall. Table 5.1 shows the recent winning level of price support from auctions.

[1] Global Wind Energy Council (2017), Global Wind Report 2016, 76 pp. Last accessed August 2017 http://www.gwec.net/publications/global-wind-report-2/global-wind-report-2016/

[2] WindEurope (2017). The European offshore wind industry – key trends and statistics 2016. A report by WindEurope (formally European Wind Energy Association). 25 pp. Last accessed August 2017. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf.

Table 5.1 Recent price support for offshore wind farms

Country	Owner	Project	Unit	Price[3]	Date of Auction Win	First Operation Expected at Time of Bid
UK	Mainstream	Neart na Gaoithe	£/MWh	114.39	Feb-15	2018
UK	Scottish Power Renewables	East Anglia 1	£/MWh	119.89	Feb-15	2019
DK	Vattenfall	Horns Rev 3	€ /MWh	103.1	Feb-15	2020
NL	DONG Energy	Borssele 1&2	€ /MWh	72.7	Jul-16	2020
DK	Vattenfall	Vesterhav (Nord & Syd)	€ /MWh	64.0	Sep-16	2020
SE	EnBW/Macquarie Capital	Kriegers Flak (Baltic 2a&2b)	€ /MWh	49.9	Nov-16	2021
NL	Shell/Eneco/Van Oord/Mitsubishi DNG	Borssele 3&4	€ /MWh	54.5	Dec-16	2022
UK	Innogy	Triton Knoll	€ /MWh	83.6	Oct-17	2021/22
UK	DONG	Hornsea Project 2	€ /MWh	64.3	Oct-17	2022/23
UK	EDP	Renewables Moray (East)	€ /MWh	64.3	Oct-17	2022/23

The Mediterranean and Caribbean basins do not currently have any commercial offshore wind installations. The Mediterranean could capitalise on its proximity to the established markets in the Atlantic and Baltic to develop a commercial market. This is not likely by 2020 due to the limited number of projects currently in development. The Caribbean could capitalise on synergies in the established oil and gas industry. Despite relatively high costs of electricity from new electricity generating plant, low annual electricity demand may limit the ability to establish a cost competitive market beyond a few projects. Combining with another sector such as desalination or with a floating deeper-water shipping terminal might help enable a bigger market.

A report prepared for WindEurope by BVG Associates and Geospatial Enterprises, highlighted the economically attractive offshore wind resource that is potentially available to Europe in the Baltic, North Sea and Atlantic from France to the north of the UK in 2030. Offshore wind could, in theory, reach a capacity of between 600 GW and 1,350 GW in the modelled baseline and upside scenarios respectively. This would generate between 2,600 TWh

[3]Note that the figures are not directly comparable. The duration of the support is different and not all include the cost of transmission.

and 6,000 TWh per year at a competitive cost of €65/MWh or below, including grid connection and using the technologies that will have developed by 2030. This economically attractive resource potential would represent between 80% and 180% of the EU's total electricity demand.[4]

5.2 Market

5.2.1 Atlantic and Baltic Basins

European activity is primarily in the Atlantic and Baltic basins, which function as a single market. Wind farms are developed either by large utilities, which they subsequently operate, or by independent developers. Often, they are developed by joint ventures to spread the risk. In the past, utilities tended to finance projects from their balance sheets and contracted up to 10 large packages (multi-contracting). With the increasing scale and complexity of projects, there are an increasing number of project-financed wind farms. Here investors typically prefer a small number of contracted packages to push the project risk down the supply chain and minimise the project's interface risks. There is a decreasing role for independent developers as they can rarely support project development teams for several years.

The key players are the turbine manufacturers. Turbines typically cost 30–40% of CAPEX (capital expenditure) and manufacturers have a major role in driving innovation and reducing costs. In an engineer, procure, construct (EPC) contracting environment, the turbines are usually procured separately as this contract has to be awarded before detailed engineering can begin. EPC contractors are usually offshore construction companies active in a range of sectors. The turbine contract generally includes a service agreement. Historically, this has been five years but this is increasingly variable as owners seek either to reduce cost by breaking the tie with the turbine manufacturer early or to increase the project's attractiveness to investors by negotiating a longer service agreement.

