THE EUROPEAN WIND ENERGY ASSOCIATION

# Wind in our Sails

## The coming of Europe's offshore wind energy industry

A report by the European Wind Energy Association - 2011

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**Cover photo:** Dong

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# Foreword

The European Union leads the world in offshore wind power with 4,000 MW already installed, and this is only the beginning of a major industrial development. This industry will not only help revitalise European economies, but will place Europe at the heart of global offshore wind developments benefitting European companies which are well established as first movers, and provide thousands of jobs for European citizens. Our market and technology leadership in the offshore wind sector will serve us well.

It is my pleasure to provide this foreword to *Wind in our Sails – The coming of Europe's offshore wind industry*, produced by the European Wind Energy Association, once again showing overwhelming investor interest and the huge contribution this innovative industry can make to Europe. Offshore wind power contributes to the EU goals of competitiveness, energy security and reducing greenhouse gas emissions. As this report highlights, the developing of a new industrial supply chain will bring new jobs and a wealth of commercial opportunities.

The European Environment Agency, in its 2009 report[1] confirms that the wind resource is not a constraint. In fact, the EEA illustrate that offshore wind power's economically competitive potential is around 3,400 TWh in 2030, about 80% of the EU's projected electricity demand.

At a time where Europe is at a major crossroads for its energy future, offshore wind provides a powerful domestic answer to Europe's energy supply and climate dilemma. However, this development will not happen without ambitious national programmes, and support from the European Union, underpinning the market promise.

There is strong evidence that the supply chain for offshore wind is dynamic and responding to challenges through investment in innovation. Nevertheless, developing the necessary technology and industrial capacity and getting projects through planning and consenting takes time. To make the necessary investments, the industry needs certainty and stability. Favourable national framework conditions implementing the Renewable Energy Directive, together with a stable post-2020 legislative framework and more innovative financing will be key to achieving it.

But none of these goals will be reached without solid, reliable electricity networks. They are – and will become even more – the backbone of our energy system. The European Commission, in its energy infrastructure package, stresses the urgent need to invest in energy infrastructure in order to transport large amounts of offshore wind energy to the consumption centres.

By working together we can build a cleaner, greener energy future. This EWEA report shows us that coordinated action is needed across the supply chain, supported by a stable and clear legislative framework and new financial instruments to tap into this unlimited indigenous and clean energy resource.

I know the European Commission can count on the Member States, the European Parliament and all relevant stakeholders at local, regional, national and European level to work together in order to make it happen.

**Günther H. Oettinger,**
European Commissioner for Energy

[1] EEA (European Environment Agency), 2009. 'Europe's onshore and offshore wind energy potential'. Technical report No 6/2009.

# Contents


# EXECUTIVE SUMMARY

The European Wind Energy Association (EWEA) expects around 1 GW of new offshore wind capacity to be installed in European waters during the course of 2011. This will bring total offshore wind capacity to almost 4 GW confirming Europe as the world leader in offshore wind power. Currently, almost 6 GW of offshore wind capacity is under construction in Europe, 17 GW have been consented by EU Member States and there are future plans for a further 114 GW. Therefore, it is expected that during this decade, offshore wind power capacity in Europe will grow tenfold.

EWEA estimates that by 2020, 40 GW of offshore wind power will produce 148 TWh annually, meeting over 4% of the EU's total electricity demand and avoiding 87 million tonnes of $CO_2$ emissions[2].

Between 2020 and 2030 a further 110 GW of offshore wind capacity is expected to be added in European waters. 150 GW of wind power would produce 562 TWh annually, enough to cover 14% of the EU's 2030 electricity demand and avoid 315 million tonnes of $CO_2$ emissions[3].

The projected growth of offshore wind energy resembles the growth witnessed in the onshore wind sector at a similar time in the industry's development. Onshore wind energy deployment picked up speed in the mid-1990s. With a 15 year difference, offshore wind seems, today, to be following a similar growth path.

The foreseen growth of the sector will push offshore wind power to the forefront of the EU's climate and energy strategy.

The development of a new industrial sector in Europe provides significant opportunities, particularly in the current economic climate, for growth and job creation.

Offshore wind power will play a key role in Europe's future renewable energy economy. However, a prerequisite for this is the provision by governments and the European Union of stable legislative frameworks for offshore wind, and access to and availability of, sufficient levels of financing. In order to reap the benefits the offshore wind power sector offers, governments need to play their role.

### Offshore wind, creating high-skilled jobs

The offshore industry is forecast to see a steep rise in employment numbers over the course of the next decade. It is estimated that the wind energy sector will employ 462,000 people in 2020. Of these 169,500, almost 40% will be in offshore. By 2030, jobs in offshore are expected to count for 62% of total employment in the wind energy sector: around 300,000 jobs out of a total of 480,000.

Moreover, following in the wake of substantial success in the onshore wind industry, Europe as a first-mover could exploit future export opportunities to other emerging markets.

The renewable industry generally has a higher proportion of jobs classified as "high-skilled" than the economy at large. Companies are finding these positions difficult to fill, highlighting the importance of a focus on training and education measures to prevent future shortage in this often neglected yet essential element of the supply chain.

### A rapidly maturing and increasingly competitive market

Over the coming two decades, offshore wind will move rapidly from an emerging, immature technology to a key component of the EU's energy mix. Consequently, competition across the supply chain for offshore wind is increasing with an influx of significant new entrants.

[2-3] EWEA Pure Power 2011 report, http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_III.pdf

The contracting format turned away from, but then moved back towards, Engineer-Procure-Construct-Install (EPCI) turnkey contracts – which mean one company is in charge of all the different stages – as developers and suppliers become more knowledgeable concerning the risks involved and can allocate them in a more cost effective way.

The emergence of major contractors from the offshore oil and gas (O&G) and traditional maritime sectors may prove to be a significant shift in the dynamics of the supply chain.

### Increasing reliability driving down costs

An impressive and growing list of manufacturers are developing new wind turbines dedicated to the offshore wind sector. It is estimated that the supply of offshore wind turbines will meet and exceed demand for the next decade, leading to healthy levels of competition within Europe with the potential for export to emerging offshore markets.

Sites for new projects are moving further from shore and into deeper waters. To offset the costs involved in developing such challenging projects, there is a clear trend towards reducing the cost of energy through lessons learnt, improved reliability and structural efficiency. Design trends are driving the supply chain towards specialisation – partially decoupling it from the onshore wind industry and developing specific offshore solutions.

### High elasticity of supply enables domestic manufacturing of substructures

Substructures present an opportunity for domestic manufacturing due to lower technical barriers for entry via, for example, the diversification of shipyards or tower manufacturers. Substructure manufacturing brings a significant amount of supply chain value as substructures represent a large part of the capital expenditure in an offshore wind farm. This shows that it is not necessary for there to be a wind turbine manufacturer in a country for that country to have a significant wind energy industry and job creation.

Substructures have a relatively high elasticity of supply, potentially reducing the risk of bottlenecks. They present an attractive diversification opportunity for substantial existing marine and oil and gas (O&G) manufacturing capacity in Europe.

The move into deeper waters will see "space-frame structures" – that is, wind turbine substructures which use several "piles" to keep the turbine stable – having an increased market share, and new fixed and floating structures in the longer term. Nevertheless improved fabrication and installation procedures could also enhance the depths at which monopiles are used.

### Subsea cables – a critical bottleneck?

There is a limited range of suppliers for high voltage (HV) subsea cables due to high investment costs and long lead times for new capacity. Significant advances are being made in the use of high voltage direct current (HVDC) cables with a wider range of suppliers and there is potential for multi-terminal capability.

Without increased capacity in manufacturing, a shortage of high voltage (HV) subsea cables is likely. Other equipment is generally drawn from much larger transmission and distribution (T&D) industries which are relatively unconstrained, with the exception of HV transformers, where delivery times are set by general world demand.

### Jack-up vessels remain industry workhorse as vessel specialisation increases

The industry is seeing increased specialisation of vessels for offshore wind generally and for the specific tasks performed on an offshore wind site. Nevertheless jack-up designs are expected to continue to dominate vital installation procedures and particularly turbine installation.

Developers are looking at strategic investments to secure vessels. However, in the near term, supply constraints are decreasing, which may stem this trend. The vessel supply chain outlook is strong through to 2015 with several new builds, increased levels of competition and supply likely to meet demand. Through the latter half of the decade increasing pressure may return if further investments are not made.

### Ports – a key stepping stone for the offshore wind industry

There is a general move away from the use of mobilisation ports and instead components are exported directly from the manufacturing facilities to offshore wind farms to save on logistical costs. However potential future production in Eastern Europe to take advantage of lower labour costs may reverse or slow this trend.

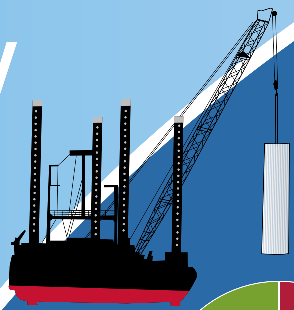
There is a drive in certain regions towards cluster-building for offshore wind manufacturing in closely located ports. These initiatives are being pursued via co-operation between the public and private sectors.

## ► RECOMMENDATIONS

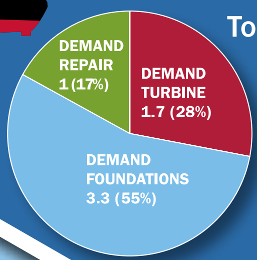
**To fully tap its potential and fully exploit the benefits of this clean and abundant energy source, Europe needs to set ambitious, but achievable, renewable energy targets beyond 2020, invest in wind power research and development and develop the grid infrastructure to bring offshore wind's power from the seas to the main areas of energy consumption on land.**

# The coming of Europe's offshore wind energy industry

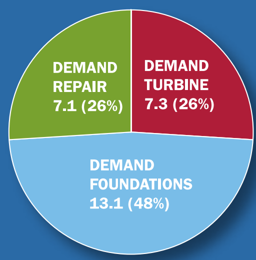
## VESSELS



At least 6 different types of vessels are needed to survey the site, carry components and personnel, install substructure, turbines and substations, lay cables and complete the installation of an offshore wind farm.

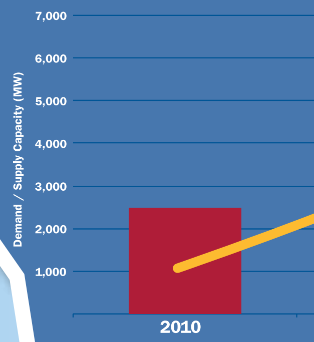


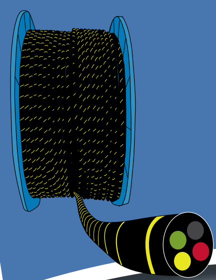

**Total demand 2010: 6 vessels**




**Total demand 2020: 27.5 vessels**

## ELECTRICAL INFR



## PORTS

Two main types of ports:

**MANUFACTURING PORTS:** where the manufacturing facility is closely located to/or at the port and the components are exported directly to the offshore site.

**MOBILIZATION PORTS:** where the components and turbines are received ready and transported to either the installation vessels directly or the feeder vessels which take them on the offshore site.

Offshore wind energy is a significant opportunity for ports to counter-balance the downturn hitting traditional activities.

What makes a suitable construction port

**Water depth:** >10m

**Storage area:** 25ha

**Quayside length: Quay bearing** 15-20t/m²

**Waterway for:** 150-200m diameter rotors

## THE SUPPLY CHA

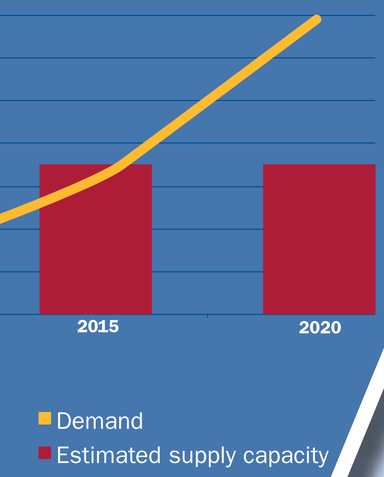
### 2020

- Total installed capacity of 40,000 MW
- Annual installations of 6,900 MW
- Total electricity production of 148 TWh
- Meeting between 4% and 4.2% of total EU electricity demand
- Avoiding 102 Mt of $CO_2$ annually
- Annual investments in offshore wind turbines of €10.4 billion
- Cumulative investments in offshore wind turbines of €65.9 billion in the period 2011-2020

### 2030

- Total installed capacity of 150,000 MW
- Annual installations of 13,700 MW
- Total electricity production of 562 TWh
- Meeting 13.9% of total EU electricity demand
- Avoiding 315 Mt of $CO_2$ in 2030
- Annual investments in offshore wind turbines of €17 billion in 2030
- Cumulative investments of €145.2 billion from 2021 to 2030

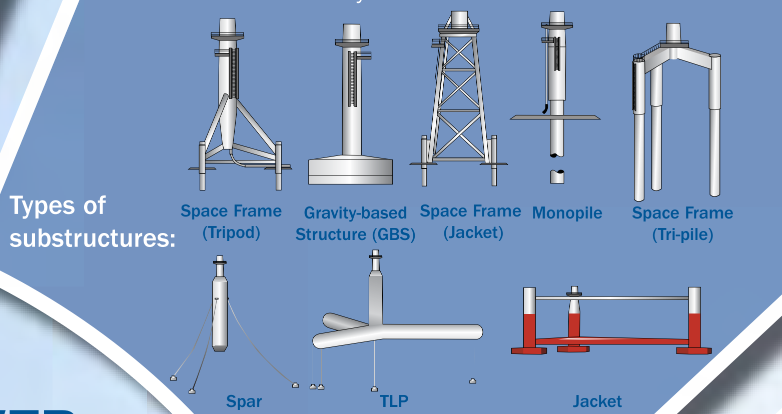
# RASTRUCTURE




## AIN WILL DELIVER

## SUBSTRUCTURES

Substructures present major opportunities for domestic manufacturing thanks to low technical barriers for entry. Substructure manufacturing also brings a significant amount of supply chain value as it represents a large part of the capital expenditure in an offshore wind farm. It is not essential to have turbine manufacturing to develop an offshore wind industry.




## TURBINES

Four to 12 new wind turbines models are expected to reach some level of market readiness in the next decade. Supply of offshore wind turbines will meet and exceed demand for the next decade, leading to healthy levels of competition within Europe with the potential for export.

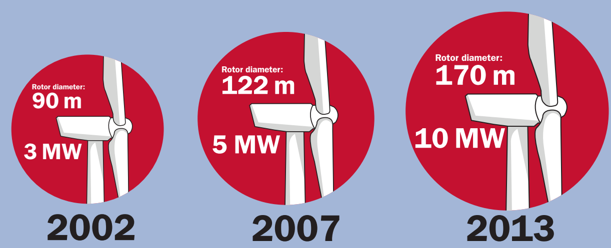



Photo: Dong

# 1 OFFSHORE WIND POWER MARKET

# 1.1 Historical development of offshore wind power in Europe

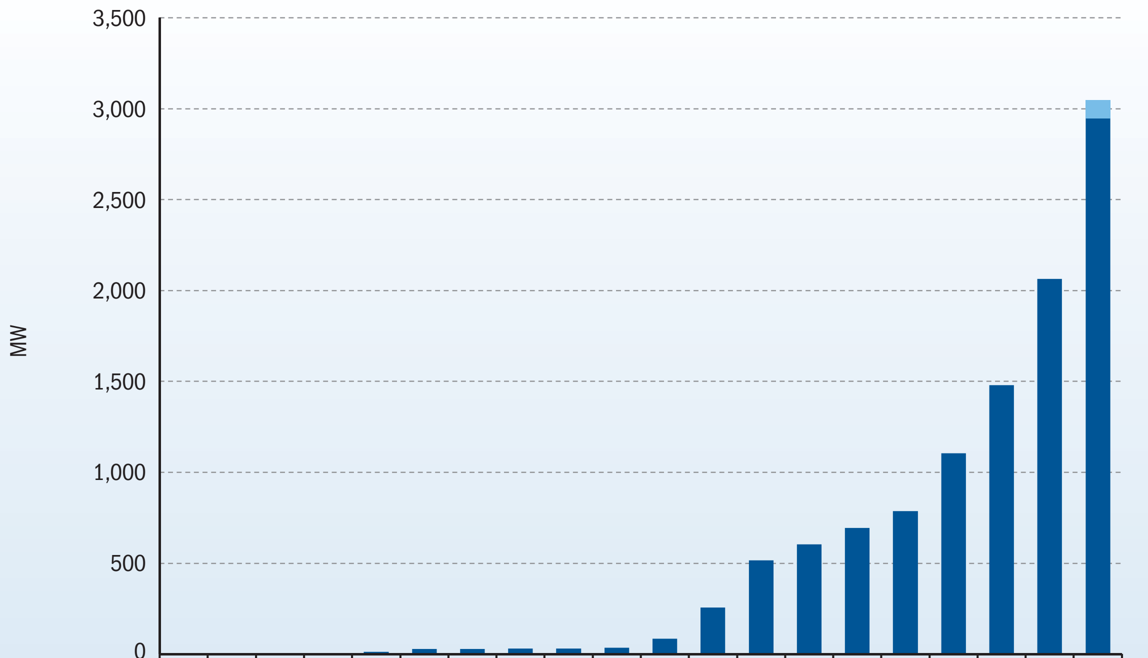
The first offshore wind farm was inaugurated in 1991, 2.5 km off the Danish coast at Vindeby. Developed by DONG Energy, it features eleven 450 kW turbines for a total capacity of 4.95 MW. 20 years later, by the end of 2010, 2,946 MW of offshore wind capacity in 45 wind farms spread across nine countries were feeding an estimated 10.6 TWh of electricity into the European grid.

Until 2001, the growth of the offshore wind power sector was irregular and mainly depended on a handful of small near-shore projects in Danish and Dutch waters featuring wind turbines with a capacity of less than 1 MW.

With 20 turbines and a total capacity of 40 MW, in 2001, the Middelgrunden project in Danish waters became the first "utility-scale" offshore wind farm. That same year, seven 1.5 MW turbines were grid connected off Utgrunden in Sweden.

Since the beginning of the decade, new offshore wind capacity has been going online every year. Moreover, the share of new offshore wind capacity in total wind capacity additions has been increasing. In 2001 the 50.5 MW of installed offshore capacity represented 1% of total new European annual wind capacity, the 883 MW installed in 2010 represented 9.5% of the annual European wind energy market.

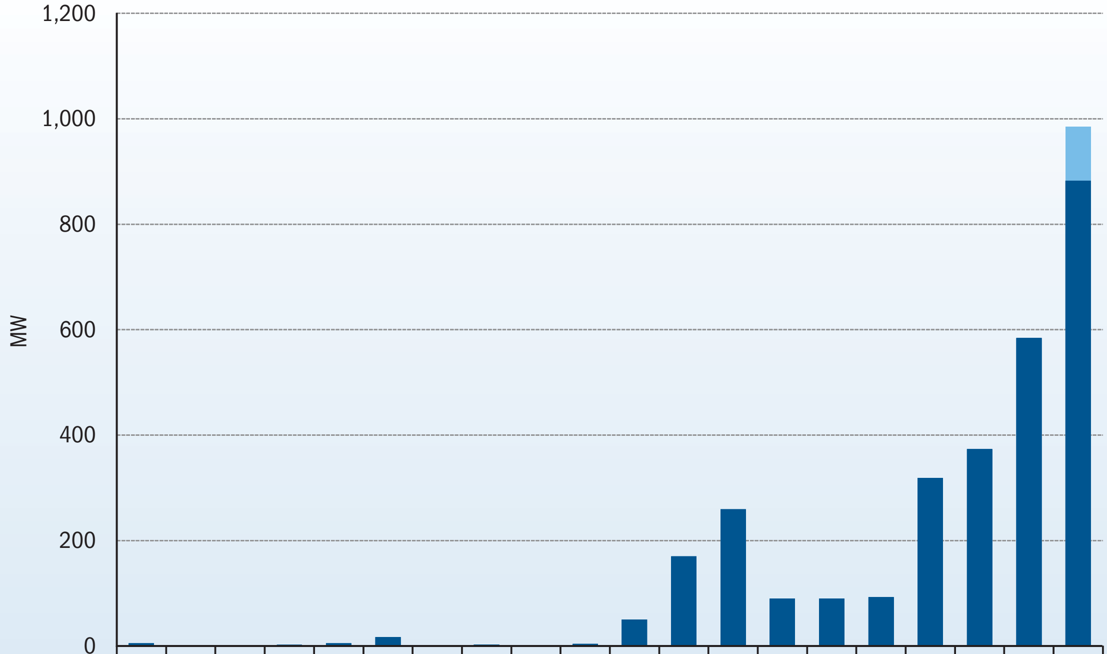
FIGURE 1.1 CUMULATIVE OFFSHORE WIND CAPACITY – EU AND NON EU (1991-2010)




| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative non EU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 102 |
| Cumulative EU | 5 | 5 | 5 | 7 | 12 | 29 | 29 | 32 | 32 | 36 | 86 | 256 | 515 | 605 | 695 | 787 | 1,106 | 1,479 | 2,063 | 2,946 |

Source: EWEA

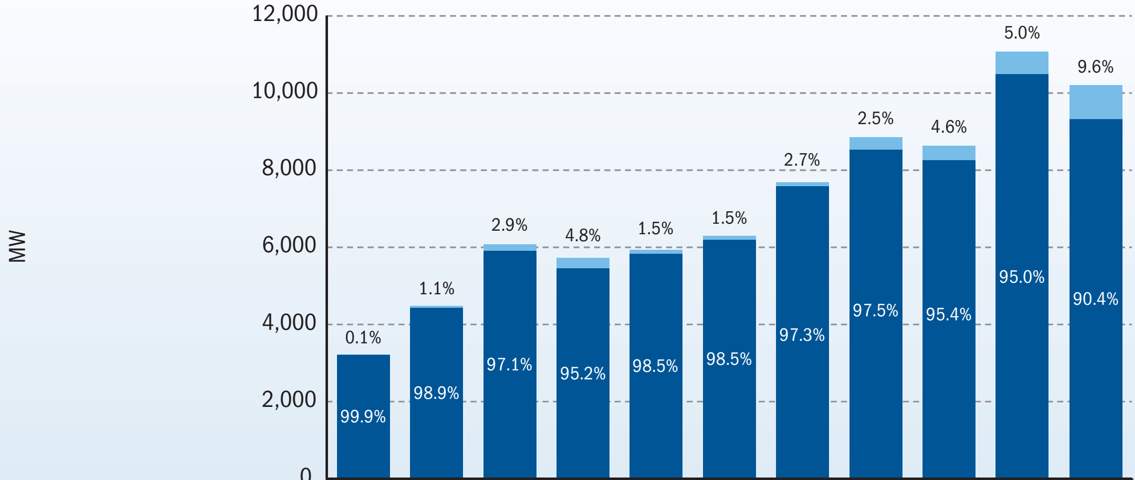
FIGURE 1.2 ANNUAL OFFSHORE WIND CAPACITY – EU AND NON EU (1991-2010)




| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual non-EU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 102 |
| Annual EU | 5 | 0 | 0 | 2 | 5 | 17 | 0 | 3 | 0 | 4 | 51 | 170 | 259 | 90 | 90 | 93 | 318 | 374 | 584 | 883 |

Source: EWEA

FIGURE 1.3 NEW OFFSHORE CAPACITY SHARE OF TOTAL NEW WIND POWER CAPACITY IN THE EU




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Offshore new annual capacity (MW) | 4 | 51 | 170 | 259 | 90 | 90 | 93 | 318 | 373 | 584 | 883 |
| Total new annual capacity (MW) | 3,209 | 4,428 | 5,913 | 5,462 | 5,838 | 6,204 | 7,592 | 8,535 | 8,263 | 10,499 | 9,332 |

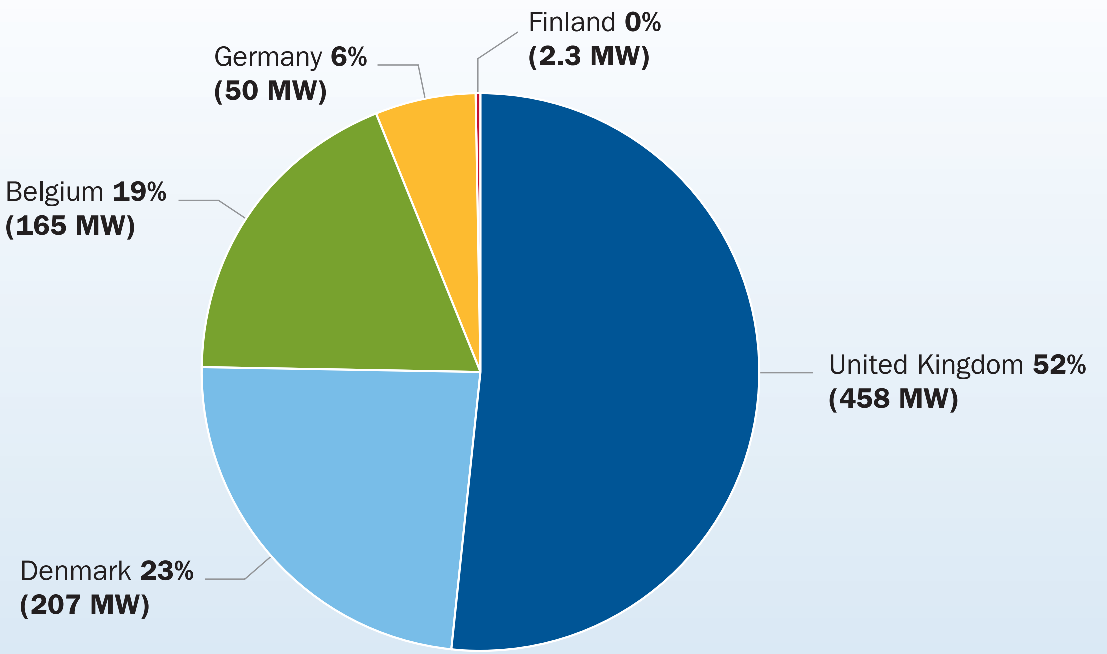
Source: EWEA

# 1.2 Wind power market today

308 new offshore wind turbines, worth some €2.6 billion (20.5% of total EU investments in wind), were fully grid connected in the EU during 2010, totalling 883 MW in nine separate offshore wind farms. This is the biggest annual increase in capacity since the first offshore turbines were installed in 1991 and a 51% increase compared to the annual market in 2009. Total installed capacity at the end of 2010 was 2,944 MW spread over eight EU Member States, with a further 2.3 MW as a floating turbine operating since 2009 off the coast of Norway.

More than half the total annual capacity (458 MW – 52%) was installed in the UK, which remains the country with the largest installed offshore capacity in the world after having overtaken Denmark during the previous year.

FIGURE 1.4 SHARE OF NEW INSTALLED CAPACITY IN EUROPE IN 2010




Source: EWEA

During 2010, the largest offshore wind farm to date (300 MW), Thanet, was fully grid connected in British waters. Furthermore, the first four turbines at BARD offshore 1 wind farm were grid connected at a distance of 100 km from the German coast.

In addition to these record-breaking projects, large projects in Denmark (Rødsand 2) and Belgium (Belwind) were completed. Moreover, a 0.03 MW experimental floating concept combining wave and wind technologies (Poseidon) was connected in Danish waters.

A 102 MW offshore wind farm was also grid-connected in Chinese waters.

## 2011: annual market passes 1 GW

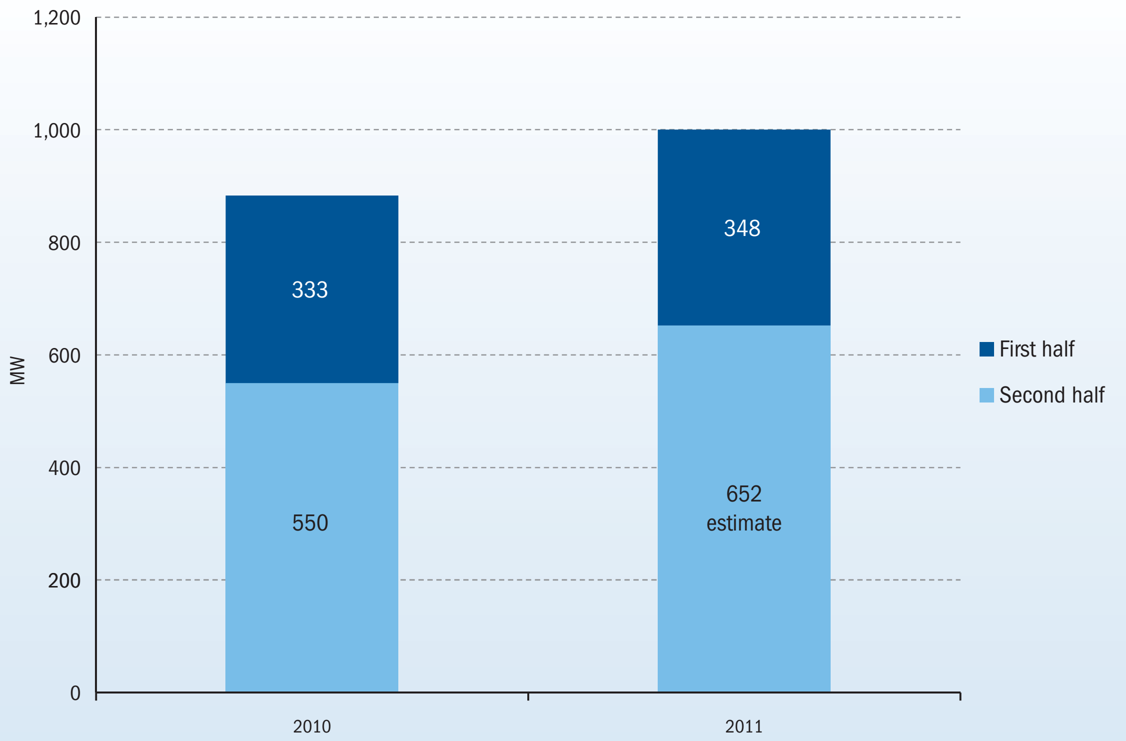
2010 saw strong market development with a much larger number of projects beginning construction than in 2009, under construction, expected to be completed, or completed during the course of the year.

During the first half of 2011 (from 1 January to 30 June), 101 offshore wind turbines were fully grid connected in five wind farms in European waters totalling 348 MW. Total installed capacity at the end of June 2011 reached 3,294 MW.

Overall, 16 offshore wind farms are under construction in 2011. During the first half of the year, 129 offshore foundations were installed and a further 108 turbines were erected but not yet grid connected. Once completed, the 16 wind farms under construction will have a total capacity of 5,603 MW.

During the first six months of 2011, the total offshore capacity connected to the grid was 4.5% higher than during the same period the previous year, when 333 MW were connected to the grid. Moreover this growth was achieved with fewer turbines (17 fewer) than during the same period in the previous year, indicating a move towards larger machines for offshore projects.

FIGURE 1.5 EU OFFSHORE WIND POWER CAPACITY CONNECTED TO THE GRID ANNUAL AND CUMULATIVE 2010-2011




Source: EWEA

Depending on the amount of wind power installed onshore, it looks as if Europe's 2011 offshore market could make up approximately 10% of Europe's total annual wind capacity market and more than 20% of total European wind farm capital investments, making the offshore industry a significant mainstream energy player in its own right.

EWEA expects a total installed offshore capacity of just under 4,000 MW in Europe by the end of 2011.

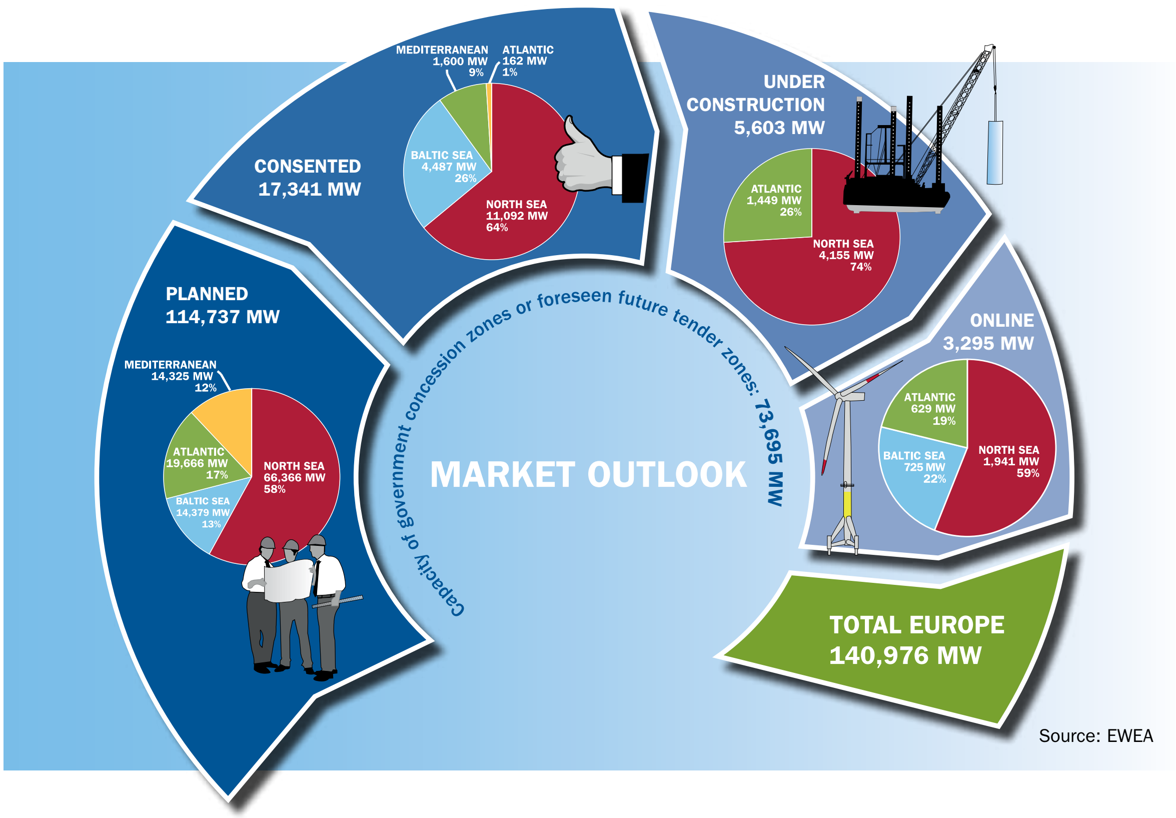
**Summary of the offshore wind energy market in the EU in 2011**

- Total installed capacity of 4,000 MW
- Meeting 0.4% of total EU electricity demand
- Annual installations of 1,000 MW
- Avoiding 9.9 Mt of $CO_2$ annually
- Total electricity production of 14.4 TWh
- Annual investments in wind turbines of €2.8 billion.

## 141 GW and counting…

EWEA has identified 141 GW of offshore wind projects in European waters – either operational, under construction, consented, in the consenting phase or proposed by project developers or government proposed development zones. This 141 GW shows tremendous developer interest. With 26 GW already operational, under construction or consented, solid progress has been made towards 40 GW of offshore wind by 2020. Moreover, it provides a good indication that EWEA's expectation that 150 GW of offshore wind power will be operating by 2030 is both accurate and credible.

FIGURE 1.6 TOTAL OFFSHORE WIND CAPACITY INSTALLED, UNDER CONSTRUCTION, CONSENTED, PLANNED AT 30 JUNE 2011 AND PER SEA BASIN IN MW




Source: EWEA

TABLE 1.1 TOTAL OFFSHORE WIND CAPACITY INSTALLED, UNDER CONSTRUCTION, CONSENTED, PLANNED ON 30 JUNE 2011 AND SIZE OF GOVERNMENT CONCESSION ZONES OR FORESEEN FUTURE TENDER ZONES IN MW

| | Online | Under construction | Consented | Planned | Total projects | Size of government concession zones or foreseen future tender zones |
|---|---|---|---|---|---|---|
| Belgium | 195 | 462 | 750 | 450 | 1,857 | 2,000 |
| Denmark | 854 | 0 | 418 | 1,200 | 2,471 | 4,600 |
| Finland | 26 | 0 | 765 | 3,502 | 4,294 | n/a |
| Estonia | 0 | 0 | 1,000 | 0 | 1,000 | n/a |
| France | 0 | 0 | 0 | 6,000 | 6,000 | 6,000 |
| Germany | 195 | 833 | 8,725 | 21,493 | 31,247 | 8,000 |
| Greece | 0 | 0 | 0 | 4,889 | 4,889 | n/a |
| Ireland | 25 | 0 | 1,600 | 2,155 | 3,780 | n/a |
| Italy | 0 | 0 | 162 | 2,538 | 2,700 | n/a |
| Latvia | 0 | 0 | 200 | 0 | 200 | n/a |
| Malta | 0 | 0 | 0 | 95 | 95 | 95 |
| Netherlands | 247 | 0 | 1,792 | 3,953 | 5,992 | 6,000 |
| Norway | 2 | 0 | 350 | 11,042 | 11,394 | n/a |
| Poland | 0 | 0 | 0 | 900 | 900 | n/a |
| Portugal | 0 | 0 | 0 | 478 | 478 | n/a |
| Spain | 0 | 0 | 0 | 6,804 | 6,804 | n/a |
| Sweden | 164 | 0 | 991 | 7,124 | 8,279 | n/a |
| UK | 1,586 | 4,308 | 588 | 42,114 | 48,596 | 47,000 |
| **Total Europe** | **3,294** | **5,603** | **17,341** | **114,737** | **140,976** | **73,695** |

Table 1.1 confirms that offshore wind energy is currently most developed amongst the North Sea countries. The United Kingdom alone represents, on 30 June 2011, almost 45% of total installed capacity in Europe. By 2020 it is expected that 18 European countries will have developed offshore capacity.

Only four EU Member States with a coastline (Bulgaria, Lithuania, Romania and Slovenia) have no identified offshore pipeline, however, it is expected that offshore wind will be a part of the energy mix in all the Baltic states over the coming years.

# 1.3 Market outlook (2011-2020, 2020-2030)

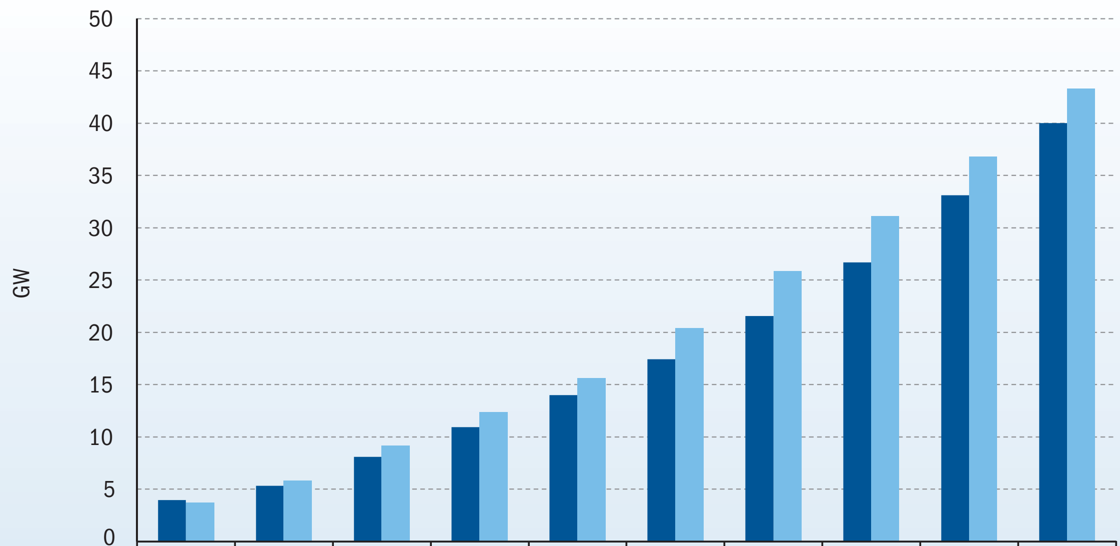
## 2011-2020

In December 2008 the European Union agreed on a binding target of 20% renewable energy by 2020. To meet the 20% target for renewable energy, the European Commission expected 34%[4] of electricity to come from renewable energy sources by 2020 and believed that "wind could contribute 12% of EU electricity by 2020".

Not least due to the 2009 Renewable Energy Directive and the 27 mandatory national renewable energy targets, the Commission's expectations for 2020 were increased. Based on the PRIMES energy model developed by the E3M Lab at the National Technical University of Athens, the Commission published new figures in 2010[5]. These expected wind to cover 14.2% of total electricity consumption in the EU by 2020, with an installed capacity in 2020 of 55.6 GW offshore wind power, meeting between 4 and 4.2% of the EU's electricity demand. EWEA expects the total installed offshore wind capacity in 2020 to be 40 GW, up from just less than 3 GW at the end of 2010.

The 2009 directive also required all Member States to produce National Renewable Energy Action Plans (NREAPs) determining the share of each renewable technology in the energy mix from 2010 to 2020 and, therefore, setting sectoral objectives. The 27 NREAPs' combined objective for offshore wind capacity by 2020 is 43.3 GW[6]. EWEA's predictions are, thus, for the first time below those of the national governments.

FIGURE 1.7 PROJECTED CUMULATIVE OFFSHORE WIND CAPACITY (EWEA AND NATIONAL RENEWABLE ENERGY ACTION PLANS)




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| EWEA | 3.9 | 5.3 | 8.1 | 10.9 | 14.0 | 17.4 | 21.6 | 26.7 | 33.1 | 40.0 |
| NREAPs | 3.7 | 5.8 | 9.1 | 12.4 | 15.6 | 20.4 | 25.8 | 31.1 | 36.8 | 43.3 |

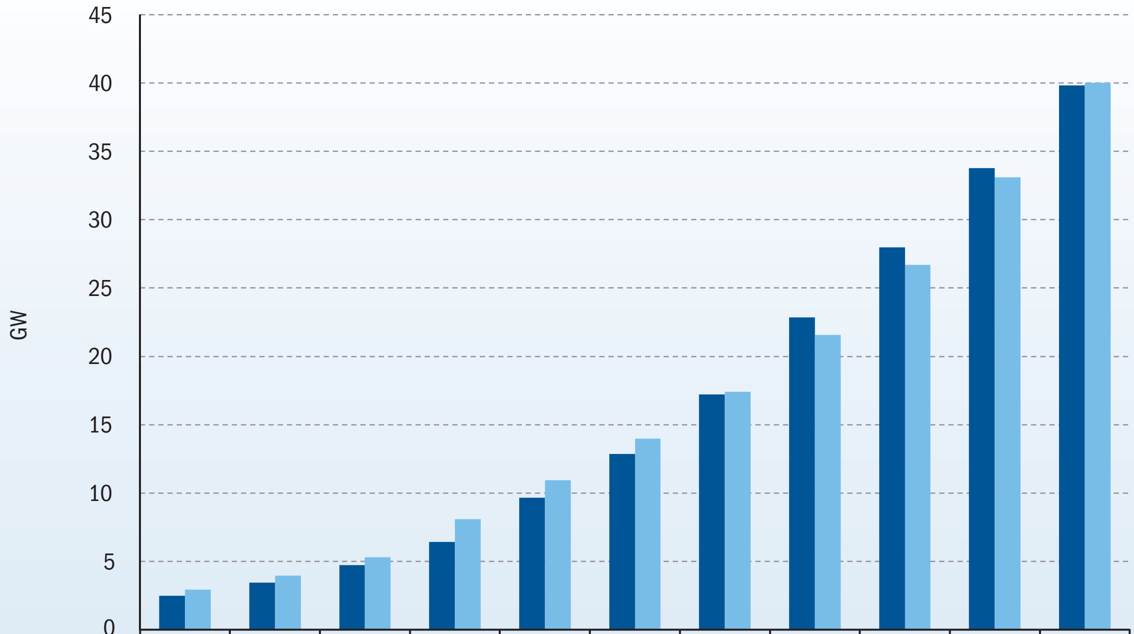
Source: EWEA

[4] European Commission, 2006. 'Renewable Energy Roadmap', COM (2006) 848 final.
[5] "Energy trends to 2030 - 2009 update". European Commission, 2010.
[6] Belgium did not provide separate figures for onshore and offshore wind capacity to the Commission. Information subsequently obtained by EWEA indicates that Belgium's offshore wind energy target for 2020 determined in light of the NREAP exercise is 2,000 MW.

The reasons for the discrepancy between EWEA's predictions and those of the EU Member States include the fact that EWEA has always made conservative forecasts in terms of installed wind energy capacity, but are also strongly linked to the need for additional R&D in offshore wind energy, for steadier financing, and for an updated, European power grid to transport the electricity produced in the seas.

EWEA's projected growth of offshore wind energy resembles the growth witnessed in the onshore sector at a similar time in the industry's development. Figure 1.8 compares EWEA's assumed offshore development to the actual development of onshore wind capacity from 1995 to 2005.

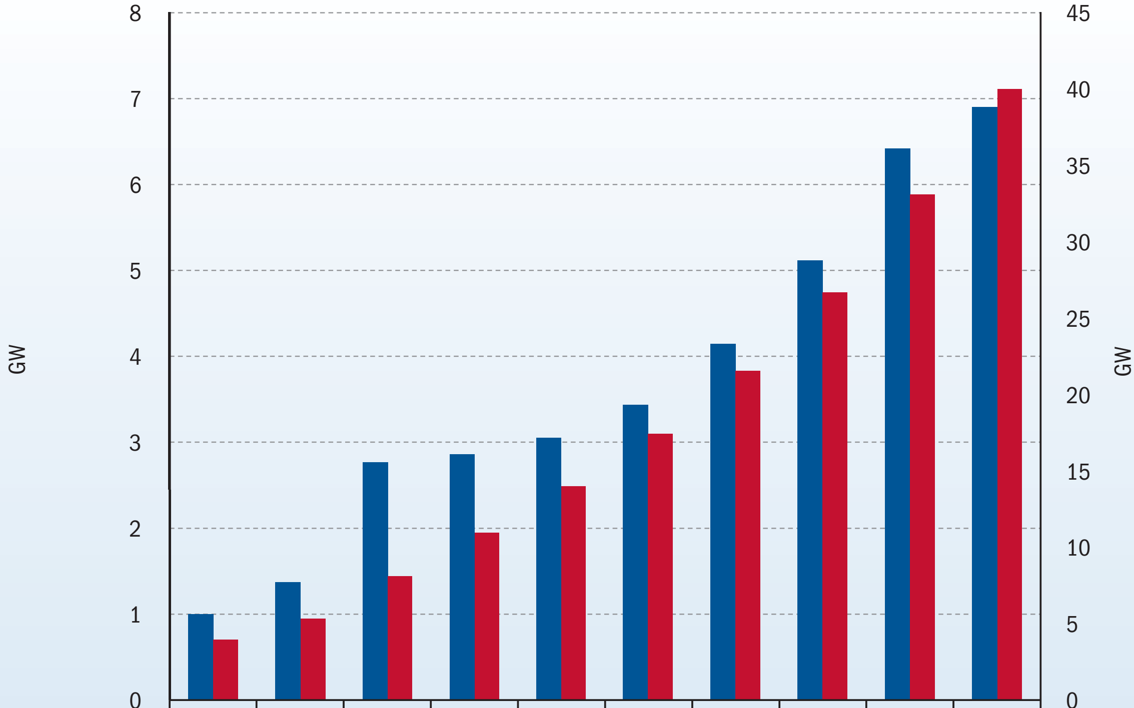
FIGURE 1.8 HISTORICAL ONSHORE GROWTH (1995-2005) COMPARED TO EWEA'S OFFSHORE PROJECTION (2010-2020)




| | 1995 / 2010 | 1996 / 2011 | 1997 / 2012 | 1998 / 2013 | 1999 / 2014 | 2000 / 2015 | 2001 / 2016 | 2002 / 2017 | 2003 / 2018 | 2004 / 2019 | 2005 / 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Onshore | 2.5 | 3.4 | 4.7 | 6.4 | 9.6 | 12.9 | 17.2 | 22.8 | 28.0 | 33.8 | 39.8 |
| Offshore | 2.9 | 3.9 | 5.3 | 8.1 | 10.9 | 14.0 | 17.4 | 21.6 | 26.7 | 33.1 | 40.0 |

Source: EWEA

FIGURE 1.9 OFFSHORE WIND POWER ANNUAL (LEFT) AND CUMULATIVE (RIGHT) INSTALLATIONS 2010-2020



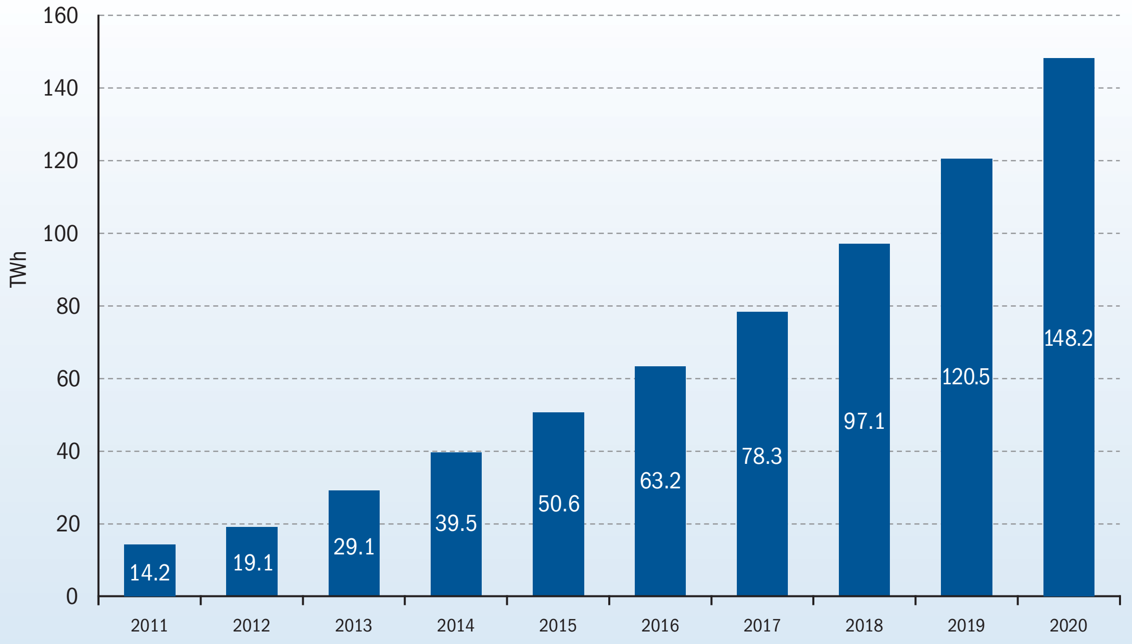

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual | 1.0 | 1.4 | 2.8 | 2.9 | 3.1 | 3.4 | 4.1 | 5.1 | 6.4 | 6.9 |
| Cumulative | 3.9 | 5.3 | 8.1 | 10.9 | 14.0 | 17.4 | 21.6 | 26.7 | 33.1 | 40.0 |

Source: EWEA

## Annual installations

Between 2011 and 2020, EWEA expects the annual offshore market for wind turbines to grow steadily from 1 GW in 2011 to 6.9 GW in 2020. Throughout this period, the market for onshore wind turbines will exceed the offshore market in the EU. In 2010, offshore made up 9.5% of the annual wind energy market. By 2020, offshore will make up 28% of the annual wind energy market.

FIGURE 1.10 OFFSHORE WIND ELECTRICITY PRODUCTION 2010-2020



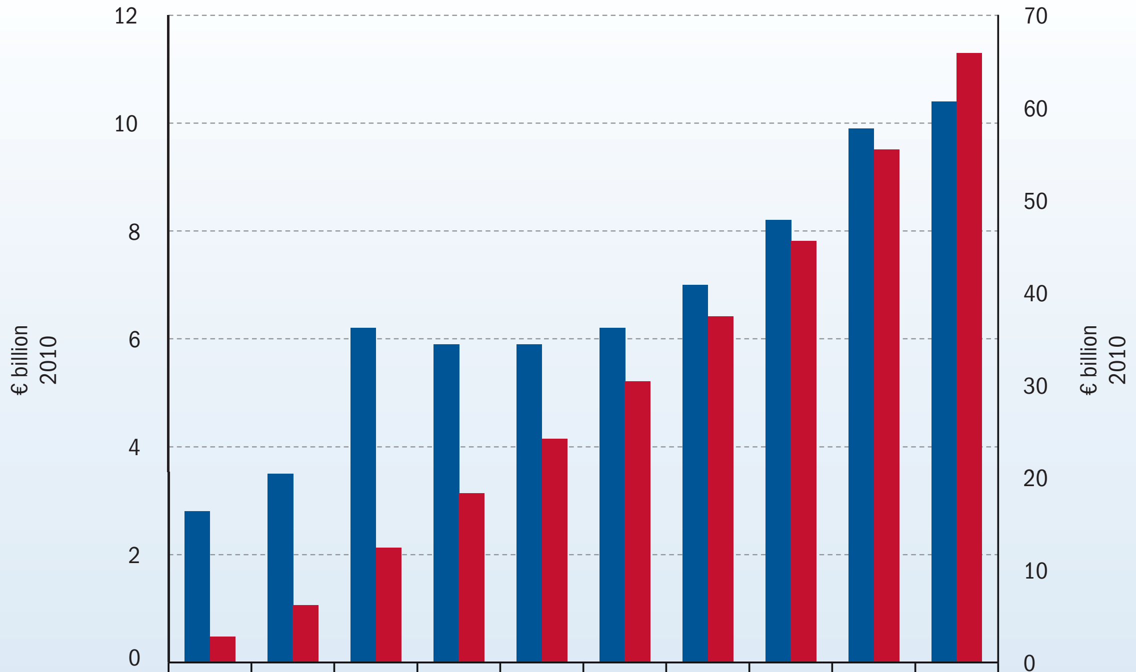

Source: EWEA

## Wind energy production

The 40 GW of installed capacity in 2020 would produce 148 TWh of electricity, equal to between 4% and 4.2% of EU electricity consumption, depending on the development in electricity demand[7]. Approximately a quarter of Europe's wind energy would be produced offshore in 2020, according to EWEA's scenarios. Including onshore, wind energy would produce 581 TWh, enough to meet between 15.7% and 16.5% of total EU electricity demand by 2020.

[7] EWEA forecasts a total installed wind capacity of 230 GW in 2020 producing 581 TWh of electricity, with the 40 GW offshore contributing 148 TWh.