5.2.2 Mediterranean Basin

The Mediterranean is an emerging market and a small number of projects may be built before 2020. The characteristics of the market have not yet

[4]BVG Associates for Wind Europe (2017), Unleashing Europe's offshore wind potential, A new resource assessment, available online at: https://bvgassociates.com/publications/, last accessed August 2017.

emerged but the size of projects means that independent developers can play a significant role. In time, the market is likely to evolve in line with the Atlantic and Baltic basin markets. This is because the turbine manufacturers will be the same and they, largely, shape the market.

5.2.3 Caribbean Basin and Rest of World

Outside of Europe, there is an establishing market in China, and the first commercial sites are being developed in Japan, South Korea, Taiwan and the US. There is no commercial market in the Caribbean.

Table 5.2 presents key data for the offshore wind market of each basin.

5.3 Sector Industry Structure and Lifecycle

Offshore wind market activity is currently focused in the Atlantic and Baltic basins as Northern European countries such as UK, Germany and Denmark have driven the market in the North Sea, Irish Sea and Baltic Sea. Future activity in Europe will continue to focus on these areas. There is a good level of confidence that the geographic spread will expand to the English Channel and Bay of Biscay as there are a number of UK and French projects under development that are expected to be operating, under construction, or have reached final investment decision (FID) by 2020. To date, there is no commercial activity within the Mediterranean or Caribbean basins.

At the end of 2016, the Mediterranean had 1.1% of Europe's total consented offshore wind capacity.[5] The basin is therefore not expected to have any significant commercial activity before 2020. The Caribbean basin is currently dominated by oil and gas activity. This could provide synergies with existing infrastructure and supply chain capability if offshore wind was ever developed and deployed at a commercial scale. Offshore wind commercially leased areas and demonstration sites in the US are currently located elsewhere along the East Atlantic coast, with some early activity also in the Pacific Northwest, California, Hawaii and the Great Lakes.

The Atlantic and Baltic basins together can primarily be classified into lifecycle stage two (growth stage) and three (mature stage). The Mediterranean and Caribbean basins together can primarily be classified into lifecycle stage nought (development) and one (embryonic). To date, offshore wind

[5]The European offshore wind industry – key trends and statistics 2016, WindEurope, 2017, available online at https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2016.pdf, last accessed August 2017.

Table 5.2 Offshore wind market by basin

Basin	Country	Installed Capacity[6] (GW)	Consented Capacity[7] (GW)	Cost (CAPEX)	Price Support Last Awarded[8]	Targets[9]
Atlantic	UK	5.3	14.6 (57%)	CAPEX ∼€4 million per MW	£57.5–£74.75/MWh[10]	No formal targets, but range of 8GW to 13GW stated by Government by 2020. Provisional budget for about 10GW by 2020
	Germany	3.8	5.3 (21%)		€60/MWh[11]	6.5GW by 2020 (covering both Atlantic and Baltic basins)
	Netherlands	1.1	2.1 (8%)		€54.5/MWh[12]	5.2GW by 2020
	Denmark	0.4	0.0 (0%)		€64.0/MWh[13]	1.4GW by 2020 (covering both Atlantic and Baltic basins)
	France	0.0	0.0 (0%)		FIT of €130/MWh, or competitive tender[14]	6GW by 2020 (covering both Atlantic and Baltic basins)

(*Continued*)

[6] Installed capacity to the end of 2016.

[7] Share of consented offshore wind farms (totalling 25.8GW) in Europe at the end of 2016. Some countries with consented capacity are not included in Table 5.2.

[8] Note that the figures for different countries are not directly comparable. The duration of the support is different and not all include the cost of transmission.

[9] Targets taken from National action plans available online at: https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans, last accessed August 2017.

[10] Competitive contract for difference. Over 15 years for projects reaching final investment decision in 2017. Includes transmission.

[11] Auction April 2017 price for Gode Wind 3 offshore wind farm. There were three other wind farms that were bid at zero whose effective price is unclear.