FIGURE 1.11 ANNUAL AND CUMULATIVE INVESTMENTS IN OFFSHORE WIND POWER 2010-2020



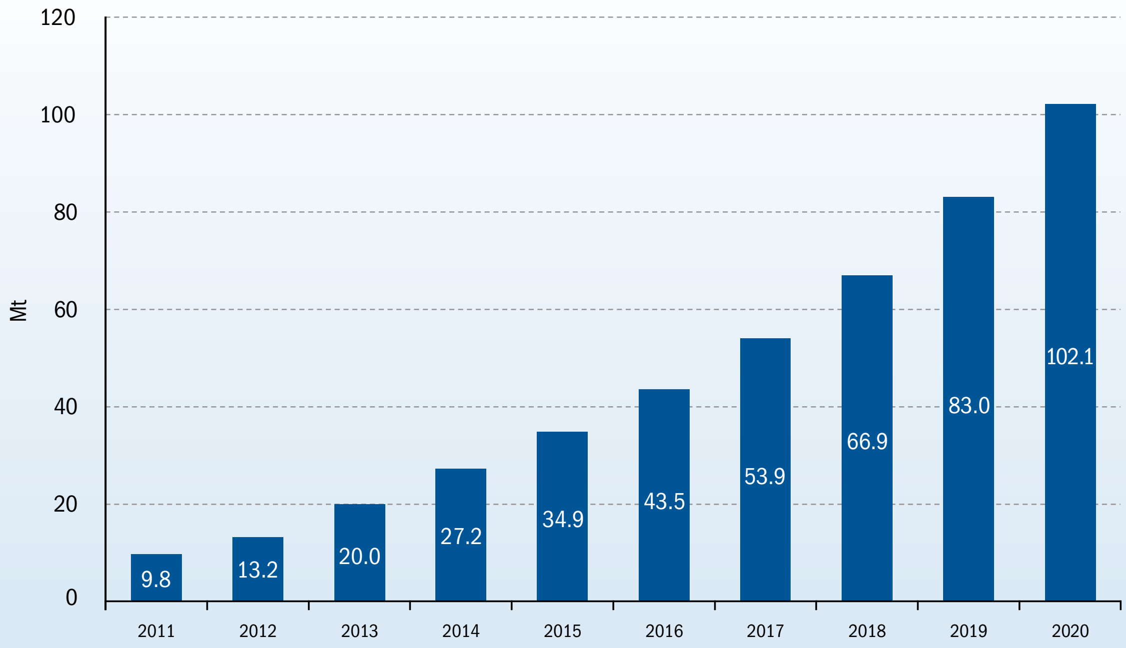

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual | 2.8 | 3.5 | 6.2 | 5.9 | 5.9 | 6.2 | 7 | 8.2 | 9.9 | 10.4 |
| Cumulative | 2.8 | 6.2 | 12.4 | 18.3 | 24.2 | 30.4 | 37.4 | 45.6 | 55.5 | 65.9 |

Source: EWEA

## Offshore wind power investments

Annual investments in offshore wind power are expected to increase from €2.8 billion in 2011 to €10.4 billion in 2020.

FIGURE 1.12 $CO_2$ EMISSIONS AVOIDED BY OFFSHORE WIND




Source: EWEA

## Avoiding climate change

In 2011, offshore wind power will avoid the emission of 9.8 million tonnes (Mt) of $CO_2$, a figure that will rise to 102.1 Mt in 2020.

**Summary of the offshore wind energy market in the EU in 2020**

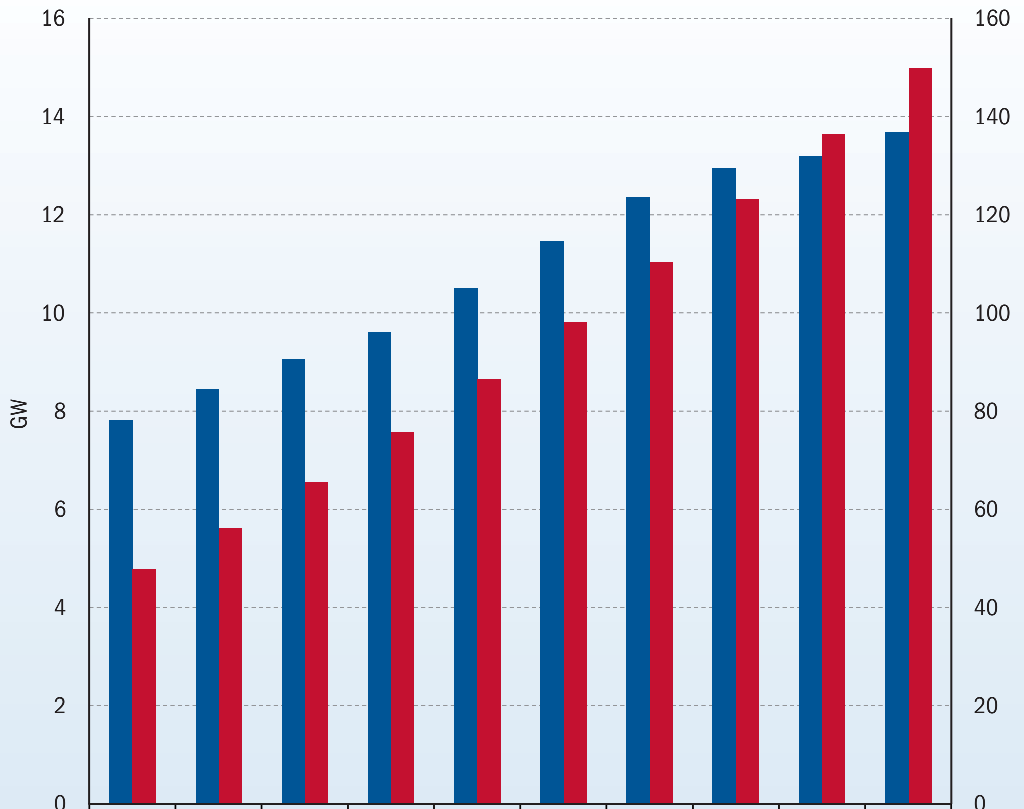
- Total installed capacity of 40,000 MW
- Meeting between 4% and 4.2% of total EU electricity demand
- Annual installations of 6,900 MW
- Avoiding 102 Mt of $CO_2$ annually
- Total electricity production of 148 TWh
- Annual investments in offshore wind turbines of €10.4 billion
- Cumulative investments in offshore wind turbines of €65.9 billion in the period 2011-2020.

## 2021-2030

### Annual installations

Between 2021 and 2030, the annual offshore market for wind turbines is estimated to grow steadily from 7.8 GW in 2021 to reach 13.7 GW in 2030. 2027 would be the first year in which the market for offshore wind turbines (in MW) exceeds the onshore market in the EU.

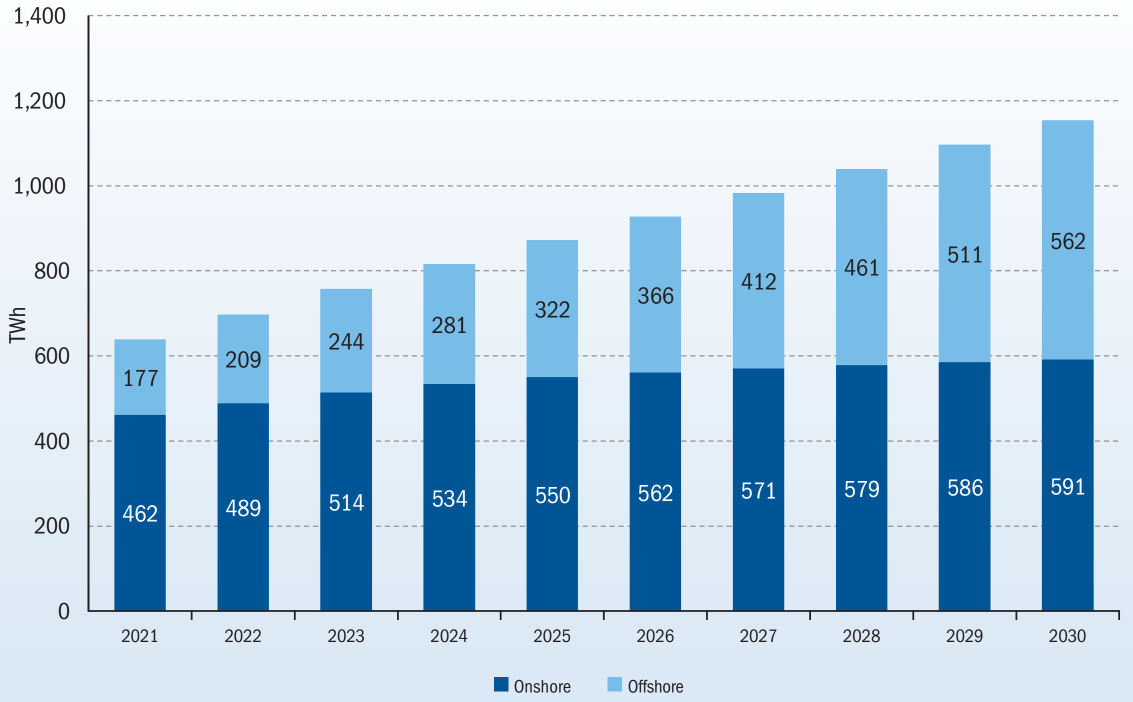
FIGURE 1.13 OFFSHORE WIND POWER ANNUAL (LEFT) AND CUMULATIVE (RIGHT) INSTALLATIONS (2021-2030)




| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual | 7.8 | 8.5 | 9.1 | 9.6 | 10.5 | 11.5 | 12.4 | 13.0 | 13.2 | 13.7 |
| Cumulative | 47.7 | 56.2 | 65.5 | 75.6 | 86.5 | 98.1 | 110.4 | 123.2 | 136.4 | 150.0 |

Source: EWEA

FIGURE 1.14 ONSHORE AND OFFSHORE WIND ELECTRICITY PRODUCTION 2021-2030




Source: EWEA

## Wind energy production

The 150 GW of installed capacity in 2030 would produce 562 TWh of electricity, equal to 13.9% of EU electricity consumption, depending on the development in demand for power. Approximately half of Europe's wind electricity would be produced offshore in 2030[8]. An additional 591 TWh would be produced onshore, bringing wind energy's total share to 28.5% of EU electricity demand.

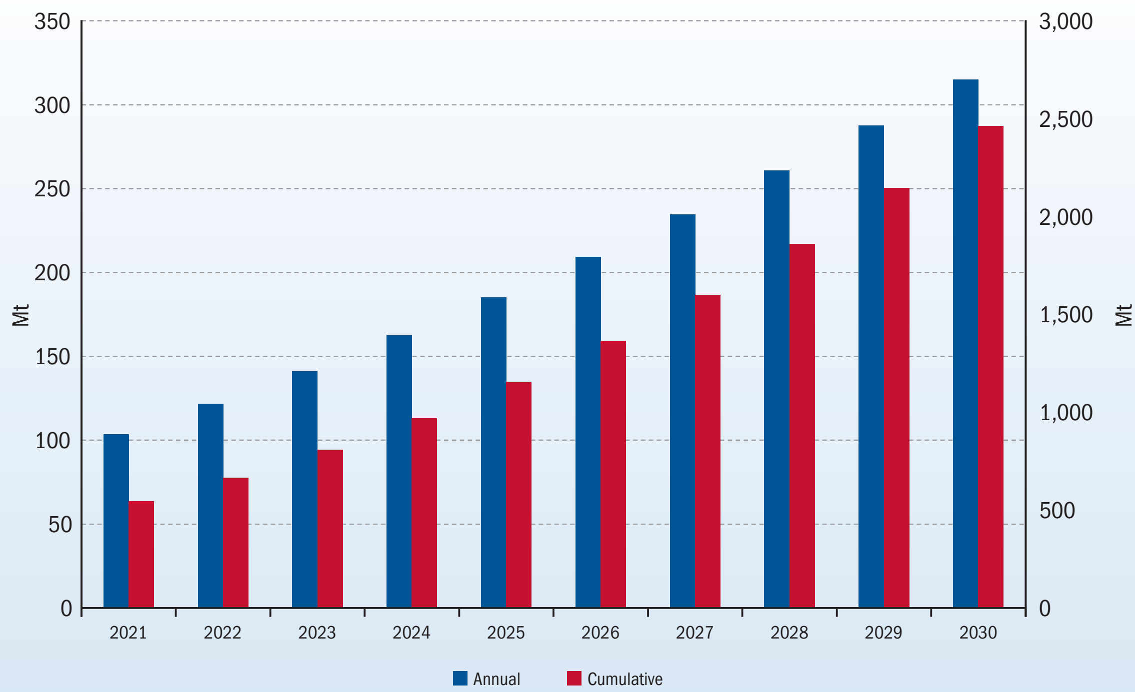
[8] The 400 GW of wind power operating in 2030 would produce 1,154 TWh of electricity, with the 150 GW offshore contributing 562 TWh.

FIGURE 1.15 ANNUAL (LEFT) AND CUMULATIVE (RIGHT) INVESTMENTS IN OFFSHORE WIND POWER


## Offshore wind power investments

Annual investments in offshore wind power are expected to increase from €11.5 billion in 2021 to €17 billion in 2030.

FIGURE 1.16 ANNUAL (LEFT) AND CUMULATIVE (RIGHT) AVOIDED $CO_2$ EMISSIONS 2021-2030




Source: EWEA

## Avoiding climate change

In 2021, offshore wind power will avoid the emission of 104 Mt $CO_2$, a figure that will rise to 315 Mt $CO_2$ in the year 2030.

**Summary of the offshore wind energy market in the EU in 2030**

- Total installed capacity of 150,000 MW
- Annual installations of 13,700 MW
- Total electricity production of 562 TWh
- Meeting 13.9% of total EU electricity demand
- Avoiding 315 Mt of $CO^2$ in 2030
- Annual investments in offshore wind turbines of €17 billion in 2030
- Cumulative investments of €145.2 billion from 2021 to 2030.

# 1.4 Offshore development trends – bigger, deeper and further

As the technology develops, valuable experience is being gained and the offshore wind industry is moving into deeper waters, further from the shore with bigger farms. Looking at the online wind farms along with the ones under construction and already consented, the following graph represents the current trends in distances to shore and water depths.

The wind farms that are already operating are concentrated in the 20x20 zone (up to 20 km from shore and in water depths of up to 20 metres). The majority of future offshore wind farms will be bigger in terms of capacity (bubble size in Figure 1.17), going into deeper waters and certainly moving further away from the shore.

Figure 1.18 presents offshore wind farms planned for development after 2015.

Figure 1.18 shows that the offshore wind projects planned for post 2015 are expected to be built in deeper waters and further from shore than existing projects and projects planned to go online before 2015. The following analysis identifies the trends, based on the information in Figures 1.17 and 1.18.

### <20 km - <20 m

The majority of the wind farms that have come on line to date have been built 20 km or less from the shore and in up to 20 m of water depth. A large amount of planned projects is also to be developed in this area.

### <60 km - <60 m

A large amount of consented and under construction offshore wind farms are already located in depths up to 60 m and up to 60 km from shore (Figure 1.17). Figure 1.18 indicates that a significant number of the planned wind farms fall into this category as well.

### >60 km - <60 m

Far offshore development, which includes current development zones (those illustrated in figs 1.17 and 1.18 are mainly in Germany but will include in the future the UK's Round 3), is characterised by farms far from shore (more than 60km), which will ideally be connected to offshore supernodes[9], with a water depth generally between 20 m and 60 m. Both Figures 1.17 and 1.18 illustrate this trend.

### <60 km - >60 m

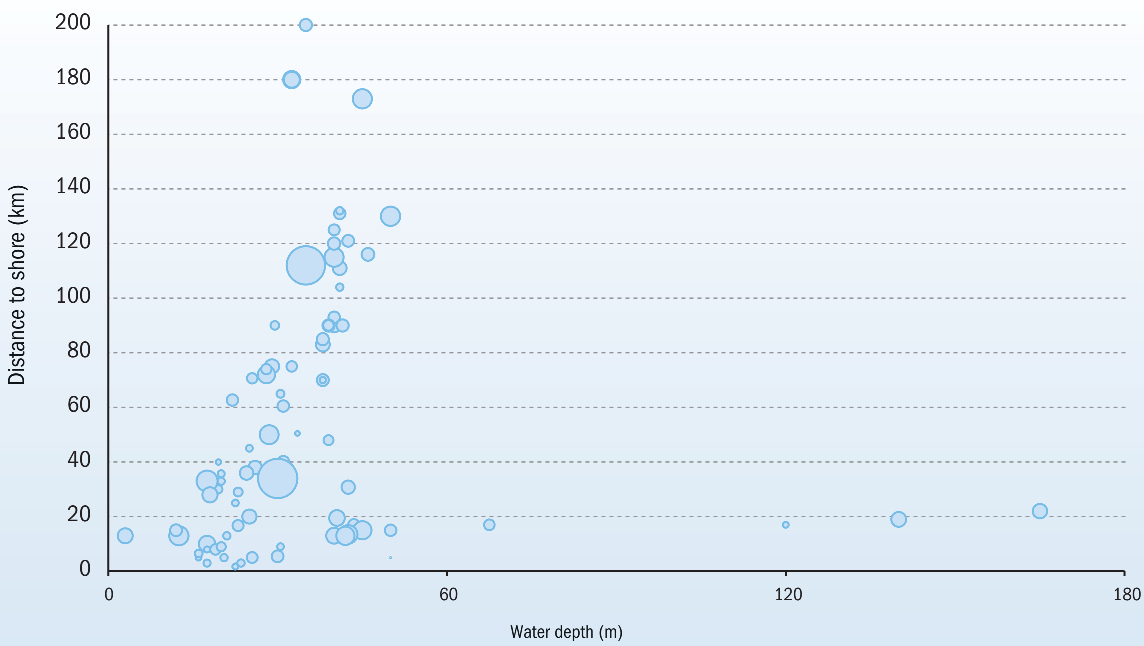
Deep offshore wind farms are planned (Figure 1.18) and consist of new concepts using floating platform technologies during the course of the next decade.

[9] Multi-terminal HVDC station.

FIGURE 1.17 DISTANCE AND DEPTH OF ONLINE, CONSENTED AND UNDER CONSTRUCTION OFFSHORE WIND FARMS


Source: EWEA

FIGURE 1.18 DISTANCE AND DEPTH OF PLANNED OFFSHORE WIND FARMS




Source: EWEA

# 1.5 Europe's first mover advantage

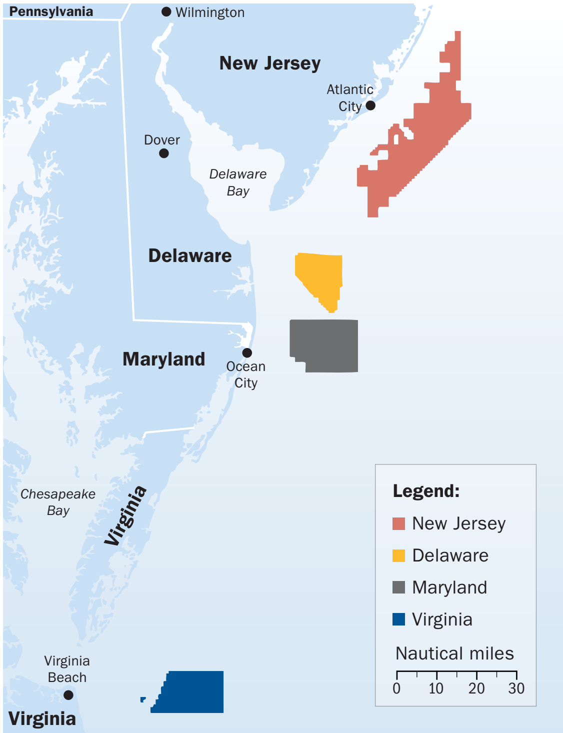
Currently all major operational offshore wind farms are in European waters with the exception of the first Chinese offshore wind farm in Shanghai, with a capacity of 102 MW. The development of offshore wind energy globally creates significant opportunities for European companies, from manufacturers to developers, to expand their activities beyond European waters.

## The United States

In the US, no offshore projects have been built to date. Political support is slowly growing but planning, siting and permitting procedures are still a challenge. Policy developments show a clear trend in boosting offshore wind development[10].

In June 2010, the US Department of the Interior (DOI) signed a Memorandum of Understanding together with the governors of ten coastal states[11] and formed the Atlantic Offshore Wind Consortium. Its principle aim is to facilitate the co-ordination of offshore development off the eastern coast. In addition, in late 2009, the DOI's Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) formed renewable energy task forces in several coastal states. In 2010, the task forces in Maryland, Delaware and Massachusetts published Requests for Information (RFI) to measure the commercial interest in designated areas for offshore development. In April 2010, the Cape Wind project in Massachusetts became the first proposed offshore wind farm to obtain final federal regulatory approval from the BOEMRE and the final lease was issued in October. The "Smart from the Start" initiative was announced in November 2010 from the DOI, aiming at shortening the federal offshore permitting process. Following that, in February 2011, BOEMRE defined four areas for potential wind energy development in the mid-Atlantic for public comments shown in Figure 1.19.

FIGURE 1.19 MID-ATLANTIC WIND ENERGY AREAS UNDER CONSIDERATION BY BOEMRE



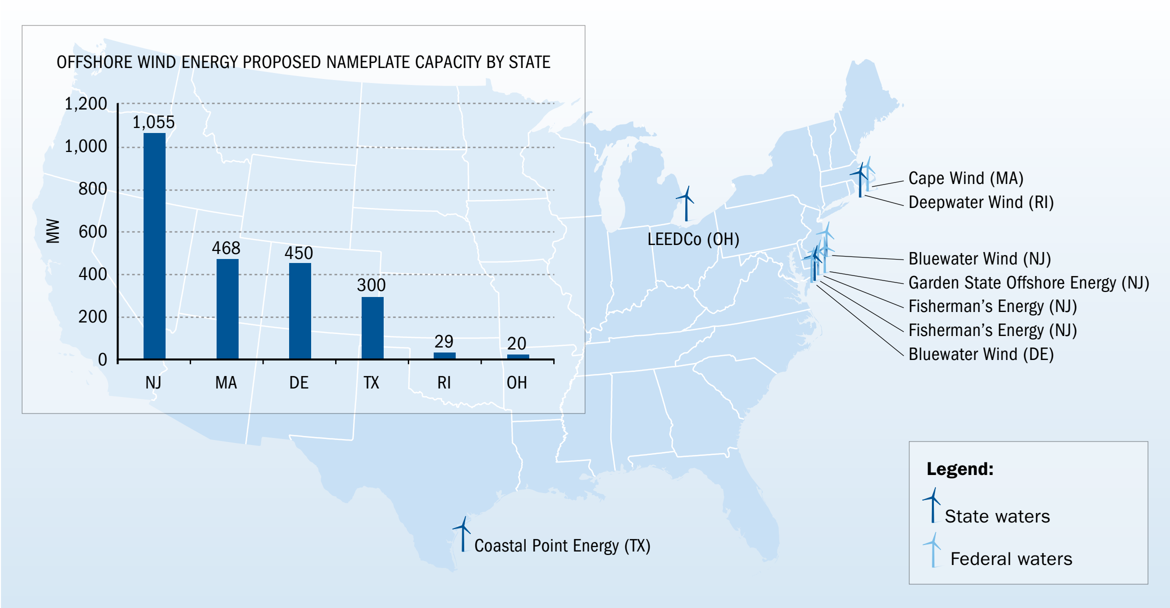

Source: US Department of Energy's "2010 Wind Technologies Market Report"

In February 2011, the Department of Energy (DOE) announced $50.5 million (€35.4 million) to support the joint national strategy to accelerate the development of the US offshore wind power industry, agreed between the Secretary of Interior and the Secretary of Energy. In this context at least nine projects have been proposed, totalling 2,322 MW (Figure 1.20).

Three of the proposed projects (NRG Bluewater Wind in Delaware, Deepwater wind in Rhode Island and Cape Wind in Massachusetts) have already signed power purchase agreements.

[10] Information based on: U.S. Department of Energy's "2010 Wind Technologies Market Report."
[11] Maine, New Hampshire, Massachusetts, Rhode Island, New York, New Jersey, Delaware, Maryland, Virginia and North Carolina.

FIGURE 1.20 PROPOSED OFFSHORE WIND FARM PROJECTS IN AN ADVANCED STATE OF DEVELOPMENT




Source: US Department of Energy's "2010 Wind Technologies Market Report"

In addition to the proposed projects, a major development on the infrastructure side came in October 2010. According to the recent US DOE report for wind technologies, a $5 billion transmission project was announced by Trans-Elect. The Atlantic Wind Connection project received financial support from Google, Good Energies and Marubeni Corporation. This transmission line will be underwater and will be built in five phases. The final capacity is expected to be as much as 7,000 MW. It will connect Virginia to northern New Jersey and possibly New York City. During the first phase a line will connect Northern New Jersey with southern Delaware with a 2,000 MW capacity and it is expected to be built by 2016.

## China

China has put great emphasis on offshore development in the past two years. The wind base programme started in 2008, aiming at developing some 70 GW of wind power by 2020. Onshore wind development is mainly in the north and western areas of the country where the wind resource is biggest.

However, the main centres of electricity consumption are in the eastern and other coastal areas. The need to overcome this grid bottleneck has pushed the development of offshore wind farms off the coasts near the main consumption areas.

The first commercial offshore wind farm in China, the 102 MW Donghai Daqiao offshore wind project, came online in June 2010. Located off Shanghai City, it is composed of 34 3 MW Sinovel turbines. The closest turbine to shore is situated 6 km out to sea and the furthest at 13 km.

China is also developing a number of near-shore projects in its vast intertidal areas. The advantage of exploiting inter-tidal sites is shallow waters with water depths of seldom more than five metres. Three inter-tidal projects have already been built in China: Rudong (30 MW), Jiangsu Xiangshui (6 MW) and Shandong Rongcheng (6 MW).

Moreover, the 30 MW Rudong intertidal project is a demonstration project in which nine different turbine models are being tested, mainly from Chinese manufacturers.

### Policy development

The eleventh Five Year plan for energy and renewable energy, which is currently under development, has a tentative offshore wind development target of 5 GW by 2015 and 30 GW by 2020.

In 2010, the National Energy Administration (NEA) and the State Oceanic Administration (SOA) jointly issued "Offshore project development interim management rules". They stipulate that offshore projects will be authorised on the basis of concession tenders to determine the tariff.

In July 2011, a new policy was issued by the NEA and SOA: "Detailed rules for offshore project development". This stipulates that offshore projects should be at least 10 km from the shore and in water depths of no less than 10 metres. These rules aim to minimise conflicts with other sea uses such as fishing and aquaculture. Consequently, the scope for developing intertidal projects further will be limited.

### The first offshore concession tender in 2010

In May 2010, the first round of tenders took place for four wind farms totalling 100MW, all located in Jiangsu province. Two of the projects are intertidal the other two are further offshore.

The tariffs retained range from 624 RMB/MWh (€73/MWh) to 737 RMB/MWh (€87MWh). Compared to the onshore tariff of RMB 510 (€60) to RMB 640 (€75) per MWh, the offshore bids are quite low.

The tender winners are all domestic utilities, as the rules stipulate that only Chinese companies (at least 51% share owned by Chinese company) can participate in the process. The turbine suppliers are Sinovel (3 MW model), Goldwind (2.5 MW model) and Shanghai Electric (3.6 MW model).

The second round of offshore concession tenders is planned for the second half of 2011, for a capacity totalling 200 MW.