[12] Netherland price support awarded through tender process. Price support awarded to Shell/Eneco/Van Oord/Mitsubishi DNG for Borssele 3 and 4 in December 2016. Transmission is excluded.

[13] Price support awarded to Vattenfall for Vesterhav (Nord & Syd) in September 2016.

[14] A FIT is available for offshore wind projects in France at €130/MWh, however a competitive tender was run in 2012 for 3GW of projects. Transmission costs are financed by developer in a competitive tender, but compensated at-cost as an incremental part of the tariff in €/MWh.

Table 5.2 Continued

Basin	Country	Installed Capacity[6] (GW)	Consented Capacity[7] (GW)	Cost (CAPEX)	Price Support Last Awarded[8]	Targets[9]
Baltic	Denmark	0.9	0.9 (3%)	Lower costs than Atlantic basin, as sites are less challenging	€ 103.1/MWh[11]	1.4GW by 2020 (covering both Atlantic and Baltic basins)
	Germany	0.35	0.3 (1%)		€ 150–180/MWh[10]	10GW by 2020 (covering both Atlantic and Baltic basins)
	Sweden	0.2	2.6 (10%)		Tradable Green Certificates	0.2GW by 2020
	Finland	0.03	0 (0%)	Lower wind speeds lead to lower yields	€ 83.5/MWh[15]	No offshore specific target[16]
	Poland	0.0	0.0 (0%)		Tradable Green Certificates	500MW by 2020
	Estonia	0.0	0.0 (0%)		System in the process of reform	Overall 2020 renewables targets are expect to be exceeded.
Mediterranean	Italy	∼0	0.03 (0.1%)	Likely to be similar to the Baltic basin	Tradable Green Certificates moving to a FIT in 2016	0.7GW by 2020
	Greece	∼0	0.0 (0%)		€ 108.30/MWh[17]	No offshore specific target
	France	∼0	0.0 (0%)		FIT of € 130/MWh, or competitive tender[13]	6GW by 2020 (covering both Atlantic and Baltic basins)
Caribbean		∼0	n/a	n/a		

[15] The FIT price set for wind power (onshore and offshore). There is no offshore wind specific subsidy.

[16] Target of 2.5GW for onshore and offshore wind by the end of 2020.

[17] An increase of up to 30% on the base FIT for offshore wind is available on a project-by-project basis if the Regulatory Authority for Energy deems it required for the level of investment required.

farms have primarily been developed as stand-alone projects. In the next five years this is unlikely to change. As markets and technology matures, especially where the state develops the site and then auctions it, leading developers such as DONG and Vattenfall are already adopting a ‘pipeline’ approach to site selection, progressive technology and procurement decisions.

5.3.1 Lifecycle

The offshore wind lifecycle can be classified into five main stages:

1. Development and consenting,
2. Final investment decision (FID),
3. Supply, installation and commissioning,
4. Operations, maintenance and service (OMS), and
5. Decommissioning.

Development and Consenting

Wind farm development and consenting covers work on the offshore wind farm from the point of site identification, to FID. Processes for completing activities vary widely between countries and basins. Here they are described typical to the UK and German markets. The main activities undertaken include:

- Site identification to establish areas of seabed suitable for wind farm development. This is typically undertaken by a leasing body, such as UK’s The Crown Estate and Germany’s BSH (Federal Maritime and Hydrographic Agency).
- Front-end engineering and design (Pre-FEED and FEED) studies to identify and address areas of technical uncertainty and develop the concept design of the wind farm in advance of contracting. The developer will use specialist subcontractors for specific activities like preliminary foundation design. Key parameters such as turbine rating, foundation type, wind farm layout, and grid connection method are considered to optimise economic viability. Onshore and offshore operation strategy is formed and procedures are planned, contracting methodologies determined, and key risk management and health and safety policies developed. Construction management teams use the studies to implement the wind farm.
- Wind farm design, which includes input from the FEED studies, wind modelling and turbine wake analysis, array optimisation, and wind

resource assessment. The developer typically completes most wind farm design in-house but places contracts with specialist engineering firms for key component design. Meteorological stations are often installed at wind farm sites at an early stage of development to monitor meteorological and oceanographic conditions.

- Surveys are typically contracted by the developer to specialist data acquisition companies. Surveys include environmental surveys (benthic and pelagic, marine mammal and ornithological), coastal process (sedimentation and erosion impact) and geotechnical and geophysical surveys.
- Stakeholder engagement is undertaken by the developer in parallel with the wind farm design and surveys. Stakeholders engaged included statutory bodies, non-statutory bodies, businesses and members of the public.
- Consenting is the process of regulatory approval for offshore works and grid connection. This is a process that varies between countries and basins.
- Procurement, which is the process of the developer contracting work packages for the supply and installation of components. Potential suppliers are qualified and progress through a bespoke selection process.

Final Investment Decision

FID is defined as the point of a project life cycle at which all consents, agreements and contracts required to commence project construction have been signed (or are at or near execution form) and there is a firm commitment by equity holders and debt funders to provide funding to cover the majority of construction costs.

Supply, Installation and Commissioning

Supply, installation and commissioning is the period where the offshore wind farm components are manufactured, installed, fully grid connected and brought into operation. Installation and commissioning covers work on all balance of plant as well as turbines. It can be broken down into the following areas: transport of completed sub-assemblies from manufacturing facilities; installation port facilities preparation and marshalling of sub-assemblies; foundation installation; array and export cable installation; offshore substation installation; turbine installation and commissioning; and sea-based support.

Operations, Maintenance and Service

A typical offshore wind farm is expected to have an operating lifetime of around 20 to 25 years, during which time maintenance and minor service and major service activities will take place including:

- Operation relating to the day-to-day control of the wind farm, including minor spares and consumables;
- Condition monitoring;
- Rental of the operations base, port facility, mother ship and crew transfer vessels;
- The repair or replacement of minor components using the wind farm's normal staff and equipment;
- The repair or replacement of major components that cannot be undertaken using the wind farm's normal staff and equipment;
- The use of any additional vessels required to repair faults;
- The implementation of improvements to equipment.

Decommissioning

No commercial scale offshore wind farm has yet been decommissioned, however some single turbines and small projects have been decommissioned. There is a lot of uncertainty about the process. Generally it is assumed that turbines and transition pieces will be removed with foundations cut off at a depth below seabed which is unlikely to lead to uncovering. Cables are likely to be pulled up, due to the recycling value. Environmental monitoring will be conducted after the decommissioning process. It may be that some wind farms will be repowered using new foundations, array cables and turbines, re-using most transmission and grid infrastructure.

5.3.2 Economics

The cost breakdown of a typical offshore wind farm can be classified into five main areas:

1. Development and project management up to the end of commissioning (2%)
2. Wind turbine supply (26%)
3. Balance of plant (19%)
4. Installation and commissioning (14%)
5. Operation, maintenance and service (39%)

These costs represent a breakdown of undiscounted capital and operational costs of a typical 500MW wind farm using 6MW turbines on jacket foundations, with a 20 year operating life.[18]

5.3.3 Supply Chain

The offshore wind supply chain is increasingly formed from companies also active in other sectors. The participation of North Sea oil and gas companies is lower than many anticipated although many offshore wind personnel will have had experience in oil and gas. The offshore wind farms have multiple units spread over a wide area (each turbine is 1 km to 2 km apart) and this better suits other onshore and offshore construction sectors, such as dredging, aggregates and harbour construction. The characteristics of companies in each element of the supply chain are shown in Table 5.3.