### Offshore wind starting elsewhere in Asia

The Korean government has announced an offshore wind energy strategy to attract investments worth around €6 billion to develop offshore wind farms with a total capacity of 2.5 GW during this decade. The government is aiming to set up a private-public partnership (PPP) to install about 500 turbines off the country's west coast. Under this PPP 100 MW of wind projects should be operational by 2013, a further 900 MW by 2016 and the final 1.5 GW by 2016. Moreover, local governments are promoting another 4.5 GW of offshore wind projects across the country.

In the aftermath of events at Fukushima, Japan is stepping up its efforts to develop renewables. Offshore wind is seen as a key technology despite the challenging sea environment off the Japanese coasts. Japan has already some 25 MW of offshore projects, near shore, with the first turbines operating since 2003. In 2011 a senior government panel developed plans for a 1 GW offshore wind farm to be operational by 2020. An initial five year programme should fund six or more floating turbines off the North Eastern coast as a first step towards the larger project.

# 1.6 Offshore wind energy employment and future skill requirements

### Offshore wind employment

Historically, the principal political drivers for the deployment of renewable energy in many countries were the twin pillars of climate change objectives and energy security – the former being influenced through international agreements notably within the UNFCCC and more stringently through the EU with the 20% renewable energy by 2020 target. However the financial crisis of 2008-2009 and the resultant recession are adding industrial development, export potentials and employment opportunities associated with renewable energy as a primary motivation for promoting renewable energy development.

The potential rewards are vast – EWEA estimates that the wind energy sector in Europe will create around 273,000 direct and indirect new jobs over the next decade, taking the industry to a total of approximately 462,000 direct and indirect jobs by 2020[12]. The corresponding figures for the offshore sector alone are 134,000 and 169,500 respectively, highlighting the fast increasing importance of offshore development within the broader wind industry in Europe. By 2030, around 480,000 people are expected to be employed in the sector, around 300,000 of whom in the offshore sector (almost 62% of the total).

### Requirements for future

Very high growth rates are expected in the offshore wind sector over the next decade, therefore this will create huge demand for appropriately skilled staff. There is general agreement in the industry that it faces a shortage of skilled labour, notably engineers, O&M technicians and project managers, and that this is an area which needs addressing.

Institutes in both Germany and the UK – the two countries expected to lead European offshore wind development during the next decade – have taken measures to address this shortage through training programmes. In Germany the Education Centre for Renewable Energies (BZEE) founded in 2000 by the German Wind Energy Association (BWE), the Chamber of Industry and Commerce in Flensburg and wind energy enterprises in northern Germany, provides a number of specialised training courses. The institute recently developed a qualification programme dedicated to the service and maintenance of offshore wind farms[13]. In the UK a similar collaboration between industry, government bodies and Narec, the UK National Renewable Energy centre for renewable energy development and testing, has resulted in the opening of a new training tower. This is designed to provide academic and industrial training programmes for technicians in the wind industry, with a strong focus on the offshore sector[14].

The University of Aalborg in Denmark has been a forerunner in offering academic programmes focused on wind energy including a dedicated Master's course in wind energy as well as other related on-site training possibilities.

Over the last three years the POWER Cluster project (Pushing Offshore Wind Energy Regions), the direct successor of the North Sea Region (NSR) Interreg IIIB's programme POWER project, has been running. The project comprises eighteen partners from six countries: Germany, the UK, Denmark the Netherlands, Norway and Sweden[15]. As part of its objectives, the project has been tackling the problem of missing specialists

[12] EWEA Pure Power 2011 report, http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_III.pdf
[13] http://www.wwindea.org/technology/ch03/en/3_5_1.html
[14] http://www.narec.co.uk/media/news/n/successful_collaboration_launches_new_wind_training_facility_in_the_north_east
[15] http://www.power-cluster.net/AboutPOWERcluster/tabid/587/Default.aspx

in offshore wind by promoting career opportunities to young people and students and facilitating qualification pathways. A sister project named the "South Baltic OFF.E.R." project (South Baltic Offshore Wind Energy Regions) was initiated in 2010 and is due for completion in February 2013. Part of the project is specifically aimed at enhancing educational possibilities in offshore wind and generating opportunities in the wind industry for highly qualified workers.

Further potential exists for the transfer of skills from the oil & gas sector in areas expected to see declining demand for their services, such as Aberdeen in Scotland. There are significant skill-set cross-over opportunities with the wind industry as noted by reference to the oil and gas sector at numerous points within this report. Specifically, the transfer of Health, Safety and Environment (HSE) skills from this sector are likely to be required.

However in order to prevent skills shortages severely impacting offshore wind farm development, further measures to provide training courses and education for engineers and technical staff need to be addressed by industry, universities and policy-makers across Europe.

Photo: Offshorestatoil

# 2 SUPPLY CHAIN – INTRODUCTION

The supply chain for the offshore wind industry is evolving rapidly. The market promise underpinned by ambitious national programmes, particularly in the UK and Germany, has sparked an enormous volume of industrial interest as well as a significant amount of new investment in plant and facilities. This burst of activity should be set against the backdrop of a recessionary climate in other industries, which has historically been responsible for the diversion of investment and supply chain resources from offshore wind.

Contracting practices have also shifted significantly in the last few years, perhaps in part as a result of the changes in the available companies in the supply chain mix. The emergence of larger, more financially sound contracting partners who are willing to take on a broader scope of supply within an individual project is seen as a positive development from the perspective of investor confidence. Also, perhaps for the first time, these developments offer the real possibility of the widely discussed cross fertilisation of skills and knowledge from the offshore oil and gas sector to come to fruition.

Increased levels of competition within the supply chain are observed as a result of new capacity and companies becoming engaged in the industry. In the short term, this is likely to help stabilise capital pricing of projects with the prospect of significant further savings through scale, learning and innovation effects so long as competition levels remain healthy. Clearly this trend should be set against the increased technical challenges associated with moving further from shore and in to deeper waters. New approaches and technologies will be required in order to meet these challenges, and as explored in this chapter, there is strong evidence that the supply chain is responding through investment in innovation.

We are also witnessing the development of more long-term commercial partnerships between some of the leading project developers and their supply chain. This brings greater certainty and continuity to the industry.

The remainder of this chapter provides an overview of the history and current status of the supply chain for the offshore wind power industries, as well as anticipated future trends for each of the key subsectors: wind turbines, substructures, electrical systems, installation vessels and ports.

## 2.1 Contracting trends

Unlike more mature sectors such as the automotive industry and indeed onshore wind, the offshore wind supply chain is currently flexible in terms of both participants and contracting structures. The following section is intended to provide a snapshot of the contracting landscape in order to characterise the type of companies involved in the supply chain and the relationships between them.

A potted history of contracting structures within the offshore wind sector is given below.

### 2000-2004: "Engineer-Procure-Construct-Install" contracts (EPCI) the norm

The majority of early commercial offshore wind projects were contracted on the basis of a single major construction contract under an EPCI (Engineer-Procure-Construct-Install) arrangement. The wind turbine manufacturers were the turnkey counterparty in these cases, usually via a joint venture with a marine contractor. These offers coincided with high levels of early competition as the supply chain fought for early-mover advantage in this promising new industry.

### 2004-2010: switch to multi-contracting

Whether due to a deliberate policy of 'loss-leading' or inadvertent cost optimism, it is considered unlikely that the principal contractors turned a profit on the preceding early engagements. Evidence for this is demonstrated through the subsequent insolvency or buy-outs of several key second level contractors – notable examples including Dutch Sea Cable, CNS Renewables, Mayflower Energy and more recently

Oceanteam and Subocean. In some cases these failures may have been caused by inappropriate risk allocation through the supply chain. This early negative experience led to the withdrawal of EPCI contract offers by the leading wind turbine suppliers for future projects in 2004, as the full extent of the offshore construction risks were recognised as being outside of core competencies. The consequent switch to multi-contracting caused a loss of early momentum in the industry as project developers were forced to readjust to the challenge of managing and delivering complex construction projects involving many contracts.

### 2010-2012: trend towards larger contracts

Primarily due to increasing levels of competition within the supply chain, we are now beginning to see an increased appetite from suppliers for a broader scope of work. The increased involvement of large civil engineering and oil and gas multinationals is one of the key drivers of this trend, as explored later in the chapter. In addition, the increased reliance on more risk-adverse capital such as pre-construction non-recourse project finance is also driving procurement towards fewer, larger contracts, as developers seek to minimise interface risk.

### >2012: re-emergence of EPCI?

A logical extension of the trend described above would be the re-emergence of full EPCI contracts, perhaps via joint ventures between the plant contractors – which are more numerous – and the wind turbine manufacturers. Interestingly this would mean the contracting environment for offshore wind had come full circle in about a decade. Given the commercial and technical lessons learnt over the last 10 years, it may be argued that the industry is now mature enough for turnkey contracting. However, it should be noted that given the investment that leading developers have made in acquiring the required skills and commercial appetite to meet the multi-contracting challenge, some may take the view that they are better off under this more flexible regime, given the associated expected cost-reduction potential of having a more experienced and comprehensive management.

To summarise, increasing levels of flexibility are available to the industry when considering contractual practise as supply chain participation and competition increase. These trends are summarised in Figure 2.1 opposite, with the slices representing the approximate relative size and number of major construction contracts for a typical offshore wind project in each period.

## Company types

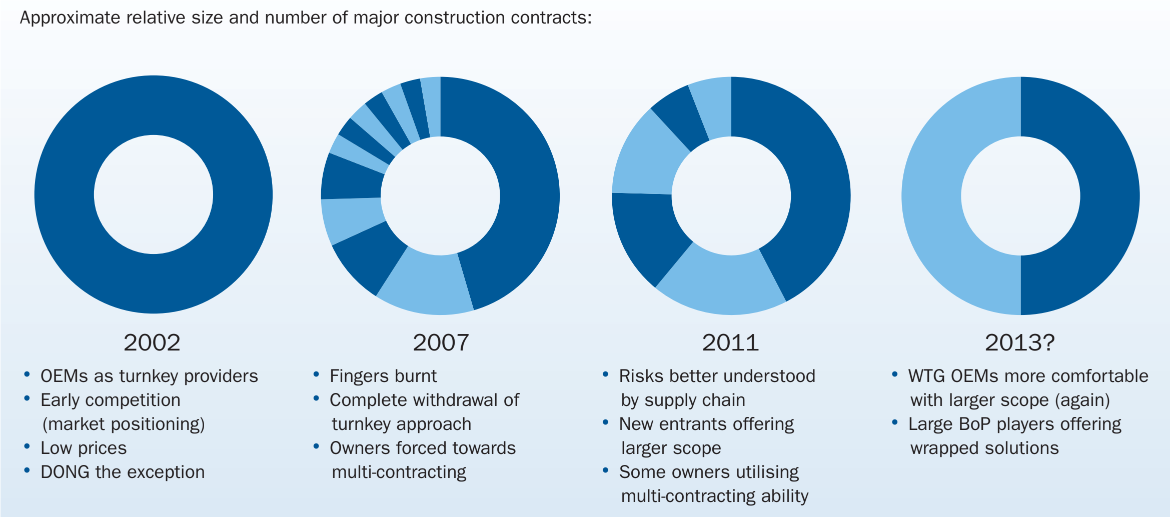
Participants in the upper levels of the offshore wind supply chain can generally be put into eight main categories, as follows:

1. ***Wind turbine manufacturers*** – responsible for supplying wind turbines, with a broader scope of work in some instances.
3. ***Structural manufacturers*** – responsible for manufacturing substructures and foundations for the wind turbines, and possibly also the offshore sub-stations.
4. ***Electrical equipment suppliers*** – responsible for the electrical system design and for supplying all electrical equipment for onshore and offshore substations.
5. ***Marine contractors*** – responsible for various aspects of offshore installation including one or more of the following: wind turbines, wind turbine substructures and offshore substation foundation / topsides.
6. ***Cable suppliers*** – responsible for at least supply of export or array cables with partial market segmentation into these two categories, which are typically demarcated at ~50kV.
7. ***Cable installers*** – niche marine contractors responsible for array and export cable installation.

8. ***EPCI contractors*** – large construction firms or joint ventures between parties from one or more of the above categories taking responsibility for a broader scope of work, in some cases comprising the vast majority of the capital spend.
9. ***Port operators*** – various private port companies and publically owned harbours providing facilities for manufacturing and/or assembly, acting as a mobilisation port for the construction phase and as base for operation and maintenance during the lifetime of the projects.

In addition to these main categories, smaller contract lots will be awarded to specialist design houses (primarily for foundation design), certification authorities, project management companies, Health & Safety consultants, marine warranty surveyors, insurance providers and other minor contractors. The position of any individual company amongst the above mentioned categories within the value-chain is highly uncertain, with a wide variety of approaches to procurement strategy being adopted to date, as illustrated in Figure 2.2. In this context "Level" refers to the position of the entity in question in the contracting hierarchy e.g. Level 1 represents a direct contractual relationship with the project owner, Level 2 a sub-contract let by a Level 1 supplier, and so on.

FIGURE 2.1. ILLUSTRATION OF TRENDS IN CONTRACTUAL PRACTISE




Source: GL Garrad Hassan

FIGURE 2.2. A FLUID SUPPLY CHAIN – INCUMBENT AND NEW ENTRANT SUPPLIERS

| | Wind turbine manufacturers | Structural fabricators | Electrical suppliers | Marine contractors | Cable suppliers | Cable installers | EPCI contractors | Port operators |
|---|---|---|---|---|---|---|---|---|
| Example incumbents | Siemens, Vestas, REpower, Areva | SIF, Smulders, Bladt, EEW, Weserwind, BiFAB, Aker | ABB, Siemens Energy, Alstom Grid | A2Sea, MPI, SHL, Geosea | Nexans, Prysmian, ABB NKT, Scanrope | Technip, CT Offshore, Global Marine, Visser&Smit | Fluor, Van Oord, ABJV, MT Hojgaard, DEME | Various |
| Example new entrants | BARD, GE, Doosan, Gamesa, Alstom, Nordex, Mitsubishi | H&W, TAG, Tata, Hereema, ZPMC, Shinan, Fabricom | C&G | Fred Olsen, Beluga, Inwind, GOAH, Sea Jacks | DRAKA, JDR | Beluga | Hochtief, Saipem, Technip, Subsea7 | Various |
| Level 1 | Likely | Possible | Likely | Possible | Possible | Likely | Likely | Possible |
| Level 2 | Unlikely | Likely | Likely | Likely | Likely | Likely | Unlikely | Likely |
| Level 3 | Unlikely | Possible | Possible | Possible | Possible | Possible | Unlikely | Possible |

**Legend:**
Ticks and crosses represent likelihood of positioning at relevant Level in the contractual hierarchy:

- ✓ Likely
- ✓ Possible
- ✗ Unlikely

Source: GL Garrad Hassan

This fluid picture is primarily a symptom of the relative immaturity of the offshore wind industry which may be contrasted with the relatively stable and well-defined supply chain for mature sectors, such as the automotive industry, for example.

## 2.2 Scope allocation

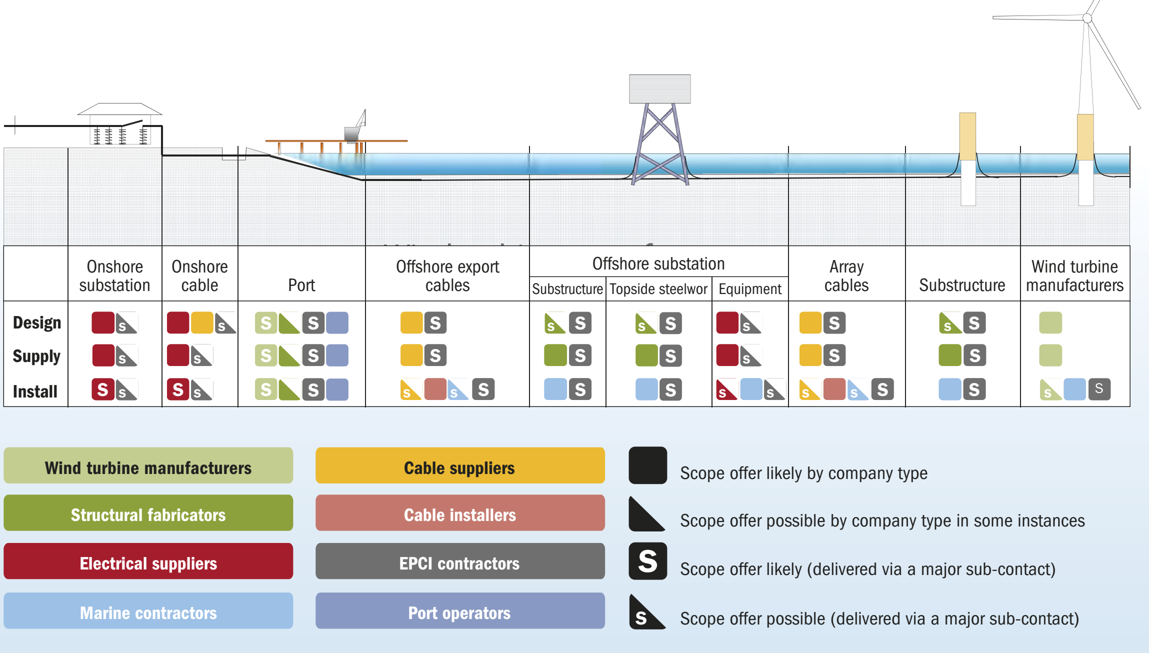
The goods and services provided by each of the identified supply chain categories to an individual project are also pertinent to the categorisation, as in some cases the exact services they are providing are not immediately obvious. Figure 2.3 attempts to summarise the potential scope allocation against the anatomy of a representative offshore wind project.

It is clear that for the vast majority of the supply chain, there is more than one type of company which could supply the required goods or services. The design and supply of the wind turbine units themselves is the notable exception to this rule, where the manufacturers are currently the exclusive providers.

The supply chain landscape depicted above provides the project developer with a reasonable degree of flexibility when approaching the contracting market.

The emergence of major contractors from the offshore oil and gas sector as active participants in the upper levels of the supply chain for offshore wind is an interesting recent development. In many cases it could be argued that these companies offer the financial strength, offshore project execution experience and strategic assets that some incumbent participants lack. However, the difference in the nature of the engineering problem (which for offshore wind primarily consists of serial production processes rather than "one-offs" as for the oil and gas sector), as well as the marginal economics of offshore wind as a technology, are factors which may prove challenging for this class of contractor.

FIGURE 2.3 SCOPE ALLOCATION POSSIBILITIES

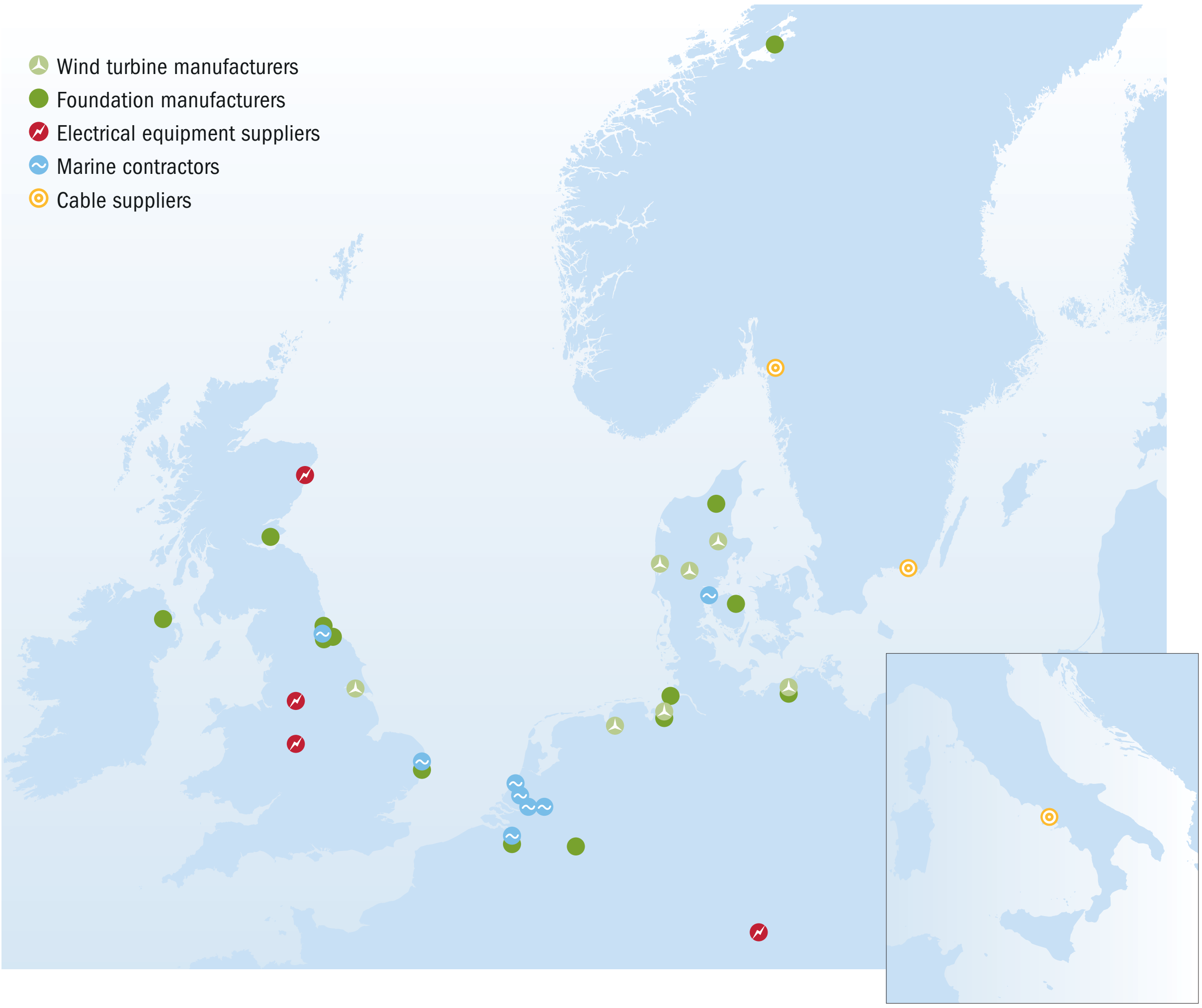


# 2.3 Location of key players

Figure 2.4 shows the geographical distribution of some of the key suppliers from the upper levels of the offshore wind supply chain in Europe, including established and planned manufacturing infrastructure. Denmark and Germany have historically played and continue to play host to a significant amount of established infrastructure, particularly in terms of wind turbine manufacturing facilities. The Netherlands and Belgium have also enjoyed significant participation, especially via the provision of installation services drawing on significant North Sea oil and gas and coastal engineering experience. Electrical equipment and subsea cable supply has a somewhat more distributed supply base with notable contributions from Norway, Sweden, Germany and Italy. The UK, which until recently had not played a significant role in the supply to the offshore wind sector, has seen substantial recent investment, with new facilities being established primarily along its east coast to serve domestic and export markets in the North Sea.

The specific companies featuring in Figure 2.4 are discussed in more detail later in the report. See figures 3.3 and 4.3 for more detail.

FIGURE 2.4 AN EXAMPLE OF KEY SUPPLIERS AND MANUFACTURING INFRASTRUCTURE



## KEY FINDINGS

- Competition across the supply chain for offshore wind is increasing with an influx of significant new entrants over the last 12-24 months. The contracting format has taken a full turn away from and back towards EPCI turnkey contracts: wind turbine manufacturers initially vied for early-mover advantage, but they are now in a knowledgeable and risk-averse market with multiple contracting practices. Looking to the future, more mature risk-effective and cost-effective supplier collaborations are likely to be developed.

- The emergence of major contractors from the offshore oil and gas and traditional maritime sectors may prove to be a significant shift in the dynamics of the supply chain.


Photo: Eon

# 3 WIND TURBINES

# 3.1 Historical context and market options

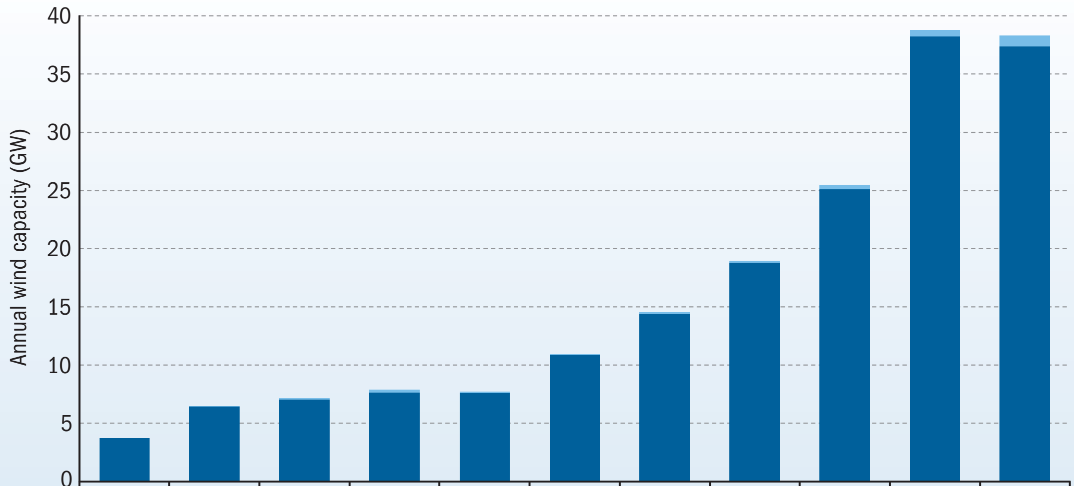
The rapid acceleration of onshore wind energy deployment, fuelled by particularly strong growth in North America and Asia as well as sustained expansion in Europe, has placed significant pressure on the global wind energy supply chain as demand has come to outstrip supply. Turbine production capacity has, to a large degree, been limited by second and third level supplier constraints. In particular, shortages of key components such as gears, large bearings, transformers, castings, forgings and carbon-fibre have contributed to this trend. Currently, the market for offshore wind turbines largely coincides with that for onshore turbines in terms of players, products and production facilities.

Given the additional risks associated with supplying technology to the offshore market and the high demand for turbines in lower-risk onshore markets, manufacturers have until recently had limited incentive to participate in offshore wind. Indeed there is only limited incentive to invest heavily in ramping up production facilities for what is still considered by some as a high-risk, marginal market. The plot in Figure 3.1 shows how historically offshore wind has been dwarfed by the scale of onshore wind deployment, globally.

Despite this, build-out rates for offshore wind over the last three years have been relatively impressive with year on year average growth of ~40%, leading to a total installed base of around 3 GW by the end of 2010.

As momentum increases, there are some indications that the supply-demand imbalance of recent years is beginning to ease, with increased levels of competition between the handful of existing incumbent suppliers. In the medium term, the prospects for further improvements in the level of competition increases with new entrant suppliers from both Europe and Asia, providing additional supply capacity.

FIGURE 3.1 GLOBAL OFFSHORE WIND – HISTORICALLY A NICHE MARKET




| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Onshore | 3.7 | 6.4 | 7.0 | 7.6 | 7.6 | 10.8 | 14.3 | 18.8 | 25.1 | 38.2 | 37.3 |
| Offshore | 0.0 | 0.1 | 0.2 | 0.3 | 0.1 | 0.1 | 0.2 | 0.2 | 0.4 | 0.6 | 1.0 |

Source: EWEA and GWEC

There is now clear evidence of a trend towards offshore specific wind turbine models and in some instances, manufacturers. This trend should mitigate the historical 'resource diversion' suffered by the offshore wind industry, particularly as manufacturers commit to significant investment in bespoke production facilities. There is strong evidence for this with three manufacturers with turbines in the 5-6 MW range commissioning substantial production facilities in the last few years (BARD, REpower and Areva). Whilst production is yet to ramp up to serial levels at these sites (all in northern Germany), the development signals that this critical part of the supply chain is now confident of long-term, sustainable markets.