Table 5.3 Leading companies in the offshore wind market and their characteristics

Element of Supply	Leading Companies	Characteristics
Developers	DONG, EnBW, E.ON, Iberdrola, Innogy, Vattenfall, WPD	Large multinational utilities with a strategic focus on renewables
EPC contractors	Boskalis, DEME, Van Oord, VolkerWessels	Dominated by Dutch and Belgian dredging companies; companies typically have their own vessels; oil and gas contractors not successful
Turbine nacelles	Adwen, GE, MHI-Vestas, Senvion, Siemens Gamesa	Offshore wind joint ventures (Adwen, MHI-Vestas) and engineering conglomerates. Specialist wind companies such as Senvion struggling to compete
Turbine blades	Adwen, LM Wind Power, MHI-Vestas, Senvion, Siemens Gamesa	Mostly produced in house by turbine suppliers; potential role for an independent
Turbine towers	Ambau, Titan, Valmont	Suppliers to offshore and onshore construction industry
Foundations	Ambau, Bladt, EEW, Navantia, Sif, Smulders, Steelwind Nordenham, ST[3]	Suppliers to offshore and onshore construction industry. Market mostly monopiles and split between steel rollers (EEW, Sif) and fabricators (Bladt, Smulders)

[18]The costs are a combination of real project and modelled data. The operations, maintenance and service includes the maintenance of transmission assets. The cost of building the transmission assets is included in balance of plant.

Substation electrical	ABB, Alstom, CG Power, Siemens	Large multinational high voltage electrical suppliers. May include the offshore substation structure supply and installation within their scope
Offshore substation platforms	Bladt, Fabricom, Harland & Wolff, STX	Large fabricators usually involved in oil and gas and shipbuilding industries
Cables	ABB, JDR, Nexans, Prysmian, NKT	At medium voltage (array cable) companies supplying wind and oil and gas. At high voltage (export cable) companies also supplying subsea interconnector market
Turbine installation	A2SEA, MPI Offshore, DEME, Fred Olsen, Swire Blue Ocean, Van Oord	Mostly specialist wind companies with some having the capability to work in oil and gas. Includes EPC contractors which are active in inshore construction and dredging
Foundation installation	A2SEA, MPI Offshore, DEME, Fred Olsen, Swire Blue Ocean, Van Oord, Seaway Heavy Lifting	As for turbine installation but market leaders are different with the fleets of some operators better suited to foundation installation (typically larger cranes are needed for foundation installation)
Cable installation	Jan de Nul, Siem, VolkerWessels-Boskalis, Van Oord	Usually contractors are different from turbine and foundation installers. Cable vessels also used in oil and gas umbilical laying and in interconnector installation
O&M vessels	Njord Offshore, Seacat, Windcat Workboats	Large number (>30) of specialist operators of crew transfer vessels (up to 26m). Many turbine installation contractors also operate such vessels. Increasing use of service operations vessels (about 90m) permanently stationed offshore, often taken on long-term charter from offshore fleet owners that supply other offshore sectors

5.4 Working Environment

The European Wind Energy Association (EWEA) published a skills gap analysis for the onshore and offshore industries in 2013.[19] It identified skills shortages are likely to be greatest in operations and maintenance roles, though due to the long gestation time for projects, such needs will be known at a project level 2 years before the jobs are needed. In 2010, The Crown Estate

[19] EWEA (2013), Workers wanted: The EU wind energy sector skills gap available online at http://www.ewea.org/fileadmin/files/library/publications/reports/Workers_Wanted_TPwind.pdf, last accessed August 2017.

commissioned a careers guide in the offshore wind industry (the guide covers the UK industry, but is relevant to any offshore wind industry).[20] Wage costs generally vary given the vast range of roles in the industry and between basins. The operations, maintenance and service of a 500MW wind farm supports about 400 to 500 FTE jobs.[21]

5.5 Innovation

5.5.1 Atlantic, Baltic and Mediterranean Basins

Innovations are relevant to both Atlantic and Baltic basins where offshore wind is commercially deployed and most mature. Such innovations will be used in the Mediterranean in due course but because there are limited shallow water sites, innovation in floating foundations is likely to have the biggest impact. Offshore wind is still considered as a high technical innovation sector and funding into technological advancement is still significant. The strong focus is to reduce cost of energy for the sector to become more cost-comparative with other renewable and fossil fuel energy generation. Key technology and trends includes:

- Innovations in larger rated turbines. Turbines installed to date have typically had rated capacity of 6MW or below. There are now 8MW turbines installed in a commercial wind farm. Technical innovations are being made for the different components of a turbine. For example, SSP and LM Wind Power, have both received government funding to develop blades in excess of 88m long for offshore wind turbines.
- Innovations in foundation design. Steel tubular monopiles have been the standard foundation choice for projects using 4MW turbines in water depths of up to 25m but industry expected that they would become less cost effective than other foundation types (such as jackets) with larger turbines and deeper water depths. This was a problem because

[20]BVG Associates (2010), Your career in offshore wind energy, on behalf of The Crown Estate (with RenewableUK) 32 pp. available online at https://bvgassociates.com/publications/, last accessed August 2017.

[21]Value breakdown for the offshore wind sector, A report commissioned by the Renewables Advisory Board, [RAB (2010) 0365] (2010), BVG Associates for Renewables Advisory Board, available online at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48171/2806-value-breakdown-offshore-wind-sector.pdf, last accessed August 2017.

there was a proven supply chain for monopile production and installation and developers were relatively unfamiliar with the new foundation designs. In recent years, however, strong industry collaboration between developers, designers, suppliers and installers has meant monopiles have remained the most cost effective option in much more challenging conditions than previously expected. So-called "XL" monopiles have now been used with 6MW turbines in water depths of up to 35m deep water and for Burbo Bank Extension, with 8MW turbines in 10m water depth. Monopile foundations are planned to be used further with 8MW turbines in deeper water. These monopiles may be up to 10m in diameter, 120m long with a plate thickness of up to 112mm and a mass of more than 1,500 tonnes. This innovation has been based on detailed performance data gathered from existing projects that has allowed designers to stretch the design envelope of the structures.

- Alternative foundation. Where the combination of turbine size, water depth and soil conditions mean monopiles are not the most cost effective solution, jackets are currently the preferred alternative foundation in waters up to about 50m depth, though concrete solutions have been used in some cases. A BVG Associates study looking at how technology innovation is anticipated to reduce the cost of energy from offshore wind farms stated that most innovations in balance of plant are centred on improvements in the manufacture and design of jacket foundations.[22] To date, jacket production has been influenced by one-off or low volume production practices from the oil and gas sector. As the growth of the offshore wind market continues, new fabrication facilities are being developed for example by ST^3 that are more optimised for serial fabrication. The report also identifies that an introduction of commercial scale suction-bucket foundation technology could reduce LCOE. To date, it has typically been demonstrated on small, close to shore turbines, but could be used on up to 25% of projects with FIDs in 2025.
- Floating foundations are also being proposed for deep water offshore wind farms, which generally are likely to be close to shore to take benefit of lower transmission costs. Wind turbines with floating foundations are at the demonstration stage with the Japanese Fukushima floating demonstrator phase two project the first to install a 5MW and 7MW class

[22] KIC InnoEnergy, (2014). Future renewable energy costs: offshore wind – How technology innovation is anticipated to reduce the cost of energy from European offshore wind farms. A report by BVG Associates. 80 pp., available online at: https://bvgassociates.com/publications/, last accessed August 2017.

turbine on a floating foundation beginning in 2015. In August 2017, the Hywind demonstrator of 5 turbines each rated at 6MW with Spar Buoy foundations was installed by Statoil in the Buchan Deep off Scotland. In the Atlantic basin, Norway, Portugal, Wales, and Scotland have waters suitable for wind farms with floating foundations but the Atlantic basin has plenty of cheaper shallower sites likely to be developed first with fixed foundations. The Mediterranean basin has fewer potential shallow sites so could most benefit from wind farms with floating foundations. Four demonstration sites off the French Atlantic and Mediterranean coast are in development.

- Innovations in high voltage alternating current (HVAC) subsea cables. HVAC technology is being used for wind farms located further from shore due to innovations in the technology. It was anticipated HVDC cables would be used as export cables as the most cost efficient means to transport electricity back to shore; although the cables are more expensive than HVAC per km, they have fewer electrical losses over longer distances. However innovations in HVAC cable have reduced the amount of electrical losses when using this type of cable over longer distances, making it a more cost effective technology compared to HVDC over greater distances than previously anticipated, though HVDC technology is also progressing quickly.

Cross-sectoral innovation may include the combination of offshore wind and aquaculture. There have been several studies into the applicability of this cross-sector growth.[23,24,25]

5.5.2 Caribbean Basin

Unlike the Atlantic, Baltic and Mediterranean basins, the Caribbean basin is subject to hurricanes. This may mean that standard turbine technology may

[23]M. Syvret, (2013), Shellfish Aquaculture in Welsh Offshore Wind Farms The Potential for Co-location (2014), available online at: http://www.thefishsite.com/articles/1918/shellfish-aquaculture-in-welsh-offshore-wind-farms-the-potential-for-colocation/, last accessed August 2017.

[24]L. Mee (2006), Complementary Benefits of Alternative Energy: Suitability of Offshore Wind Farms as Aquaculture Sites Inshore Fisheries and Aquaculture Technology Innovation and Development, SEAFISH – Project Ref: 10517, available online at: http://www.seafish.org/media/Publications/10517_Seafish_aquaculture_windfarms.pdf, last accessed August 2017.

[25]J. Allard (2009), Symbiotic relationship: aquaculture and wind energy? available online at: http://ecologicalaquaculture.org/Allard%282009%29.pdf, last accessed August 2017.

be limited to areas with low hurricane risk in the Caribbean basin. Elsewhere, it will either need to be adapted, perhaps allowing turbines to be lowered, or an alternative technology used such as kites which can be stowed away. Kite technology is being developed but it is at an early stage of readiness with KPS due to operate a 500kW kite in 2018. There have been several reports attempting to quantify the hurricane risk to offshore wind turbines. One simulated around 50% of offshore turbines being damaged by hurricanes during a 20-year operational life.[26] In 2014, the US National Oceanic and Atmospheric Administration (NOAA) has collected hurricane data with the aim of improving offshore wind turbine designs.[27]

5.6 Investment

Investments into offshore wind industry can be generally categorised into three profiles:

1. **Project acquisition and capital ventures:** If a wind farm is owned by several owners in a subsidiary joint venture (JV) company, one usually assumes a lead developer role on the project. The owners making up the JV may have equal or different shares in the project. Acquisition of these shares can take place at any stage of a project lifecycle. Typically, if a project share is acquired at the pre-construction stage, it is by another developer. For example, Dong acquired the remaining 66.6% of 1.2GW Hornsea 1 from its JV partner SMart Wind (a 50/50 joint venture between Mainstream Renewable Power and Siemens Financial Services). Acquisitions into operational wind farms are more likely to be from a wider variety of investors such as pension funds and private investment firms with the original developer, usually a utility, retaining a significant share of the project. For example, in January 2014, La Caisse de Dépôt et Placement du Québec (financial institution managing funds primarily for Québec's public) acquired a 25% share in the operational London Array 1 for £644 million. The project's other partners are E.ON (30%), Dong Energy (25%) and Masdar (20%).

[26] S. Rose, P. Jaramillo, M. J Small, I. Goodman and J. Apt (2012), Quantifying the hurricane risk to offshore wind turbines, available online at: http://www.pnas.org/content/109/9/3247.full.pdf, last accessed August 2017.

[27] US storm chasers on a mission (2014), available online at: http://renews.biz/68177/us-storm-chasers-on-a-mission/ last accessed August 2017.