However, the bifurcation discussed above, which is considered to be an important current trend, will not entirely resolve the resource diversion caused by continued high demand from the global onshore wind business, since second and third level sub-suppliers are likely to remain largely common to both onshore and offshore products and players. Recent announcements have indicated a scaling-back of new production capacity from previous plans for certain key sub-suppliers which on the surface would suggest a further tightening of supply. In reality it is considered that this development is a reaction to lower than anticipated demand from onshore wind, particularly from North American markets and in this respect the offshore market may not be affected directly.

In the short term new entrant wind turbine manufacturers will rely on strategic partnerships with third party suppliers until they establish themselves in the industry. Against this, we are likely to see more strategic acquisitions as the manufacturers seek to secure a competitive advantage.

# 3.2 Key sub-components

## Towers

Supply of towers for offshore wind turbines is considered to be relatively elastic, with low barriers to entry and an economic driver to manufacture close to market. A mixture of in-house and outsourcing approaches has been adopted by the wind turbine manufacturers. A reasonably wide selection of tower manufacturing facilities exists in Europe, although those capable of manufacturing larger diameter towers required for wind turbines in the 5-7 MW range are more limited. Whilst manufacturing equipment can be upgraded to cope with this, transportation constraints may prevent access to market in some cases. To mitigate the impact of this, it is considered likely that additional coastal tower manufacturing facilities will be required in Europe in the coming decade.

## Blades

Blade technology and manufacturing is increasingly viewed as a highly strategic element of the value chain for wind energy, given the high technological barriers to entry and the value of Intellectual Property associated with their design / production. In addition, previous shortages of materials and production capacity may have contributed to cost increases. The longer blades required by offshore wind turbine manufacturers bring additional manufacturing and logistical requirements and are likely to limit additional supply chain capacity to coastal locations. Independent suppliers are likely to continue to have a limited role supplying part of the new entrant wind turbine manufacturers.

## Drive train components

Drive train components including gearboxes, large bearings and generators are increasingly viewed by wind turbine manufacturers as strategically critical elements of the value chain, with an increasing trend towards vertical integration. Examples include investments by Siemens and Suzlon in leading gearbox suppliers Winergy and Hansen. Looking ahead, the technological developments in the supply chain towards more specialist solutions – medium and low speed (direct drive) concepts – is likely to accelerate the process of vertical integration with wind turbine manufacturers looking to consolidate control of design, intellectual property, manufacturing and quality as well as securing supply capacity.

## Castings and forgings

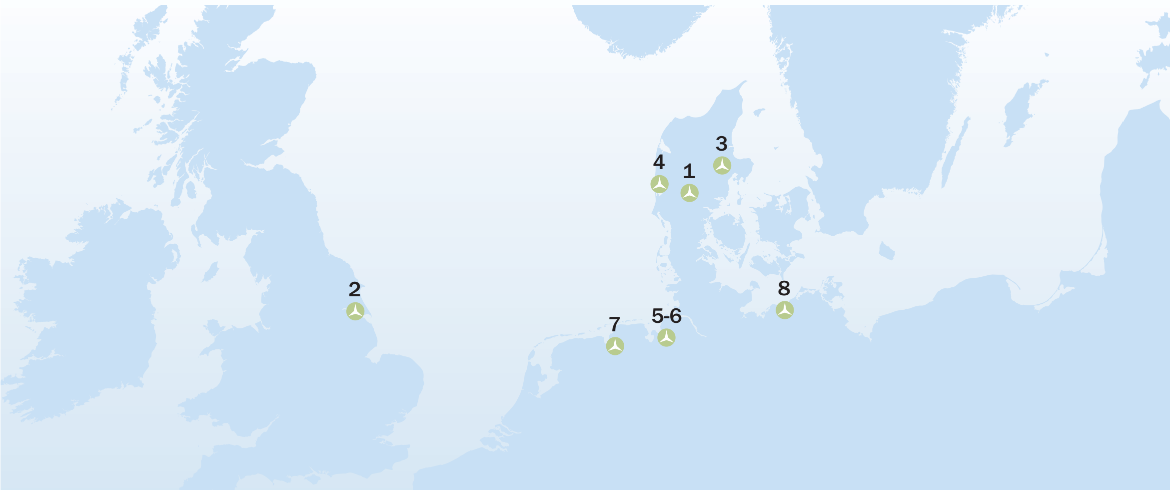
The bedframe, hub and gearbox/bearing housings are the main cast components within a modern wind turbine with the main shaft, and bearing/gear rings being forged constructions. Whilst there is a large global supply base for castings and forgings, the dimensional demands of wind energy, and in particular for large wind turbines reduces the field of available suppliers. Although there is some evidence of vertical integration (e.g. Vestas), the majority of cast and forged components are supplied by independent companies. Supply capacity in both cases has increased over the last two to three years.

Overall, key trends in the supply chain for offshore wind turbines may be summarised as follows:

- Incumbent wind turbine manufacturers are moving towards vertical integration of their supply chains through investments and acquisitions. This is driven by the desire to secure design and production IP as well as capacity for future expansion. Wind turbine designers are shifting towards more specialist technologies and this is likely to increase the trend towards vertical integration further still.
- In the short term new entrant wind turbine manufacturers will have to rely on strategic partnerships with third party suppliers until they establish themselves in the industry. Against this, we are likely to see more strategic acquisitions of specific technology providers as the manufacturers seek to secure a competitive advantage. A recent example of this is Mitsubishi's purchase of specialist technology provider, Artemis, and GE's investment in power converter supplier Converteam.

# 3.3 Current status of industry supply chain

FIGURE 3.2 SELECTION OF LEADING OFFSHORE WIND TURBINE SUPPLIERS AND FACILITIES




| No | Company | Notes |
|---|---|---|
| 1,2 | Siemens | Established supplier with a firm order book for over 3 GW of offshore wind capacity to be delivered before 2014. Existing 3.6 MW platform manufactured in Denmark with new UK assembly facility planned for forthcoming 6.0 MW direct drive model. |
| 3,4 | Vestas | Established supplier with offshore deployments totalling ~1.5 GW to date. V80 and V90 wind turbine platforms have given way to current market offering of the V112 3.0 MW unit. Recently announced plans for UK production of V164-7.0 MW unit from ~2015, the latter being the first Vestas unit to be exclusively intended for offshore deployment. |
| 5 | REpower | Previous market offering (5M) now superseded by upscaled 6.0 MW version (6M). Demonstration deployments of the 5M at Beatrice (UK-2007), Thornton Bank (BE-2009) and Alpha Ventus (DE-2009) have paved the way for the first commercial-scale sales (Ormonde, Nordsee-Ost and Thornton Bank phases 2&3) totalling ~650 MW. |
| 6 | AREVA | First prototype of M5000 (5 MW) unit deployed in 2006 with offshore demonstration of six units at Alpha Ventus producing first power from 2010. Commercial orders secured for Borkum West II Phase 1 (200 MW, DE), Global Tech I (400 MW, DE), MEG1 (400 MW, DE) to be delivered in 2012/13. |
| 7 | BARD | First prototype of BARD 5.0 (5 MW) unit deployed in 2007 followed by first commercial deployment on Bard Offshore 1 (400 MW) which is currently in construction. Unique vertically integrated business model including project development, substructure fabrication and installation. |
| 8 | Nordex | Early interest in offshore sector with marinisation of N90 (2.5 MW) product. No further offshore deployment beyond a near-shore prototype in 2006. Recent announcement of offshore-specific product (N150-6000) with first deployments of this 6 MW unit expected in 2014/15. |

There is an impressive and growing list of companies developing wind turbine designs for future deployment in the European offshore wind markets, as summarised in Table 3.1.

**TABLE 3.1 SELECTION OF FORTHCOMING OFFSHORE WIND TURBINE MODELS (EWEA DATABASE)**

| Model/ Company | Capacity (MW) |
|---|---|
| 2-B Energy | 6 |
| Acciona | 3 |
| Aerodyn SCD | 6.5 |
| Alstom/ Converteam | 6 |
| AMSC Sea Titan | 10 |
| BARD | 6.5 |
| China Shippong Industry | 5 |
| Condor | 5 |
| Darwind | 5 |
| Dongfang | 5 |
| Doosan | 6 |
| Envision Energy | 3 |
| Gamesa | 15 |
| | - |
| | 5 |
| GE | 4 |
| | 15 |
| Goldwind | 6 |
| | 10 |
| Guodian United Power | 6 |
| | 12 |
| HiPRWind | 2 |
| Huayi Electric &Mecal | 6 |
| Hyundai | 5 |
| | 2 |
| Israel Aerospace Industies | 3 |

| Model/ Company | Capacity (MW) |
|---|---|
| Mervento | - |
| Mingyang | 3 |
| | 6 |
| Mitsubishi | - |
| Nordex | 6 |
| Samsung | 2 |
| | 5 |
| | 6 |
| Schuler | 6 |
| Shanghai Electric | 3 |
| Siemens | 6 |
| Sinovel | 6 |
| | 10 |
| STX | 5 |
| SWAY | 10 |
| | 5 |
| | 3 |
| Technip -Vertiwind | 2 |
| Tianwei | 3 |
| Vestas | 7 |
| | 6 |
| WInFlo | 3 |
| WinWind | 3 |
| WPL Aerogeneratior X | 10 |
| Yinhe(Avantis | 3 |
| Zheijian Windey | 5 |

A supply-side analysis has been undertaken based on two databases, known as the "GLGH Component and Activity Costing Database" and the "GLGH Offshore Wind Installation Vessel Database", for the period 2010-2020. This has been carried out for each major Level 1 activity (wind turbine supply, foundation supply, electrical equipment supply and installation vessels) on the basis of the current and future planned expansion of capacity.

Projections of supply capacity are notoriously problematic, especially beyond a two to three year timeframe. In this regard, the following factors are highlighted:

- Supply capacity for certain items is relatively elastic and dynamic – it can be ramped up, within limits, to meet demand in quite short timeframes. In these cases, pressure on supply from the market is less likely to result in short-term upward pressure on pricing. In the majority of cases for the offshore wind sector however, investment decisions for significant additional Level 1 supply chain capacity must be made 18-36 months before that capacity is ready to be delivered, with the final stages of product development being executed in parallel with the ramp-up.
- Plans for additional supply chain capacity are mostly not in the public domain. This is particularly true for potential new entrant suppliers who may hold back specific plans because they are not fully committed or otherwise confidential for commercial reasons. The perception of future market demand will trigger investment decisions – but these are difficult to predict with any certainty.
- Those plans for additional supply chain capacity that do enter into the public domain are often not fully confirmed or do not entail a full investment commitment from the supplier in question. Again, this allows the supply chain to scale back or even cancel plans should perceived future market demand weaken significantly.

For these reasons, dealing with supply and demand independently is to some extent a flawed approach. However, the analysis that follows is intended to provide an indicative qualitative basis upon which general findings may be drawn with respect to competitive pressure within the supply chain and the commensurate effect on project costs.

## Wind turbine supply and demand analysis

At the manufacturer level, wind turbine supply capacity will be limited by the capacity of the primary assembly facilities. Downstream supply chain constraints on key components such as castings and large diameter bearings have largely been resolved, as discussed earlier. On this basis, it is possible to define generic capacity profiles, providing an assumed annual production capacity for new wind turbine products as production ramps up at new facilities in the years following the launch of the product in question.

The generic "ramp-up" profiles which follow are based on industry experience relating to the programme for the establishment of offshore wind turbine assembly facilities and their ultimate annual production capacity. Broadly speaking, German and Danish wind turbine manufacturers have adopted the following approach to establishing such facilities:

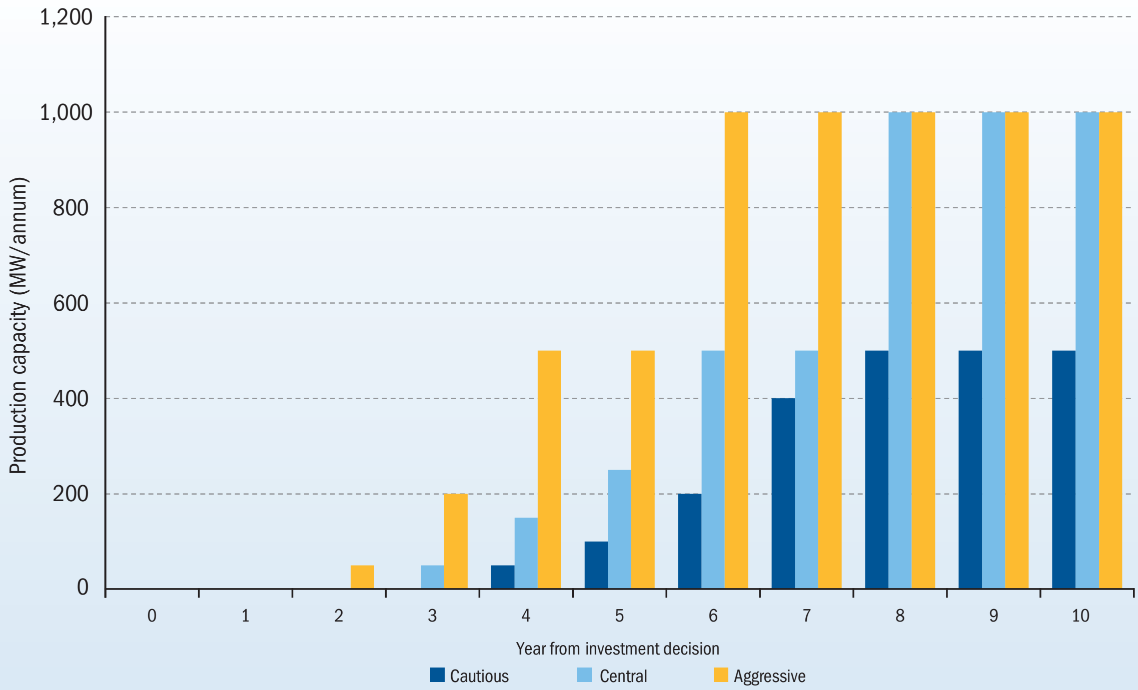
- An ultimate sales target equivalent to 1 GW / annum is usually required to justify the significant expenditure (typically in excess of €100 million) associated with product development, supply chain establishment and assembly facilities.
- In general, a single assembly hall and associated support facilities are required for a single shift, annual capacity in the order of 500 MW, ramping up to 1 GW by moving to two shifts.
- Following an investment decision to establish the required assembly / testing facilities, it can take several years to reach operational maturity given consenting, logistical and other constraints. The support of local, regional or national bodies can help to accelerate the time to market.

The above assumptions are supported by the following evidence:

- Siemens Wind Power have an order backlog of ~3 GW of capacity of their flagship offshore wind product (SWT-3.6-120) to be delivered to projects in northern Europe in the 2011-2013 timeframe – suggesting full capacity at ~1 GW / annum at their assembly facilities in Brande, Denmark.
- Areva and REpower Systems have both established assembly facilities in Bremerhaven, northern Germany, each with a single shift capacity of ~400 MW / annum.
- Direct consultation with other leading wind turbine manufacturers has revealed a consistent message annual sales target of ~1 GW to justify the launch of a new offshore wind turbine product.

On the basis of the rationale outlined above, the following generic capacity profiles may be assumed.

FIGURE 3.3 ASSUMED GENERIC WIND TURBINE MANUFACTURING CAPACITY




Source: GL Garrad Hassan

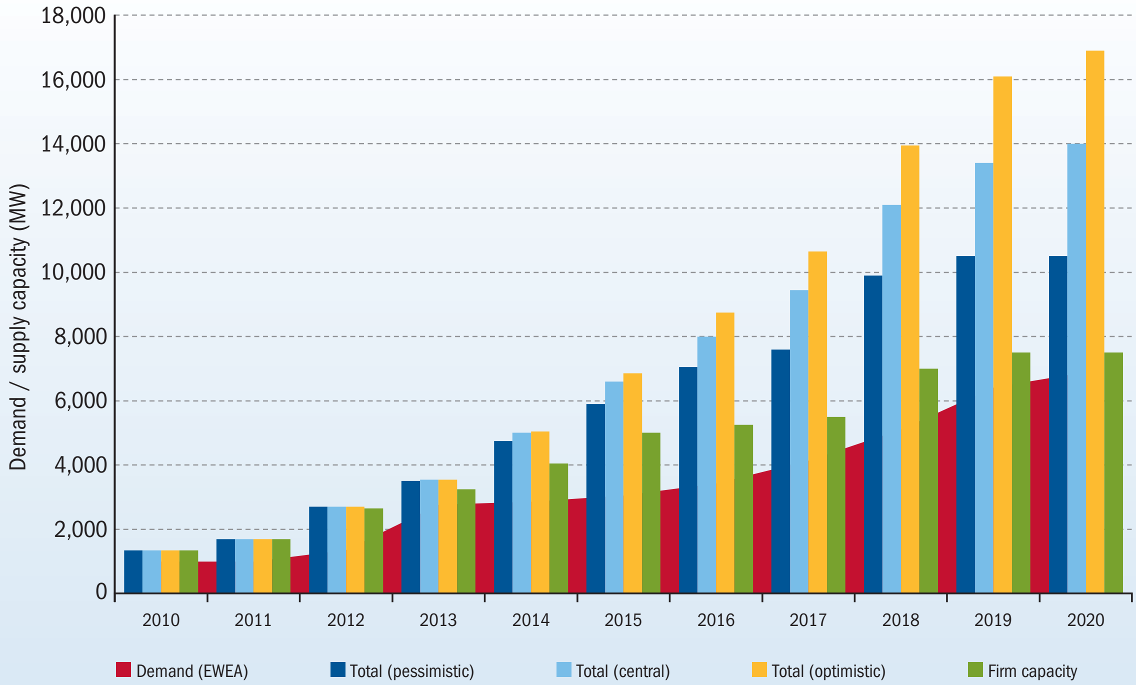
The generic capacity profiles presented above can be used to extrapolate the expected future wind turbine supply capacity for known wind turbine suppliers and models as well as identified new entrants.

In Figure 3.3, the manufacturing target is reached two years earlier in the aggressive scenario than in the central scenario.

It is reasonable to assume that a proportion of these companies will not ultimately launch an offshore wind turbine – there will be a natural cancellation or *attrition rate* as risks are fully understood and corporate policies shift. To account for this, attrition rates of 66%, 33% and 0% have been assumed in the capacity scenarios presented below, leading to four, eight and 12 new wind turbines models being assumed to reach some level of market readiness over the next decade, in addition to existing market offerings.

Figure 3.4 compares the derived wind turbine supply profiles to the assumed demand profile on the basis of EWEA market projections.

FIGURE 3.4 ANALYSIS OF SUPPLY AND DEMAND FOR OFFSHORE WIND TURBINE TECHNOLOGY IN EUROPE




Source: GL Garrad Hassan

It is clear from the results of the analysis presented in Figure 3.4 that supply is anticipated to meet demand for offshore wind turbine products over the next decade, even in the most pessimistic scenario for new entrant products. Oversupply is estimated to range between 2 and 8 GW per annum, which implies that a high and increasing degree of competition within this sector can be expected through to 2020. However, there is potential for spare capacity to be taken up, particularly by emerging export markets for offshore wind in North America.

It is noted that the "No Attrition" supply capacity profile is considered to be a very unlikely scenario and some degree of product cancellation is inevitable.

# 3.4 Future technical trends

The growth of the offshore wind sector in the last decade has presented wind turbine technology companies with new engineering challenges and possibilities.

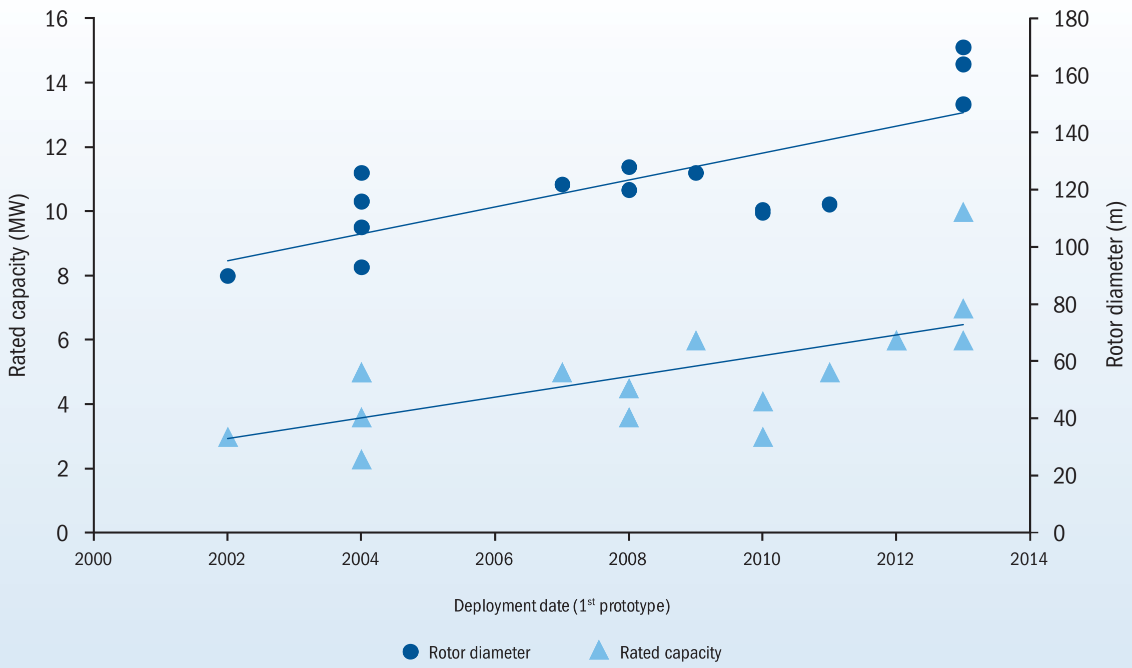
While initially onshore wind technology was used to supply this niche market, and therefore wind turbine designs were restricted by the numerous planning constraints on onshore models, such as tip height, noise emissions, aesthetics, transport and construction limits, the offshore wind market has grown to a size at which the development cost of bespoke products can be recouped over hundreds of units and is therefore possible.

The technological trends emerging from this division of supply is explored below, with commentary on the implications of these trends on the supply chain.

## Growth in offshore wind turbine size

Both in terms of rated power and in rotor swept area – as the two are closely related – onshore wind turbines have grown considerably in size over the last two decades. In parallel, technological developments in areas such as aerodynamics, variable speed regulation and independent blade pitch control have been numerous and fast paced. In the last decade, the rate of growth has seemed to slow down as a result of planning or economic constraints rather than technological issues. Because many of these constraints are eliminated or lessened in the offshore environment and because wind turbines on their own account for less than half of the capital costs in a typical project, the wind turbines aimed at the offshore market have been growing rapidly. This is illustrated in Figure 3.5.

FIGURE 3.5 GROWTH TRENDS – RATED CAPACITY AND ROTOR DIAMETER FOR OFFSHORE WIND TURBINE PRODUCTS



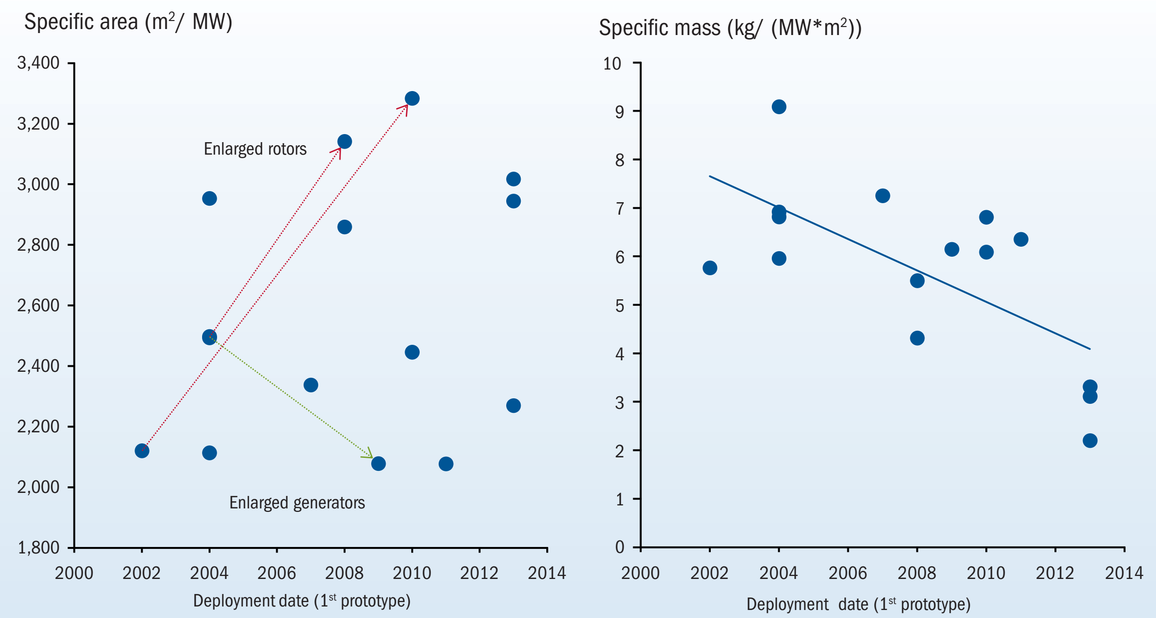

Source: GL Garrad Hassan

## Other design trends

### Specific swept area

Choosing the ratio of rotor swept area to rated power is a key decision in wind turbine design. Both dimensions have grown considerably – as shown in Figure 3.6 – but there is some evidence to suggest that turbine manufacturers developed offshore turbines with somewhat larger rotors relative to rated power capacity in the second part of the last decade, as illustrated, again, in Figure 3.6. Two manufacturers have enlarged the rotor size of an existing platform at a fixed rated power as highlighted by the red arrows in Figure 3.6. However, in contrast, one manufacturer (green arrow in Figure 3.6) decided to increase rated power as opposed to rotor size. Recent product announcements have confirmed the trend towards larger swept areas in relation to rated capacity – perhaps because this is seen as an effective way of reducing the cost of energy produced by improving the way plant infrastructure balance is utilised.

FIGURE 3.6 TRENDS IN SPECIFIC ROTOR AREA AND MASS




Source: GL Garrad Hassan

## Specific mass

Material efficiency has also improved significantly in the last decade and new products due in the next few years indicate that this trend is set to continue. This is illustrated by the specific mass plot in Figure 3.6. A combination of factors contributed to these improvements, particularly:

- The optimisation of loads via advance control systems with associated structural design efficiencies;
- The adoption of more efficient materials e.g. carbon fibre;
- Concept changes e.g. direct drive concepts with permanent magnet generators.

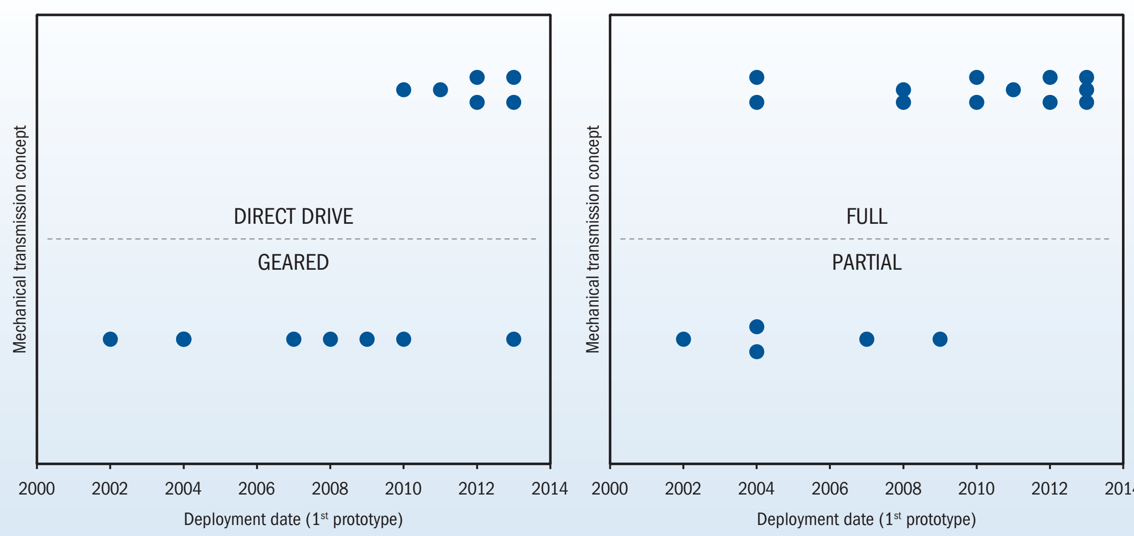
This trend has obvious economic benefits in terms of the cost of producing the wind turbines themselves as well as associated balance of plant and installation costs.

## Transmission and conversion technology

There are currently significant trends with respect to the selection of mechanical transmission and electrical conversion technologies, as illustrated in Figure 3.7.

1. There is clear evidence of a trend towards increased reliability in drive train design with various approaches being adopted. Direct drive technology is being pursued by some manufacturers with others opting for a focus on improved reliability for geared designs. So-called "hybrid" designs which employ a gearbox but with transmission only to a medium speed are also being developed further.
2. Whichever mode of mechanical transmission is selected, permanent magnet generators (PMGs) are gaining market shares as generator technologies, offering, as they do, a means of reducing nacelle mass.
3. Electrically, there is a clear trend in generator technology away from partial to full power conversion. This is partly a bi-product of the shift towards PMG technology which inherently requires full conversion but is also a result of improvements to component technology and to meet increasingly demanding grid code requirements.

FIGURE 3.7 TRANSMISSION AND CONVERSION TECHNOLOGY TRENDS




Source: GL Garrad Hassan

## Implications for the supply chain

The trends above are considered to have a number of important implications for the supply chain:

- Larger wind turbine technology means larger components: blades, towers, bed frames, hubs, etc. Logistically, this forces the supply chain towards the establishment of coastal manufacturing and assembly facilities to avoid constraints associated with road/rail transport. This will help to decouple offshore from onshore supply chain capacity, as it necessitates specialist facilities at these port locations.
- Shifts in the technological concepts for offshore wind turbines will obviously have an impact further down the supply chain. The adoption of advanced materials and processes to serve these offshore-specific concepts will contribute to a further decoupling of supply capacity between onshore and offshore wind energy for major components such as large PMG units.

To sum up, the developments in offshore wind turbine design are driving the decoupling of the supply chain between the onshore and offshore wind sectors, with dedicated offshore capacity a requirement for the future. This may be seen as a natural consequence of the maturing offshore wind industry, but it is a development with both positive and negative consequences. On the upside, the availability of dedicated supply chain resources will help insulate the offshore wind sector against the conflicts with the onshore wind industry that have historically driven up the cost of delivering offshore wind projects. However, during periods of lower demand from the onshore wind sector, the benefits of supply chain flexibility will no longer be available. Overall, the bifurcation described above is considered to be a welcome development signalling, as it does, a "coming of age" of the offshore wind sector.

## ▶ KEY FINDINGS

- **An impressive and growing list of manufacturers are developing new wind turbine models specifically for the offshore wind sector, to supplement the handful of incumbent suppliers and products. It is expected that four to 12 new wind turbine models will reach some level of market readiness over the next decade.**

- **It is estimated that the supply of offshore wind turbines will meet and exceed demand for the next decade, leading to healthy levels of competition within Europe with the potential for export to emerging North American markets.**

- **Against a backdrop of increasingly challenging project sites, there is a clear trend towards lowering energy costs through improved reliability and structural efficiency / energy capture. Improved gearbox designs, direct-drive technology, permanent magnet generators and larger rotors are the key avenues being pursued by wind turbine designers to achieve this.**

- **Design trends are driving the supply chain towards specialisation, partially decoupling it from previous entanglement with the onshore wind industry, indicating growing market maturity.**

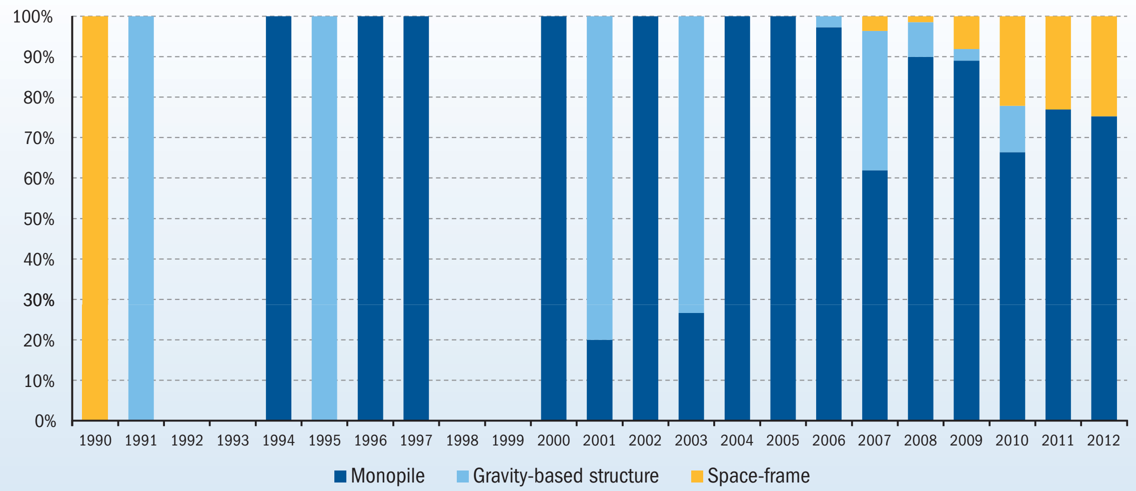

# 4 SUBSTRUCTURES

# 4.1 Historical context

A major difference between onshore and offshore wind farms is the relative complexity and cost of civil works, especially the substructures required for offshore turbines. For offshore wind farms, substructure supply and installation represents around 20% of the capital costs. The size and water-depth constraints of manufacturing, transporting and installing wind turbines are vital factors in determining the current techno-economic limitations of offshore wind farms. Meeting the massive increase in demand forecast for the next decade for offshore wind substructures will require significant expansion in manufacturing capacity. The technical barriers to manufacturing substructure components are relatively low and establishment of fabrication facilities is an obvious move for large marine engineering firms who have reduced demand from the oil and gas and maritime sectors in recent years. The relatively low barriers to entry, high supply elasticity (due to the short lead times for bringing new production facilities online) and logistical incentive to source locally will create significant industrial development opportunities in European countries with access to the offshore wind areas. Since substructures represent a large amount of the capital expenditure in a wind farm, and therefore represent a significant amount of supply chain value, it is not necessary for a country to have its own wind turbine manufacturer to have an offshore wind industry. Given these marketplace and product characteristics, it is considered unlikely that any significant supply chain constraints will emerge for the supply of substructures for the foreseeable future, except possibly as the result of short-term demand peaks or excessive resource competition from other industries.

A number of types of substructure have been utilised and proposed to date. Important considerations when selecting a structure type include cost, water depth, seabed conditions, turbine characteristics and technical / commercial risk factors. The majority of the wind farms currently in operation in water depths of under 20-25 metres have monopile foundations, as they are relatively simple to produce, easier to install and less costly. Gravity-based structures (GBS), which are also relatively easy to produce, make up most of the remainder, while only a small number of space-frame structures (e.g. jackets, tripods and tripiles) have been installed so far.

FIGURE 4.1 HISTORIC OFFSHORE WIND TURBINE FOUNDATION MARKET SHARE (BY YEAR)

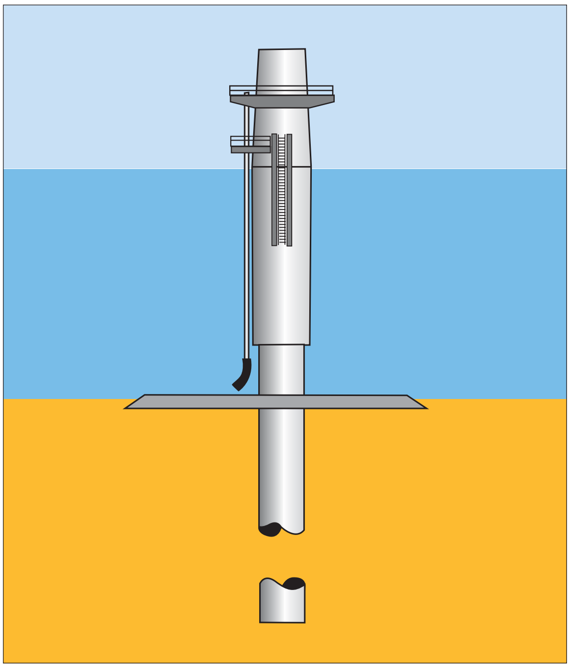



Source: GL Garrad Hassan

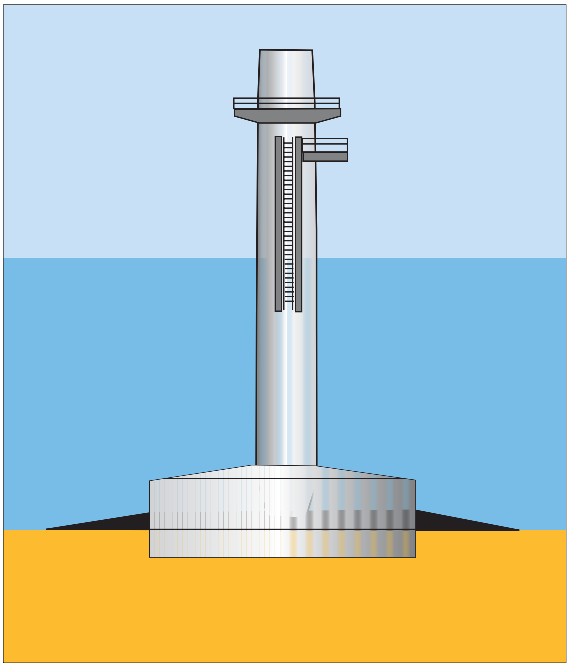
Note that the sample size in early years will generally be smaller, typically consisting of a single wind farm with, maybe, half a dozen turbines.

# 4.2 Substructure types

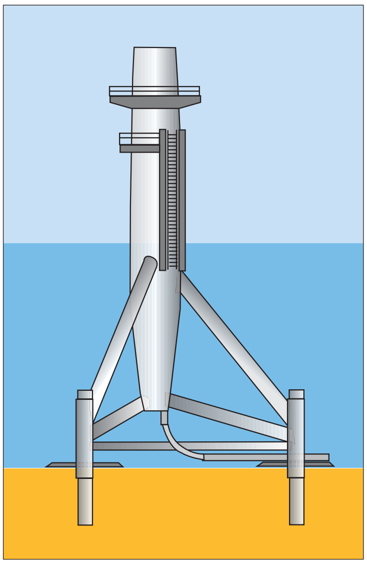
FIGURE 4.2 EXAMPLES OF TYPICAL SUBSTRUCTURE DESIGN



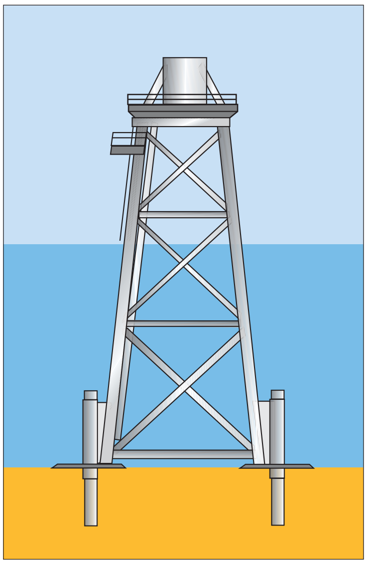
Monopile



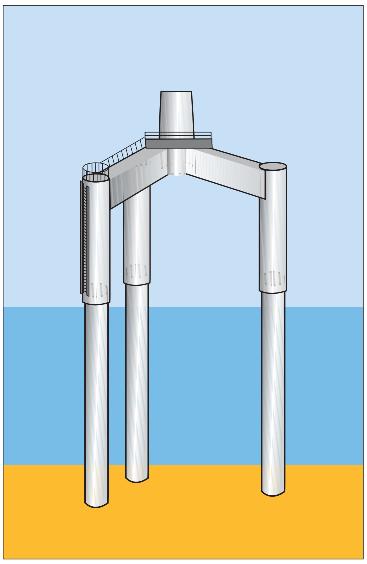
Gravity-based Structure (GBS)



Space Frame (Tripod)



Space Frame (Jacket)



Space Frame (Tri-pile)

## Monopiles

A monopile foundation consists of a single steel pile which is embedded into the sea bed. How far the pile goes into the sea bed, and its pile diameter / wall thickness are determined principally by the maximum water depth and rated capacity of the wind turbine. Typically, the turbine tower is mounted onto the foundation via a transition piece which itself is fixed on to the pile using a specialised grouted joint.

A disadvantage of the monopile is that is becomes less stable in deeper waters, and is best suited to water depths of up to 25 metres. It is possible however, that future developments in manufacturing capabilities and size of installation equipment will mean that monopile structures with very large diameters will be possible, reducing the monopile's flexibility and making it suitable for deeper water sites. As such, owing to its simplicity and relatively low labour content, the monopile solution is considered by the industry as "low hanging fruit", to be exploited before more complex and labour-intensive designs become necessary.

## Gravity-based structures

Unlike piled foundations, gravity-based structures (GBS) are designed to avoid tensile or uplift forces between the bottom of the support structure and the seabed. This is achieved by providing dead loads to weigh down the structure so it retains its stability in all environmental conditions.

GBSs are constructed in building yards and transported to site. Once in position on the seabed, their weight is increased by filling the structure with pumped-in sand, concrete, rock or iron ore as required. Gravity structures are usually competitive when the environmental loads are relatively modest or when additional ballast can be relatively easily provided at a modest cost.

To date, GBSs have been used in offshore wind projects using cylindrical or conical reinforced concrete caissons which are mounted directly on to a prepared area of the seabed.

Again, the dimensions of gravity-based foundations will increase mainly with turbine capacity, the site wave conditions and water depth. This type of structure is currently suited for sites in water depths up to 30 metres, although some designs are being considered for deeper sites. To date these designs have been used in many of the offshore wind projects in the Baltic Sea, where water depths and meteorological and oceanographic ("metocean") conditions are suitable.

## Space frame structures

For deeper locations, space frame structures are likely to be considered. Broadly speaking, these concepts fall into two categories: multipods (including tri-pods and tripiles) and jackets. These designs transmit forces to the foundations in the seabed via a structure made up of several piles, with the aim of minimising the ratio of mass to stiffness. Typically, small diameter piles ("pin-piles") are proposed for the method of fixing space frame structures to the seabed, although suction caissons have also been suggested.

### Tripods

The tripod is a standard three-legged structure made of cylindrical steel tubes. The central steel shaft of the tripod is attached to the turbine tower. The tripod can have either vertical or inclined pile sleeves. The base width and the pile penetration depth can be adjusted to suit the environmental and ground conditions. The piles in this case would be relatively small, say 2 to 3 m in diameter.

As with monopile designs, the size of the multi-pod foundation will increase with the capacity of the turbine, but it will also be affected by wave conditions and water depth at the site. The distance between the piles is likely to be around 20 to 40 m for the turbines under consideration for projects planned to come online during the next five years. This type of structure is well suited for sites ranging in water depth from 20 to 50 m.

### Tri-piles

Tri-piles consist of three foundation piles connected via a transition piece to the turbine tower with the transition piece located above the water level. BARD has patented a specific version of this concept which consists of a transition piece with three pins that slot in to the three pre-installed piles.

### Jackets

Jackets differ from tripods and tri-piles in that they consist of a larger plan area through the majority of the structure, positioning the steel further from the centre of the axis, which results in significant material savings.

The offshore wind developments to make use of jackets to date are the Beatrice Demonstrator (2006), Alpha Ventus (2009), Thornton Bank (2011) and Ormonde (2011) wind farm projects although they have been commonly employed in the offshore oil & gas sector for many decades. As with the tripod design, the structure is "pinned" to the seabed using piles. It is argued that the increased manufacturing and assembly costs of such a structure when compared to the tripod are offset by a significantly lower mass for the same stiffness characteristics, and that automated production processes have the potential to reduce costs further.

## Other demonstrated fixed substructure designs

Aside from the mainstream substructure types detailed above, there are other designs including battered piles and suction buckets which have been demonstrated to a greater or lesser extent.

Battered piles include a reinforced concrete pile cap sitting on battered (inclined) driven steel piles and are suitable only for shallow, well sheltered waters. Suction buckets consist of an upturned cylinder “sucked” into place thus removing the need for expensive and cumbersome piling. They also avoid the need for pile driving and associated noise. However, suction buckets are limited to use in relatively uniform benign soils and hence are unsuitable for many European sites.

# 4.3 Substructure market status and outlook

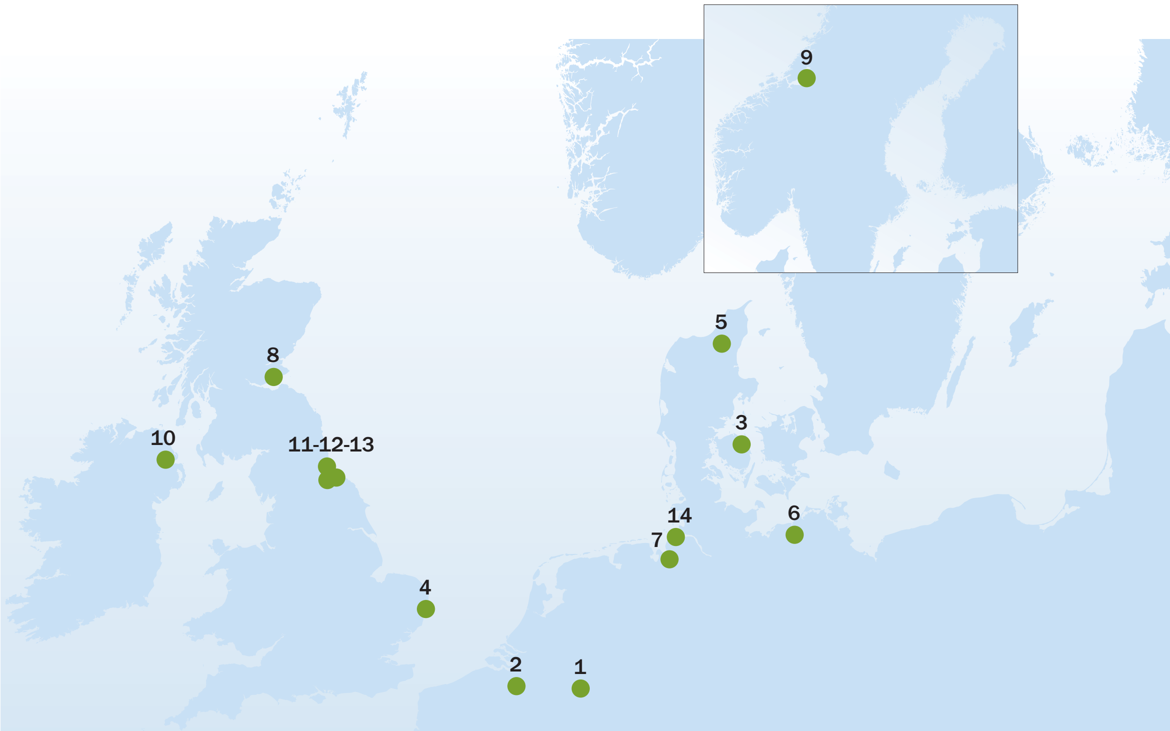
Monopiles are expected to continue to dominate the marketplace up to the technical limits of their feasibility in terms of turbine size, water depth and ground conditions. GBS designs will also continue to capture a proportion of the market share within shallower and more sheltered sites. The size of this share will vary by region, depending on local conditions and historic usage.

For most other cases such as deeper water sites, space-frame structures are expected to be the design of choice for the majority of developers. The market share of jackets should grow as more challenging sites are developed.

The challenge of decommissioning substructures at the end of their lives may in some instances be considerable, but not unprecedented with substantial experience being accrued from the North Sea offshore oil and gas sector in recent years. Developers are already putting aside money for decommissioning and in some markets this is a statutory requirement.

A selection of incumbent and new entrant structural fabricators serving the offshore wind sector is presented in Figure 4.3.

FIGURE 4.3 SELECTION OF INCUMBENT AND NEW ENTRANT STRUCTURAL MANUFACTURERS




| No | Company | Notes |
|---|---|---|
| 1 | Sif Group | Established supplier of monopile foundations – industry leader. |
| 2,3,4 | Smulders | Established manufacturer of monopile and jacket foundations – industry leader. |
| 5 | Bladt | Established manufacturer of monopile and jacket foundations – industry leader. |
| 6 | EEW | Supplier of monopile foundations – recent market entrant. |
| 7 | Weserwind | Established supplier of tripod foundations with jacket capabilities. |
| 8 | BiFAB | Established supplier of jacket foundations – industry leader. |
| 9 | Aker | Supplier of tripod and jacket foundations – recent entrant. |
| 10 | Harland and Wolff | Manufacturer with probable focus on jacket foundations – new entrant. |
| 11 | Tata Steel | Manufacturer with probable focus on monopiles – new entrant. |
| 12 | TAG | Manufacturer with probable focus on monopiles – new entrant. |
| 13 | Heerema | Manufacturer with probable focus on jacket foundations – new entrant. |
| 14 | Cuxhn. Steel. | Established supplier of tri-pile foundations – owned by Bard Group. |
| 14 | Strabag | Supplier of gravity-based foundations – new entrant. |

# 4.4 Floating structures

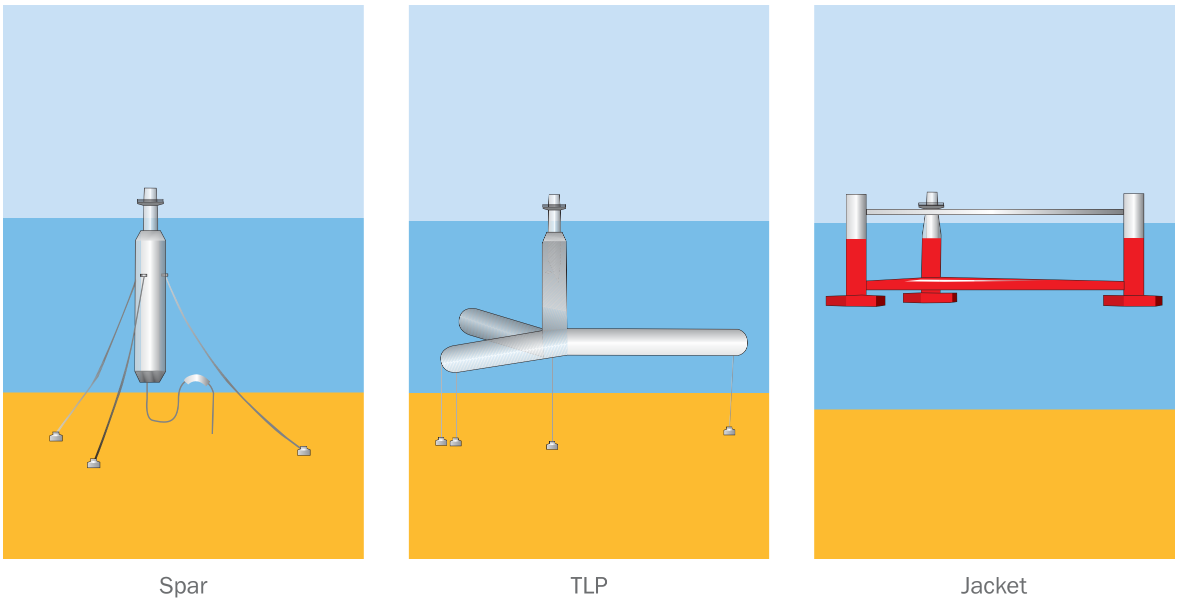
All ongoing commercial scale offshore wind developments utilise seabed mounted or "fixed" substructure concepts. However in many countries there are only a limited number of suitable sites in sufficiently shallow water to allow economically viable fixed substructures to be deployed. Within Europe, the areas faced with this difficulty include much of the Mediterranean and Atlantic basins as well as Norway.

Within these waters (over 50 m in depth) it is likely that floating support structures will prove to be more economical. In such circumstances floating structures have a number of important benefits including greater flexibility in the construction and installation procedures, the ability to transfer onerous bending loads onto water rather than rigid seafloor, which is further away, and easier removal upon site decommissioning.

Set against these benefits are a number of challenges such as minimising wind and wave-induced motion, the added complexity of the design process, electrical infrastructure design and costs (in particular the flexible cable) and construction, installation and O&M procedures.

There are three primary types of floating structures: the spar, the tensioned-leg platform (TLP) and the floating jacket structure as illustrated in Figure 4.4. To date only the spar type has been demonstrated at full size offshore.

FIGURE 4.4 FLOATING SUPPORT STRUCTURE TYPES




Sources: MSCGusto / ECN / TUDelft; others: GLGH

In the longer term, it is anticipated that such floating structures will become a more prominent feature of the offshore wind market. New opportunities will exist for the supply chain to serve the market through the provision of goods and services which are specific to this technology. Areas of focus are likely to include dynamic subsea cabling/connections, specialist installation methodologies and novel access solutions.

A summary of the recent developments in the field of floating wind technology is provided in Table 4.1 below.