2. **Company mergers and acquisitions:** Offshore wind is a dynamic market where attrition within the supply chain is expected due to the high-risk work and investment required. As a result, many company mergers and acquisitions are seen. For example, in 2017 Siemens and Gamesa merged to form Siemens Gamesa, and in 2014 Mitsubishi Heavy Industries (MHI) and Vestas merged to form MHI Vestas Offshore Wind (MVOW). Within lower tiers of the supply chain, we are seeing company acquisitions. This is shaping a market with fewer companies within the supply chain, but each with greater capability, and greater commitment to the industry and appetite to take on the associated costs and risks.
3. **Technology funding:** Offshore wind is considered as a high technical innovation sector and funding into technology advancement is still significant. Most research is funded by the wind turbine manufacturers (WTM's) for in-house technology developments but funding can be provided by a range of organisations, such as the European Commission and UK's Department of Energy and Climate Change (DECC) to other supply chain companies. R&D funding programmes have a wide range of fund totals. For example The Department of Business, Innovation and Skills 2012–2013 Regional Growth Fund Round 3, had a total fund of £1050 million. In comparison, DECC's 2011–2014 Offshore Wind Component Technologies Development and Demonstration Scheme 1 had a total fund of £5 million. Public funding can be provided to a single company (for example, DECC provided funding to Blade Dynamics' Composite Hub Technology Demonstration project under the Offshore Wind Component Technologies Development and Demonstration Scheme), or to a collaborative project comprised of several members from industry (for example, the European Commission provided funding to Gamesa Innovation and Technology and nine other project partners to undertake 'FLOATGEN: Demonstration of two floating wind turbine systems for power generation in Mediterranean deep waters' under the European Union Seventh Framework Programme).

Financial consultants play a key role in these three profiles. Merger and acquisition advisory services offered by consultants include project modelling, valuation, transaction services, due diligence and post-acquisition integration services.

5.7 Uncertainties and Concluding Remarks

Offshore wind is a significant industry within the Atlantic and Baltic basins, and there is high confidence these basins will continue to be a focus for future activity. These markets have relatively low electricity prices so output from offshore wind farms are currently explicitly subsidised. This level of price support has substantially reduced in 2016 and 2017 and grid parity with combined-cycle gas turbines for the better wind projects is likely to occur at some point in 2023 to 2025 assuming current views of likely future carbon pricing.

The Mediterranean and Caribbean basins do not currently have any commercial offshore wind installations. The Mediterranean could capitalise on its proximity to the established markets in the Atlantic and Baltic to develop a commercial market, but this is not likely by 2020 due to the limited number of projects currently in development. The Caribbean could capitalise on synergies in the established oil and gas industry. Despite relatively high cost of electricity from comparable new electricity generating plant, limited annual electricity demand may limit the ability to establish a cost competitive market beyond a few projects. Combining with another sector might help enable a bigger market.

Table 5.4 summarises each basin's current offshore wind activity and future opportunities.

Table 5.4 Offshore wind subsector summary

Basin	Summary	Opportunities
Atlantic	Focus of current activity. High confidence that basin will be a focus for future activity. Commitment to the sector by European governments. **Recommended basin for future offshore wind.**	Commercial activity at a scale that innovation in technology and competition in supply chain can reduce lifetime cost of energy. Expansion of installations within basin to English Channel and Bay of Biscay.
Baltic	Focus of current activity. High confidence basin will be a focus for future activity. Commitment to the sector by European governments. **Recommended basin for future offshore wind.**	Commercial activity at a scale that innovation in technology and competition in supply chain can reduce lifetime cost of energy.

(*Continued*)

Table 5.4 Continued

Basin	Summary	Opportunities
Mediterranean	No current activity beyond early stage development of test sites. Potential sites tend to be in deeper water than the Atlantic and Baltic so technology will need to be further developed to suit. **Limited evidence to show a significant market will be established due to current higher price of floating foundations and limited market support available from governments.**	Close to existing Atlantic and Baltic supply chains which could support future activity.
Caribbean	No current activity. Limited evidence to show a significant market will be established in the future. There is a significant risk of damage by hurricanes. Cost of offshore wind energy is tied to the scale of wind farm. Trinidad and Tobago has a population of 1.3 million whose total annual electricity consumption is equivalent to the output of a 400MW offshore wind farm. Only Cuba, Haiti, Dominican Republic, Puerto Rico (US) and Jamaica have larger populations.	Potential synergies with oil and gas supply chain/existing infrastructure in Gulf of Mexico. Quantification of the impact of hurricanes is needed across the basin to see if existing technology can be deployed. Innovations in turbine design are probably needed to reduce exposure to damage to acceptable levels.