TABLE 4.1 SELECTED EUROPEAN DEVELOPMENTS IN FLOATING SUBSTRUCTURE TECHNOLOGY

| Country | Project name | Principal partner | Description |
|---|---|---|---|
| Norway | Hywind | Statoil | Hywind is the first full scale grid-connected floating prototype (using spar class technology). It was installed off Karmøy island on the south-west coast of Norway in 2009 with a Siemens 2.3 MW machine. |
| Norway | Karmøy | Sway | Sway is building a prototype spar class floating design with the ambition of deploying a 5 MW turbine in 2013. |
| France | Vertiwind | Technip | In association with Nénuphar, Converteam and EDF Energies, Technip have launched a project to test a pre-industrial prototype of a vertical-axis floating wind turbine. |
| France | Winflo | Nass & Wind | In partnership with Saipem, DCNS and InVivo. Windflo is a 2.5 MW moored floating jacket class prototype to be installed off the coast of Brittany. Currently under development. |
| Spain | Zèfir Test Station | Catalonia Institute for Energy Research | In collaboration with a number of major industry players the Zèfir Test Station programme is intended to further deep water developments around Spain in two phases, the second of which involves installing eight turbines on floating structures at water depths of over 100 m. |
| Europe | HiPRwind | EU project consortium | Five-year programme with a total budget of €19.8 million to develop a new floating platform for "very large" offshore turbines. |
| Spain | Azimut Project | Gamesa | In partnership with Alstom Wind, Acciona and Iberdrola, the Azimut Project has the objective of providing the groundwork for the development in around 2020 of a 15 MW offshore turbine. |
| Portugal | Windfloat | Principle Power | In partnership with EDP and InovCapital, the Windfloat Project intends to install a full-scale Vestas V80 2 MW turbine for 12 months of testing in 2011. The Windfloat is a floating jacket design with novel features. |
| Italy | - | BlueH | A multi-national group of companies based in the Netherlands have developed a TLP concept consisting of a larger structure with several piles implanted in the surface. An off-grid prototype with an inactive turbine for visualisation purposes was installed 21 km off Brindisi, Italy in 100 m deep waters during 2007/8. |

## KEY FINDINGS

- Substructures present major opportunities for domestic manufacturing due to low technical barriers for entry, for example by using shipyards or tower manufacturers. Substructure manufacturing also brings a significant amount of supply chain value as substructures represent a large part of the capital expenditure in an offshore wind farm. It is not essential to have turbine manufacturing to develop an offshore wind industry.

- Substructures have a relatively high elasticity of supply, lowering bottleneck risk. They present an attractive diversification opportunity for substantial existing marine and oil and gas fabricating capacity in Europe.

- The move into deeper waters will see an increased market share from space-frame structures as well as novel fixed and floating structures further into the future. Nevertheless improved production and installation procedures could enhance the depth envelope of monopiles as well.


Photo: Stiftung Offshore Windenergie – Gehring

# 5 ELECTRICAL INFRASTRUCTURE

# 5.1 Historical context and market options

## The first offshore projects

The first offshore projects such as Vindeby (built in 1991) were all relatively modest in capacity (Vindeby has 4.95 MW of capacity) and close to shore (Vindeby is 2.5 km from shore), and so conventional medium-voltage (MV) interconnections could be used. The electrical infrastructure was very similar in principle to that of onshore wind farms of the time: the turbines were interconnected in a radial system at a voltage of 10 or 20 kV, with an onshore substation to connect to the local distribution system. The onshore substation sometimes included transformation to higher voltages such as 150 kV if it was necessary to connect to the local electricity system.

As for onshore wind farms, substantial supply chain bottlenecks existed for transformers (especially substation transformers which stepped up from MV to 100-150 kV), and for switchgear. This was because the most of these items went to electricity system operators, whose network development programme is planned on timescales of years. Therefore the suppliers concentrated on maximising throughput for their existing facilities. Delivery times were (and still can be) typically of the order of 26 weeks, or even 12 or 24 months for the larger transformers. Often these lead times were longer than the delivery times for the turbines, and determined the overall length of the project.

### Internal transformer and switchgear

The turbine generator voltage, commonly 690 V, had to be stepped up to the inter-turbine voltage of 10 to 20 kV, later 33 kV. At the time of the early offshore wind farms, the equivalent function onshore was often achieved by a transformer and associated MV switchgear located in a separate cubicle outside the base of the turbine. It was therefore necessary to provide space to locate these items inside the turbine base.

Initially these items were treated as separate from turbine supply, but as there are many engineering interface issues (mechanical, electrical, safety and installation) there were good reasons for incorporating the transformer and switchgear into the turbine supply contract. Some turbine manufacturers later took the step of moving the transformer into the nacelle. Internal transformers also started being added to onshore wind farms, for different reasons.

The MV switchgear commonly in use at the time onshore was very simple: fuses internal to the transformers, and manual disconnection of MV cables when necessary. Offshore, it was soon decided that this was unsatisfactory, and fused switches were adopted. The very tight dimensions inside the tower base limited the equipment that could be used, and resulted in at least one switchgear manufacturer with significantly smaller switchgear cabinets achieving high market penetration. As turbine rating increased beyond around 2.5 MW, suitable fuses were no longer available, resulting in a move to circuit breakers for transformer protection.

### Subsea cables

Although the arrangement and voltage of the MV cables between turbines and to shore were identical to onshore wind farms, for cables it was necessary to use submarine cable technology. At the voltage levels used, suitable products and suppliers already existed.

Subsea cable construction is “tri-core” – that is, a single cable containing three phase conductors inside an external covering. The equivalent practice onshore is to use three separate single-phase conductors, as this allows better cooling of the cable, and (for the same cable drum size) longer runs between joints. The subsea cable also contained an optical fibre communications cable, whereas in onshore wind farms this is provided by a separate cable laid in the same trench as the MV cables.

Methods were developed for cable entry to the offshore foundations, and cable support and termination. In addition, techniques for installing the relatively short lengths in shallow water had to be developed, but for these relatively sheltered sites unpowered "dumb" barges could be used.

### Earthing systems

Onshore wind farms usually require substantial buried earthing (grounding) systems, consisting of bare buried conductors around the turbines, along cable routes, and at substations. Offshore turbines consist entirely of metallic and concrete structures which are closely interconnected, and so no earthing system is required.

## Larger projects, further from shore

### Offshore substations

Offshore installations are the most obvious difference between early and later projects. Not all large projects need offshore substations: those close to shore can follow the early practice of connection to shore at Medium Voltage. However, as the maximum power that can be exported on the largest MV cable is of the order of 30-40 MW, a large wind farm will need a large number of cables. Providing landfalls and onshore cable routes to an onshore substation for many cables may not be easy. For distances of more than a few kilometres, offshore substations are chosen because of the cost advantage of using a small number of high-voltage cables (typically in the range of 120 to 150 kV). The cost comparison includes the capitalised value of the electrical losses, which are significantly lower when using higher voltages.

The electrical equipment mounted on the offshore substation is very similar to onshore substation practice, with additional environmental protection.

The offshore substation is recognised as a major risk – a failure at the substation may have a very significant effect on energy production. Designs have developed to provide substantial redundancy, and recent projects often have two transformers, and two export cables to shore. It is normal for each transformer and export cable to be rated around 50% of the wind farm rated capacity, but since the wind farm operates for most of the time well below its rated output, this arrangement still allows around 70 to 80% of the annual energy production to be exported in the event of a single failure.

For very large offshore wind farms, several offshore substations may be required, and there may then be an advantage in providing redundancy by adding HV connections between the substations.

Offshore substations largely followed offshore oil and gas practice: a foundation structure is installed, usually a jacket structure, though monopiles have also been used (see Section 4). A ‘topsides’ structure is built onshore, complete with all electrical equipment, and commissioned as far as possible, before being transported to the site and installed on the foundation structure. Cables are then pulled in and terminated, and final commissioning is completed. Installation of the foundation structure and the topsides requires larger and more expensive vessels and cranes than for turbine installation, and the availability of suitable vessels has been a limitation. Therefore alternatives have been proposed including the modularisation of the topside design, allowing for a higher number of smaller lifts, as well as "self-installing" platforms with integral jack-up mechanisms. Such approaches are yet to become widespread in the offshore wind sector, although experience from the offshore oil & gas industry may be exploited in the coming years.

### Export cables

As noted above, the MV cables used between turbines (‘array cables’) use existing subsea cable technology. The higher-voltage export cables necessary when using offshore substations also use standard subsea cable technology (though see also the section on DC cables, below). However the existing manufacturing capacity has been strained by the demand, and if offshore wind continues to expand as anticipated, substantial additional manufacturing capacity will be needed as explored in more detail below.

### Cable installation

Early projects were in relatively sheltered waters, with relatively short cable runs. Later projects had difficulty obtaining suitable cable installation vessels, and there has been substantial development of vessels, installation techniques, and installation tools. Many of the problems encountered with offshore wind farm construction have been related to cable installation and protection.

### High Voltage Direct Current

Both onshore and offshore, Alternating Current (AC) is virtually universal for electricity generation, transmission and distribution. However, High Voltage Direct Current (HVDC) is used increasingly in specific circumstances. Converter stations at each end of a DC cable or overhead line convert AC power to DC and vice versa.

HVDC in principle has advantages for subsea power transmission, and with recent developments in power electronic conversion technology, this has become a more attractive option for longer distances and larger wind farms. HVDC is being used by Transmission System Operators in Germany to connect several offshore wind farms arranged in clusters with a total installed capacity of 800-900 MW. This technology is likely to be used for the larger and more distant UK wind farms, and is considered to be cost effective for projects of around 500 MW with a cable route of around 100 km (although these figures are rather uncertain). The use of the technology offshore is still seen as a risk given its relative immaturity, lack of widespread application and perceived complexity. In addition a substantial offshore substructure is needed to support the large converter stations.

The DC/AC conversion process onshore offers significant advantages to the system operator in terms of reactive power and voltage, both steady-state and dynamically, and of the fault current. It is fair to say that commercial and regulatory arrangements have not yet been developed to allow these potential benefits to be fully realised, primarily owing to the lack of widespread deployment to date. It is anticipated that as HVDC technology is more widely deployed, the relevant stakeholders will take advantage of this potential more often once the necessary changes to regulation and commercial practice have been made. In addition, the economics of the technology is expected to improve over the next decade via learning and scale effects.

HVDC technology currently allows only ‘point to point’ transmission. ‘Multi-terminal’ systems are technically feasible, but have not yet been demonstrated on a commercial scale. This will be an important step in making use of HVDC connections to offshore wind farms to provide interconnections between countries, as proposed in the ‘Supergrid’ concept. This is also an important technical development for the German market where HVDC hubs are being installed to service multiple projects in a regional cluster. This arrangement may also be an important feature for certain projects within the UK, particularly for Round 3 developments.

With an HVDC connection, there is substantially more design freedom for the wind farm electrical system and for the wind turbines. For example, it would be possible to run the wind farm electrical system at variable frequency. Higher frequencies could substantially reduce transformer size and cost. It may also be possible to directly achieve DC output from each turbine. These issues are closely tied in with wind turbine design, and are unlikely to be tackled on a project basis.

### Electrical system within the wind farm

Currently, standard medium-voltage equipment is used, utilising the International Electro-technical Commission (IEC) standard voltage of 33 kV[16]. As noted above, this limits the power transmitted on a single cable to around 30–40 MW, as cables larger than this would be very difficult to handle. There may be advantages to utilising a higher standard voltage: 45 and 66 kV are options. These voltage levels are rarely used elsewhere so there are limited suppliers and costs are high. However, there are indications that this could change: the V164-7.0 MW offshore turbine recently announced by Vestas is stated to have an option for 66 kV connection[17].

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[16] This is the nominal voltage. The IEC standard provides more exact definitions based on maximum steady-state voltage.

[17] http://www.vestas.com/en/wind-power-plants/procurement/turbine-overview/v164-7.0-mw-offshore.aspx

# 5.2 Current status of industry supply chain

## General

From the above, it is seen that the electrical infrastructure for offshore wind projects mostly uses the existing supply chain, which has been developed for onshore electrical transmission and distribution networks. However, as wind farms are put up at increasing distances from shore, electrical infrastructure can represent a significant fraction of the total capital investment required for constructions – as much as 20% in some instances.

For most items, the demand is relatively small compared to the demand for the onshore distribution and transmission networks, and so the supply chain is adequate, and likely to remain so. However, world capacity for manufacturing large high-voltage transformers is limited, and when demand increases it results in longer manufacturing lead times. In recent years, lead times of three years or more have been known.

## Subsea cable

As noted above, the supply chain capacity for subsea cable is limited, especially at the higher voltages. The main suppliers of HV subsea cable are shown in Table 5.1.

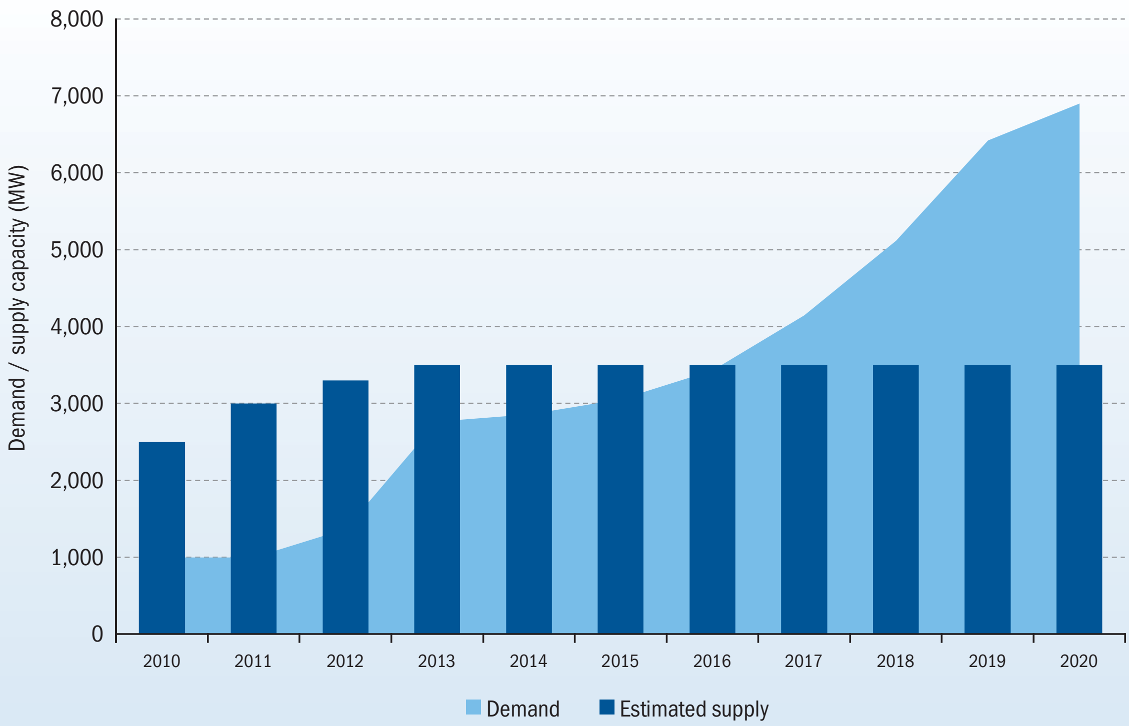
It is estimated that current capacity of the existing HV subsea cable suppliers is around 1,000 km of cable run per annum for HVDC and 700 km per annum for HVAC[18]. This would satisfy the demands of around ~3-3.5 GW of offshore wind capacity per annum. Figure 5.1 presents an analysis of the projected supply capacity against demand for the current decade. This shows that from 2015 there could be a significant lack of supply capacity.

TABLE 5.1 MAIN EUROPEAN SUPPLIERS OF HV SUBSEA CABLE (EXPORT CABLES)

| Supplier | HV export cables | Manufacturing location | Offshore wind experience |
|---|---|---|---|
| ABB | Typically 150 kV | Karlskrona, Sweden | Established supplier |
| Nexans | Typically 150 kV | Halden, Norway | Established supplier |
| Prysmian | Recently developed 245 kV | Naples, Italy | Established supplier |
| NKT | Recently developed 245 kV | Cologne, Germany | New entrant (to HV market) |
| General Cable | Recently developed 245 kV | Nordenham, Germany | New entrant (to HV market) |

[18] BVG Associates, "Towards Round 3: Building the Offshore Wind Supply Chain", 2010.

FIGURE 5.1 ANALYSIS OF SUPPLY AND DEMAND FOR HV SUBSEA CABLES




Source: GL Garrad Hassan

The lead time associated with bringing new subsea cable capacity online is significant – around three to four years. Therefore it follows that significant investment decisions in new capacity need to be made by the end of 2011 if a bottleneck situation is to be avoided in the middle of the decade.

Expansion is most likely to come from existing subsea cable suppliers setting up new production facilities. Current manufacturers of MV subsea cables may consider expanding their capabilities to supply HV subsea cables.

The supply base for MV subsea cables for array cabling is considerably more diverse and has attracted diversification from the offshore oil & gas sector which is the other key user of these products. There may be a need for some expansion of manufacturing facilities, but this is not currently seen as a critical issue. If wind farm designers seek to make the transition to higher voltages for the electrical system within the wind farm, as discussed earlier (i.e. 45 or 66 kV), there is likely to be a shortage of manufacturing capacity for these higher-voltage array cables.

In the coming decade, the offshore wind sector is expected to become the predominant market for both MV and HV subsea cables, but additional production capacity, especially for HV cables, appears to be an urgent requirement.

## Electrical switchgear and transformers

If higher voltages become widely accepted for array cables connecting turbines to each other and to the offshore substation, that is, the 45 kV or 66 kV options noted above, there will be a need for expanded production facilities for switchgear to operate at these voltage levels. This is not thought to present any major difficulty.

Supplies of transformers at these voltage levels are likely to be restricted initially, until sufficient volume builds up in the offshore wind industry to justify expanded production facilities for this niche market.

## Offshore substation suppliers

Several companies have established themselves as providers of complete offshore substation topsides: see Table 5.2. As yet, however there is little standardisation in substation ratings (MW) or configurations.

TABLE 5.2 MAIN SUPPLIERS OF OFFSHORE SUBSTATIONS TOPSIDE

| Supplier | Offshore wind experience |
|---|---|
| ABB | Established supplier |
| Alstom Grid (formerly Areva T&D) | Established supplier |
| Siemens Energy | Established supplier |
| C&G / Fabricom | New entrant |

A handful of other suppliers are actively pursuing this market, although the players mentioned above can be considered as the core of the supply-base.

The large MV/HV transformers around which offshore substations are designed and built may have delivery times of up to three years, depending on demand elsewhere. Compared to the requirements of other industries, the requirements for offshore wind are likely to be small.

## HVDC suppliers

HVDC technology is developing rapidly. Standard technology is based on current source converters, which is familiar and has a long track record, but some technical disadvantages. Developments in power semiconductor technology now allow voltage source converters at large scale. This technology is more expensive, and also has higher converter losses, but has other technical advantages which are particularly relevant for offshore wind farms. Voltage source technology is expected to dominate.

Until recently there was only one established supplier of this technology, but now, there are at least two other major players developing competing technologies. The emergence of significant offshore wind capacity in the German Bight, where "collectivised" HVDC connection is being driven by the grid operator (Tennet Offshore GmbH), is a key driver for this technology, with UK Round 3 capacity as a secondary future market.

The major components are the silicon power-electronic devices themselves. These are produced by companies producing a wide range of electronic devices, and so substantial supply-chain constraints are not expected.

## Drivers and constraints

The major driver is reduction in cost. As noted above, the major electrical items are relatively mature, and so cost reduction is likely to come from:

- Cable installation: availability of better vessels and tools, including reducing risk and increasing weather capability.
- Offshore substations: standardisation, volume production, better installation methods and optimisation of support structures.
- HVDC: competition, volume production.

The main constraint that is foreseen is the supply of subsea cable, especially at higher voltages, as discussed above.

Regulatory issues may also become constraints. In particular, it will be necessary to develop clear regulatory procedures for dealing with offshore wind farms with connections to more than one electricity market or more than one network operator, where the connections may be used as an interconnector.

Another regulatory issue to solve is the difficulty of achieving an optimal interconnection arrangement for multiple wind farms, where these are developed by different owners on different timescales.

In some locations, constraints on available routes for cables may become significant, especially where the cable reaches the shore – known as the “landfall”.

Permitting issues for onshore network reinforcements may become a constraint, as with large-scale onshore wind projects.

## 5.3 Announcements and future technical trends

Substantial deployment of HVDC technology is expected, which should lead eventually to cost reductions.

Multi-terminal HVDC systems require demonstration to increase investor confidence and "provenness". Also, equipment from different suppliers will need to be operated together given the potential for regional HVDC hubs and ultimately, the Supergrid. With the roll-out of several German offshore wind projects followed by Round 3 developments in the UK, these requirements will become increasingly pertinent in the next five years.

As noted above, the use of HVDC opens up radical options for design of the wind farm electrical system and the turbine electrical system: developments in this area are likely to be slow, because they require wind turbine manufacturers and wind farm electrical system designers to work together. Unless there are substantial advantages, project developers and funders are likely to be wary of radical changes.

It is possible, and perhaps likely, that higher voltages will become normal for the connections within the wind farm. The recent announcement from Vestas of a 66 kV option within their flagship offshore turbine is a step in this direction.

### ► KEY FINDINGS

- **There is a limited range of suppliers for HV subsea cables, a situation compounded by high investment costs and long lead times for new capacity.**
- **Significant advances are being made in the use of HVDC with a wider range of suppliers and there is future potential for multi-terminal capability.**
- **There is a move towards considering higher voltages for connections between turbines within an offshore wind farm.**
- **Substantial additional cable manufacturing capacity will be needed. Without new capacity a shortage of HV subsea cables is looming. Other equipment is generally drawn from much larger transmission and distribution (T&D) industries which are relatively unconstrained, with the exception of HV transformers, where delivery times are set by general world demand.**

Photo: Eon

# 6 VESSELS

# 6.1 Vessel use at offshore wind farms

A natural consequence of developing wind farms offshore is the need for suitable vessels for transportation and from which to perform the various activities during the development, construction, operation and decommissioning stages of a wind farm life.

Depending on the operation in question, these needs range from the simple use of basic, generic vessels currently used in other industries without the need for further modification, to bespoke, highly expensive vessels designed for specific installation tasks. Given the expected steep growth in the European offshore wind energy market over the next ten to twenty years, and given that sites will move into ever more challenging conditions, meeting the demand for the highly specialised installation vessels will be a key dynamic in the offshore wind industry supply chain. Lead times for such vessels from order to delivery are 24 to 36 months with longer for more specialised designs. These times fit relatively comfortably into a typical timetable for the development of an offshore wind farm, although experience has shown that time should be set aside for possible delays.

### Site development

The main functions of the vessels during the development stage include carrying out of the surveys required for an Environmental Impact Assessment, geophysical surveys and geotechnical surveys (including cable route survey). Of these, the latter have the most onerous requirements with the need to provide a stable platform from which to take borehole samples. Installation vessels such as jack-up types can be used for this task although the specifications for geotechnical surveys are greatly lower than those for substructure or turbine installation and it will often be uneconomical to use the same vessel for all these tasks. This kind of lower-spec jack-up vessel can also be used to perform meteorological mast installation.

### Site construction

It is during the construction phase that the greatest demands are made on vessel types, specifically during the installation of substructures and turbines. The main points of consideration when selecting vessels for these tasks include: ship performance, cost, lift capacity, precision when lifting, vessel dimensions, metocean (meteorological and oceanographic) limitations, technical risk and commercial availability. Other lower specification vessels are used to transport equipment and personnel to the site. Indeed one developer reported using over a hundred vessels at various times during the construction of a particular project, demonstrating that the main installation vessels are vastly outnumbered by the huge flotilla of support craft required.

To date, over thirty vessels consisting of a number of variant vessel designs have been utilised for substructure or turbine installation purposes. These include: jack-up vessels, leg-stabilised crane vessels, heavy lift cargo vessels, semi-submersible heavy lift vessels, shearleg cranebarges and floating dumb barges with cranes. A brief description of these different options is provided in Section 6.3.

### Site operations

Crane vessels will also be required during the operational phase of a wind farm life to perform major turbine repairs although often this will be achieved with lower specification vessels than those used above for installation purposes. Further significant demand comes from craft to transport technicians to and from site for O&M purposes. Traditionally 12-passenger work boats have been used for this task although for future projects further from shore, larger vessels as well as helicopters are increasingly being employed.

Furthermore, interest in using “floatels” or “motherships” for the operation and maintenance of projects further than 50 km from port is gaining momentum, with some major providers proposing this method during the commissioning and operational phases of a project. Crews live aboard large floating vessels located within the vicinity of the wind farm, typically adopting a two-week on, two-week off shift as practiced in the oil and gas industry. Motherships in particular would appear to have an advantage due to their ability to deploy multiple small, agile craft during periods of benign weather conditions, or transit to the turbine themselves and use a specialist access system during periods of more severe conditions. The size of floatels or motherships not only allows technicians to live near the vicinity of the wind farm for extended periods of time, but also provides sufficient deck space and stability to mount heave-compensated access systems which are generally too large for standard work boats. In this manner, time available for plant maintenance can be maximised by reducing transit time and enabling access in rougher sea conditions.

Fixed structures have also been proposed for offshore accommodation in the vicinity of the project however, these can have significant construction and installation costs associated with them. One approach which may allow these costs to be reduced is to combine the accommodation platform with the offshore substation however, this has numerous issues connected with it, such as living in close proximity to HV equipment and loss of heavy-lift access to substation components. Horns Rev 2 in Denmark is currently the only operational offshore project to utilise a fixed offshore accommodation platform and this is located adjacent to the substation on a separate foundation structure. A key limiting factor for fixed offshore structures is that whilst shift durations may be maximised by reduced transit times, accessibility is still limited by the capability of the vessels used to transport technicians to and from the turbines.

### Site decommissioning

Similar vessels to those used for installing wind turbines will be required for their removal during decommissioning or repowering of offshore wind farm sites.

## 6.2 Estimation of future demand

Given that no significant decommissioning work is expected prior to 2020, the supply of installation vessels for offshore wind projects over the next decade can be categorised into three main types of operation:

1. ***Wind turbine foundation installation:*** generally undertaken from a jack-up type vessel with some potential for utilisation of floating barges;
2. ***Wind turbine erection:*** exclusively from jack-up type vessels; and,
3. ***Wind turbine repair operations:*** where jack-up vessels are required for major operations.

Future supply-side capacity has been projected for four scenarios:

- ***Firm capacity,*** consisting of existing dedicated offshore wind installation vessels, those which are under construction or contract as well as some vessel availability from other industries (coastal engineering and offshore oil and gas);
- ***Low case,*** consisting of firm capacity with two additional new bespoke dedicated offshore wind installation vessels becoming available from 2015;
- ***Mid case,*** consisting of firm capacity with the addition of up to five new bespoke dedicated offshore wind installation vessels becoming available by 2020;
- ***High case,*** consisting of firm capacity with the addition of up to 10 new bespoke dedicated offshore wind installation vessels becoming available by 2020.

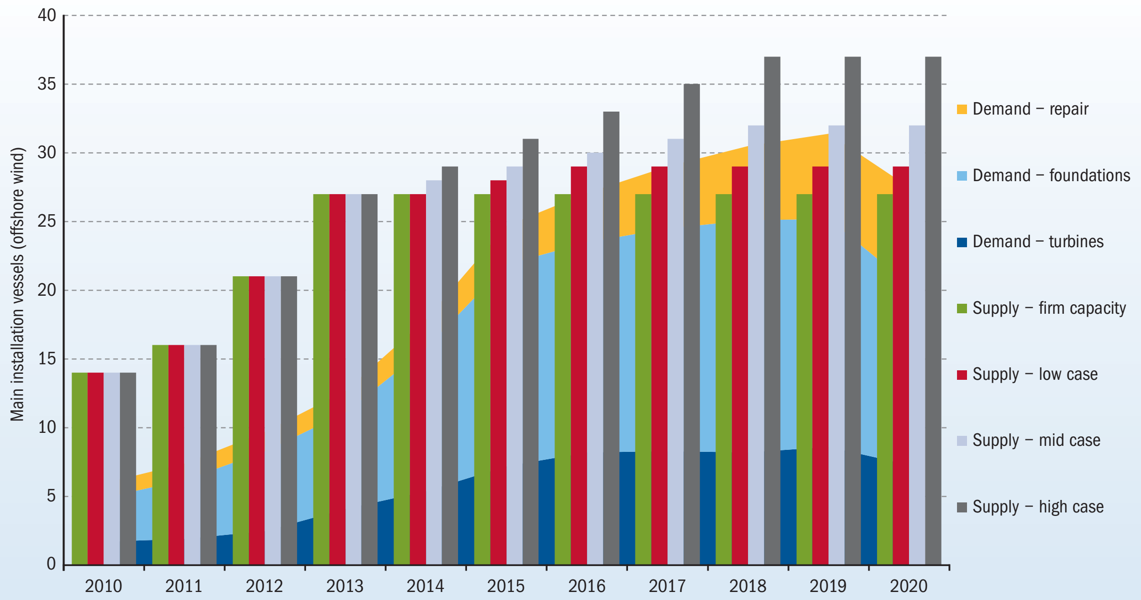
Of these scenarios, the mid case is considered to be the most likely and realistic.

Other key activities include specialist vessels for the installation of export cables, and inter-array cables and heavy lift vessels for the installation of offshore substation foundations and topsides. Consideration of the slightly less critical operations is excluded from the current assessment.

Some vessels active in the oil and gas industry have been carrying out work on offshore wind farm sites. Examples include Seaway Heavy Lifting's Stanislav Yudin performing monopile and substation installation, and Seajacks' new-build vessels Kraken, and Leviathan, specified with both wind farm and oil and gas work in mind, being chartered for wind turbine installation. Seaway Heavy Lifting's new 5,000 tonne lift crane vessel, Oleg Strashnov, and Master Marine's Edna, and Service Jack 2, may well also make the transition, and are regularly considered for work. The volatile nature of the price of oil will probably be the principal driver defining which industry makes most usage of such vessels.

Projected supply and demand for the principal vessels for installation of foundations and wind turbines are compared graphically in Figure 6.1 below.

FIGURE 6.1 PROJECTED OFFSHORE INSTALLATION VESSEL SUPPLY AND DEMAND (VESSELS PER ANNUM)




Source: GL Garrad Hassan

In general, it can be seen that supply is expected to significantly exceed demand up to 2015 although potentially shortages could occur for specific vessel categories such as cable laying. In the latter half of the decade, as demand ramps up, there appears to be potential for a significant bottleneck depending on the extent of new capacity coming on line. The lead time associated with a new main installation vessel is 24 to 36 months. However, the potential for using resources from depressed oil and gas and coastal engineering sectors should not be underestimated, although increasing oil and gas decommissioning activity in the North Sea may somewhat constrain the availability of labour from this source. Overall, the analysis indicates a good balance between demand and supply in the short to medium term followed by the potential for supply constraints.

## 6.3 Installation vessel types

The following section provides an introduction to the main vessel types used for installation at offshore wind farms.

FIGURE 6.2 EXAMPLES OF INSTALLATION VESSEL TYPES


Jack-up vessel
Excalibur


Leg-stabilised crane vessel
A2Sea Sea Power at Lilligrund


DP2 Heavy lift cargo vessel
Jumbo Javelin


Semi-submersible heavy lift vessel
Thialf at Alpha Ventus


Shearleg cranebarge
Rambiz


Floating dumb barge with crane
Haven Seaforth

## Jack-up vessels

Jack-ups are capable of most roles on wind farms sites, and their stability means that they dominate turbine installation. Smaller vessels with longer legs are likely to find favour for the pre-piling of jacket foundations.

Early wind farms used jack-up vessels for virtually every task. This was largely because wind farms were smaller than those under construction at present, and because it was most economical to use one versatile vessel for all tasks, than to mobilise a number of customised vessels to carry out specific roles. At larger future sites, greater specialisation with site-optimised vessels can be anticipated.

The stable base provided by a jack-up is equivalent to working onshore, and onshore lift specifications can be used (except when lifting from a floating plant, or when some other dynamic lifting is required). This makes them ideal for installing the nacelles and blades of turbines, which are the most precise lifts required on a project, and they effectively dominate this area of work. If there are vessel shortages in the next decade, jack-up vessels will probably be restricted to turbine installation work, and attract a premium, while floating solutions will be used for the majority of other activities.

The ever increasing water-depths and foundation and turbine weights mean that the vessels which carried out the first installations, in water depths of less than 25 m, are needed less frequently. A small number of existing vessels with longer legs will be joined by new build vessels, with the capacity to carry out the larger 5 to 7 MW class turbine installation work in waters from 30-45 m deep. More vessels are needed that are capable of operating in the large areas of the German Bight and UK Round three sites which are over 45 m in depth. However, there have been at least some announcements of new build (see 6.4).

## Leg-stabilised crane vessel

So far only two vessels of this class have entered the wind farm installation fleet and both are owned by A2Sea – Sea Energy and Sea Power. They were standard ships before they were retro-fitted. This adaption has proved a versatile reduced-budget installation craft, which was ideal to install wind turbines in the shallower sites of the early wind farms.

The origins of the vessels mean that they have good hydrodynamic hull forms and transit rapidly and economically. This has allowed some sites to collect turbines from the manufacturer's load-out facility and deliver them direct to site in reasonable cycle-times, with the commensurate saving of the costs of a construction mobilisation and storage port. It has also won them feeder vessel duties.

The 24 m maximum working water depth means that their future is limited. They may well be used for turbine, or possibly transition piece installation in shallow areas of future sites, but they are more likely to find ongoing work in the O&M vessel fleet for the existing wind farms which they helped to install, and where they have the leg-length to operate.

## DP2 heavy lift cargo vessels

Cargo vessels deliver loads rapidly and cheaply around the world, and by fitting heavy cranes to the vessel, they can collect and deliver cargo from ports where there is not enough crane capacity. Being ships, their hull-form is far sleeker that the majority of crane vessels.

With their high transit speeds, heavy-lift capacity, and lower day-rates than other equivalent lift-capacity vessels, it is likely that this type of vessel will see a greater role for future offshore wind projects.

Heave-compensation systems have been retro-fitted to these vessels in some instances, and offshore vessel-to-vessel transfers have been performed in relatively rough seas. This suggests they could find favour as feeder-vessels as wind farms move further offshore.

These vessels have been used successfully by the oil and gas industry for a wide variety of offshore installation duties. Pictured in figure 6.2 is a jacket installation, during which the vessel carries not only the jacket structure but also the pin piles as well as piling and grouting equipment. Likewise tripods would appear to be another potential application. The two-crane tandem lift configuration largely avoids problems with the limited under-hook height which many single-crane vessels struggle with when dealing with deeper water structures.

However, these vessels lack the stability necessary to install wind turbines, so jack-ups will continue to dominate in this role.

## Semi-submersible heavy lift vessel

This type of vessel has been developed by the oil and gas industry to carry out placement of oil rig modules in harsh offshore conditions. The hull can be flooded, greatly increasing the deadweight of the craft, and it is designed so that this ballasting operation dramatically lowers the period of roll of the craft. This change in vessel dynamics effectively “tunes out” the effect of the waves on the craft, and therefore the problem of inopportune wave-periods leading to resonance can be avoided. The vessel is effectively motionless in the water, unaffected by all but the biggest waves. Clearly the huge structure presents a large surface to the wind, but again, the overall stability is such that even delicate lifting operations can be carried out in deep water during relatively strong wind conditions.

The use of the Thialf crane at Alpha Ventus due to the particular circumstances of the project notwithstanding, it is unlikely that this vessel type will be used on offshore wind farms for turbine or foundation installation in the future. Day rates for this exorbitantly expensive class of vessel are prohibitive to the offshore wind installation market in general.

Occasionally there could be a role for these craft in substation installation.

## Shearleg cranebarge

The shearleg barge is fundamentally a very heavy-lift configuration of a dumb barge. The lifting frame is permanently attached to the deck, and most have some form of skid-mounted or containerised propulsion unit fitted to the deck. This sort of vessel is mainly designed for heavy-lifting in sheltered waters, but the larger vessels (over 500t) usually have some limited capability to operate offshore, in varying levels of sea-state.

Vessels of this type are available in northern European waters and have a capacity of up to 3,300t. They can transit in seas with significant wave heights of over

1 m, and carry out lifting operations in seas with waves of between 0.5 and 1 m high depending on the size of the craft.

Since lifting is always over the “end” of the barge, shearleg cranes require less beam (width) than crane vessels of an equivalent lift capacity which can carry out fully-rotating lifts. This is a major advantage in ports with narrow lock-gate widths to wet-basins.

Given that piling hammers are far lighter than the piles that they drive, a role is emerging for shearleg crane vessels to deliver monopiles, jackets or tripods to jack-up piling vessels pre-stationed at the foundation site, and for the shearleg to lower the foundation ready for piling.

Recent experience on one site led to programme delays because the metocean limits on seabed-placement of tripod foundations by the shearleg installation vessel meant that the placement could only be carried out in very fair weather conditions. It is unlikely that shearlegs will be used so far offshore in anything but summer weather windows.

The narrow beam of the vessel can on occasion allow it access to ports which even relatively small jack-ups cannot enter due to width restrictions.

## Floating dumb barge with crane

The cheapest floating lift-craft is formed by placing a land-based crane on to a dumb barge. This is the most common type of vessel used to support river, coastal and estuarine marine construction projects.

Dumb barges are the most basic of craft, and any additional equipment to enhance their capability must be added to the deck of the barge. The stability of this configuration of craft means that it is unsuitable for the role of the principal installation vessel. However, craft of this type will often be used for a multitude of small roles on any offshore construction site, and may fulfil the role of a feeder vessel – but offshore unloading will most likely be carried out by the main installation vessel in all but the most benign sea conditions (such as the Chinese inter-tidal sites).

## Current marketplace

As described in Section 3, depending upon the contracting structure employed, marine contractors typically hold responsibility for the installation of substructures, wind turbines and substation foundations and topsides. Cable installation is more commonly undertaken under a separate contract. A selection of leading European marine contractors who are active in the offshore wind sector is presented in Table 6.1.

TABLE 6.1 SELECTION OF INCUMBENT AND NEW ENTRANT MARINE CONTRACTORS

| Company | Main vessels | Comments |
|---|---|---|
| A2Sea | Sea Energy, Sea Power, Sea Jack, Sea Worker | Leading established supplier – substantial track record. |
| MPI Offshore | Resolution, Adventure, Discovery (C) | Leading established supplier – substantial track record. |
| Ballast Nedam | Svanen | Leading established supplier – substantial track record. |
| Scaldis | Rambiz | Leading established supplier – substantial track record. |
| Seaway Heavy Lift | Stanislav Yudin, Oleg Strashnov | Diversifier from offshore oil and gas. Heavy lift specialist. |
| Seajacks | Kraken, Leviathan, Zaratan (C) | Jack-up specialist targeting North Sea offshore wind and O&G. |
| Geosea | Buzzard, Goliath, Neptune (C) | Diversifier from coastal engineering/ drilling. Track record established at Thornton Bank and Alpha Ventus. |
| Fred Olsen | Windcarrier 1 (C), Windcarrier 2 (C) | New entrant with bespoke new build vessels. |
| Swire Blue Ocean | Unnamed (C) | New entrant with bespoke new build vessel. |

"(C)" denotes vessel under construction or contract.

Just over thirty vessels have been used in foundation or turbine installation roles in the offshore wind farms to date. Table 6.2 gives details of each of these vessels.

TABLE 6.2 VESSELS USED TO DATE FOR OFFSHORE WIND FARM INSTALLATION ACTIVITIES

| Name | Owner | Max lift (t) | Type | Length (m) | Laden draft (m) | Build year | Self-propelled (y/DP/n) | Max for legs depth (m) |
|---|---|---|---|---|---|---|---|---|
| 1. Buzzard | DEME | 750* | Towed jack-up | 43 | 2.97 | 1982 | n | 30 |
| 2. Eide 5 | EIDE Marine Services | 1,800 | Shearleg Cranebarge | 30.5 | 2.18 | 1971 | n | n/a |
| 3. Fen Jin | n/a | 500 | Shearleg crane | 100 | 4.8 | 2006 | y | n/a |
| 4. Excalibur | Fugro Seacore | 220 | Towed jack-up | 60 | 2.55 | n/a | n | ~40 |
| 5. Goliath | DEME | 750* | Towed jack-up | 55 | 3.6 | 2009 | n | 40 |
| 6. GPS Atlas | GPS Marine | 400 | Shearleg Cranebarge | 46.86 | 3.28 | 1967 | y | n/a |
| 7. JB114 | Jack up Barges BV | 300 | Towed jack-up | 55.5 | 3.6 | 2009 | n | 40 |
| 8. JB115 | Jack up Barges BV | 300 | Towed jack-up | 55.5 | 3.6 | 2009 | n | 40 |
| 9. JB116 | Jack up Barges BV | 80 (300+) | Towed jack-up | 67.5 | 3.9 | 2010 | n | 45 |
| 10. Jumbo Javelin | Jumbo Shipping | 1,800 | DP2 Heavy Lift Cargo | 144.21 | 8.1 | 2004 | y | n/a |
| 11. Krake n | SeaJacks | 300 | DP Propelled Jack-up | 76 | 3.65 | 2009 | DP | 48 |
| 12. Leviathan | SeaJacks | 300 | DP Propelled Jack-up | 76 | 3.65 | 2009 | DP | 48 |
| 13. Lisa A | Smit | 600 | Towed jack-up | 72.65 | 4 | n/a | n | 38 |
| 14. Matador 3 | Bonn and Mees | 1,500 | Shearleg cranebarge | 70 | 5.8 | 5.8 | y | n/a |
| 15. Muhibbah JB1 | Muhibbah Marine | 270 | Towed jack-up | 48.79 | 3 | 1960 | n | ~30 |
| 16. MPI Resolution | MPI Offshore | 300 (600) | Jack-up crane vessel | 130 | 4.3 | 2003 | y | 35+ |
| 17. Odin | Hochtief | 300 | Towed jack-up | 46.1 | 3.25 | 2004 | n | 45 |
| 18. Pauline | Besix | 200 | Towed jack-up | 48 | 2.5 | 2005 | n | 30 |
| 19. Rambiz | Scaldis | 3,300 | Shearleg cranebarge | 85 | 5.6 | 1976 | y | n/a |
| 20. Sea Energy | A2Sea | 400 | Leg-stablised vessel | 91.76 | 4.25 | 2002* | n | 24 |
| 21. Sea Jack | A2Sea | 1,300 | Towed jack-up | 91.2 | 3.8 | 2003 | n | 30 |
| 22. Sea Power | A2Sea | 400 | Leg-stablised vessel | 91.76 | 4.25 | 2002* | n | 24 |
| 23. Sea Worker | A2Sea | 400 | Towed Jack-up | 55.5 | 3.6 | 2008 | n | 40 |
| 24. Stanislav Yudin | Seaway Heavy Lifting | 2,500 | Heavy lift vessel | 185 | 9 (13) | 1985 | n | n/a |
| 25. Svanen | Ballast Nedam | 8,700 | Heavy lift vessel | 102.75 | 6 | 1991 | n | n/a |
| 26. Taklift 4 | Smit | 2,400 | Shearleg crane | 83.2 | 6.02 | 1981 | y | n/a |
| 27. Taklift 7 | Smit | 1,600 | Shearleg crane | 72.56 | 4.9 | 1976 | y | n/a |
| 28. Thor | Hochtief | 500 | Towed Jack-up | 70 | 3.5(7.4) | 2010 | n | 50 |
| 29. Titan 2 | Atlantic Oilfield Services | 400 | Self propel'd jackup | 51.97 | 4.2672 | 2008 | n | 60.96 |
| 30. Thialf | Heerema | 14,200 | Semi-sub HLV | 201.6 | 11.8 - 31.6 | 1985 | DP | n/a |
| 31. Wind | De Brandt | 200 | DP2 jackup | 55 | 2.4 | 1995 | y | 30 |
| 32. Wind Lift 1 | BARD | 500 | DP2 Jack-up vessel | 93 | 3.5 | 2010 | DP | 45 |

Source: GL Garrad Hassan

# 6.4 New build and announced vessels

A perceived shortage of suitable vessels capable of carrying out installation work for UK Round 3 and German offshore wind projects has led to a spate of new-build commissions. Specifications for these vessels were driven by the quantities of turbines and foundations that were expected to be installed, and the water depths and climatic conditions of the proposed sites.

Key trends and announcements include:

- Leading developer, RWE Innogy has decided to purchase its own vessels, Victoria Mathias, and Friedrich Ernestine, presumably for the added supply chain security this provides.
- Fred Olsen have similarly joined a joint venture which has won UK leases, and have opted to purchase vessels, but this is less surprising given their history in vessel ownership and marine contracting.
- Seajacks have been intending to increase their fleet for some time, and have not only commissioned new-build Zaratan, but have announced their intention to purchase a similar vessel shortly.
- Siemens recently took a 49% stake in A2Sea, and they have announced the long awaited Sea Installer order.
- Jack-up Barges have ordered a large number of jack-up vessels over the last few years. While approximately half have remained in their fleet, vessels have regularly been sold after completion.
- MPI Offshore bought the boat Resolution from the administrators of Mayflower, and has operated her successfully for several years. She was upgraded with a 600t crane in the winter of 2010/2011, although this may still be inadequate for the majority of UK Round 3 areas. MPI have therefore ordered two larger vessels, and as the first of the new generation of custom offshore wind farm vessels to arrive on the market in 2011, their progress will be keenly monitored.
- Van Oord has purchased two wind farm installation vessels which are to be built in Germany.
- An unknown buyer has ordered a Gusto MSC designed NG 9000 vessel, being built at Drydocks World, publically stating that it will be sold to the offshore wind industry. This will probably attract keen interest, arriving on the market as it does at a peak time for contracting activity for UK Round 3 development and a number of German wind projects. The investment of €100 m+ by entrepreneurs in an industry is a sign of the view that the industry is expected to take off in the near future, and will have been noted by many other vessel owners.
- Several deepwater installation methodologies are under development which make use of floating vessels for sites beyond the operational limits of jack-up vessels.

## ► KEY FINDINGS

- **The industry is seeing increasingly specialised vessels for offshore wind generally and in the specific tasks performed on an offshore wind site. Nevertheless jack-up designs are expected to continue to dominate vital installation procedures and particularly turbine erection.**
- **There is some evidence of strategic investment by developers to secure vessels. However the near-term relaxing of supply constraints may stem this movement.**
- **The supply chain outlook is strong through to 2015 with several new builds, increased levels of competition and supply likely to meet demand. Through the latter half of the decade increasing pressure may return if no further new investment comes forward.**


Photo: C-power

# 7 PORTS

# 7.1 Background: the role of ports in offshore wind development

The preceding chapters have provided an overview of the major supply chain components for the development of offshore wind farm projects as well as contracting structure between the players involved. In order to facilitate this development, the availability of suitable ports is a major logistical consideration for the industry. Within the next ten years, manufacturers will have moved closer to, or located outlets at, port facilities. This will require an integrated approach towards offshore wind, based on a strong manufacturing capacity, testing facilities, demonstration sites, research and training facilities, supported by dedicated harbours.

The forecast acceleration of wind turbine deployment in northern Europe has been identified by many ports as a significant opportunity to counter-balance the economic downturn hitting traditional activities. This is particularly true of those with a history in the offshore oil and gas business in areas where activities relating to exploration and production are expected to be in decline over the next two decades.

Ports can effectively be divided into two types: manufacturing ports and mobilisation ports. The use of the latter as a distinct port is dependent upon the decision to deliver turbines, substructures or sub-assembled components directly to the offshore wind farm site or not. A second decision is whether to transport components from the port on the main installation vessel itself, or to use feeder vessels for ferrying components between port and site before transferring them offshore for actual installation. These decisions and the corresponding approaches are summarised in Figure 7.1.

The decision over which approach to take will be dependent upon cost-benefit analyses. Mobilisation ports may be economically advantageous where the offshore wind site is located at some distance from the manufacturing hubs but not in an area with significant enough activity to justify long-lasting local supply chain development. A further driver can be the difference in labour costs between manufacturing locations, which could offset the added transportation costs.

It is also important to consider the implications for a port owner of the approach taken by players involved in the offshore wind industry. Manufacturing facilities are likely to be created with the intention of providing component supply over the long-term to numerous projects. In contrast, the use of a port for purely mobilisation purposes is shorter lived. In the latter circumstances a port owner will need to balance any investment in dedicated facilities for offshore wind development with demands from other business streams and the likelihood of a consistent revenue stream.

Further opportunities for ports servicing the offshore wind industry occur post-construction during project operations with the provision of O&M activities, although requirements are less demanding than during construction. Small 12-passenger workboats have traditionally been used to transport technicians between port and site however, as projects move further offshore, larger vessels and helicopters are likely to be increasingly employed, with the requirement of port-based support infrastructure.

New concepts, such as the Dutch ‘harbour at sea’ are also being researched for servicing future large offshore arrays implemented far from shore. It consists of multi-purpose platforms which could allow sailing times to be reduced for installation and maintenance.

FIGURE 7.1 ALTERNATIVE APPROACHES TO WIND TURBINE INSTALLATION


**Key to maps:**
M = Manufacturing site
MP = Mobilisation Port
WF = Wind Farm

= Transportation/Feeder vessel
= Installation vessel

## 7.2 Port requirements and current status

Depending upon the role played by a particular port in the construction and operation of offshore wind farms, different requirements will be placed upon their technical and logistical capabilities.

Some technical requirements, in terms of maritime limitations, derive from the physical dimensions of the vessels used for both the construction phase, or used for transportation as logistical elements of the supply chain, where consideration is needed of the:

- Vessel beam (width);
- The draft laden and un-laden;
- The overall length of the vessel (to a lesser extent);
- The overhead clearance required.

Other hard technical limits result from the dimensions and weight of wind farm components, at the various stages of assembly at which they are transported between manufacturing and construction facilities, where consideration is needed of the:

- ***Physical size*** range of foundation and turbine components, for each project to be supported from each port;
- ***Length, breadth,*** and height required – not only the component itself, but the area surrounding it in any storage areas to allow access for the lifting and other mechanical handling plant required to move it;
- ***Numbers of*** components that are likely to require storage during conventional project programmes.

As noted above, there are different infrastructure requirements for ports with manufacturing facilities as opposed to those used purely for mobilisation and construction purposes. Even when the same components are loaded onto the different vessels required, different crane specifications and therefore different quayside loadings are needed. A port used purely as a mobilisation port – as outlined above – will only take on the construction requirements whereas if no mobilisation port is used, the port must be capable of fulfilling both manufacturing and construction requirements.

For each type of item being produced or installed it is therefore necessary to consider what port infrastructure is needed during both the manufacturing and the construction phases, and in some cases (particularly for jacket foundation structure sub-assemblies) there are intermediate requirements during possible relocation of sub-components, between specialised manufacturing facilities.

However, even if requirements differ, the following definition of a suitable construction port for the short to long term period – based on work undertaken by EWEA's Offshore Wind Industry Group (OWIG) – applies:

- The quayside should be long enough to accommodate two to three vessels. Some vessels are more than 140 m long and need to be manoeuvred. Considering the growing size of wind turbines, future vessels may be up to 250 m long. Components should be able to be unloaded from cargo vessels or barges while the installation vessel is loading new structures. The quayside length should therefore be over 300 m, but no longer than 1 km.
- The quay should be able to bear weights of approximately 15-20 tonnes/$m^2$. Currently, costly load spreading techniques allow the crane(s) to operate on the different quays. The weight-bearing capacity of the quay should match the capacity of the vessels, in the 10-20 tonnes/$m^2$ range. Reinforced seabed along berth is recommended to ensure stability of the jack-up barge during loading operations.
- The quay should be designed to allow jacking up right next to the quayside in order to use both the boat's own crane and the crane on the harbour. The seabed capacity near the pier should also be sufficient. The quay should be designed to avoid the dents made by the jack's legs weakening its structure.

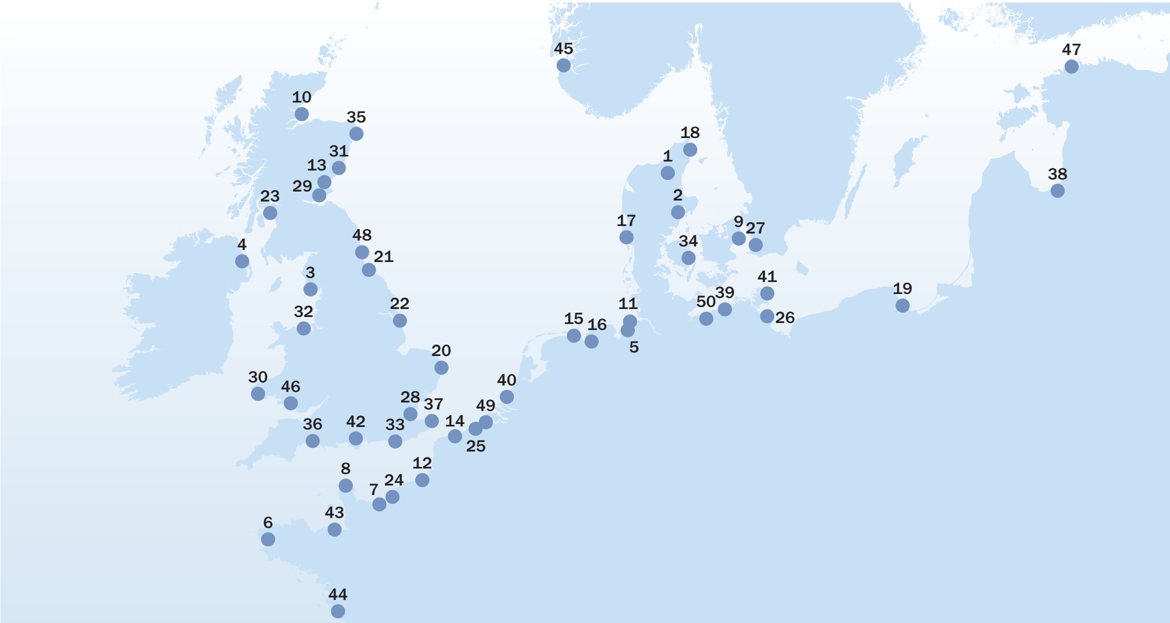
- If possible, a crane or a gantry crane of 1,000 tonnes should be used. For the moment, cranes of 750 tonnes on the quay side, and a complement when needed (floating crane) is an option. Roll-on roll-off capability (meaning access ramps are used for loading) and trailer options should be available onsite to transport items including self propelled trailers.
- In terms of access, the facilities must be available during the whole construction phase. No restrictions should apply to vessels accessing the harbour, such as tide, locks or water depths. Access should be permanently possible for smaller vessels (pontoon bridge, barge etc), for heavy/oversize trucks and/or by rail. For O&M harbours, license/approvals for helicopter transfer could be needed.
- A water depth of more than 10 m is recommended, as the biggest distance between the lowest point of a ship's hull and the surface of the water (known as a "draught") in the new installation vessel designs is 9-10 m. The future large vessels which will transport a number of wind turbines and foundations for far offshore applications will require deep sea ports. A minimum draught of 12.5 m is recommended for multipurpose vessels supplying wind turbine elements from distant production sites to the assembly site.
- The waterway should allow the transportation of a full rotor 150-200 m in diameter, to accommodate 5/6 MW turbine blades, and future developments.
- An area of storage of 25 ha for installation harbours should be made available; if manufacturing capacities are developed this should be as much as some 50 ha. Additional storage space and warehouse facilities are also required in case part of the project is delayed, and components need to be stored.
- Ports need to have permits for 24/7 labour, and authorisations for welding, painting on site, or finalising small pieces during the final assembly of foundations for instance.
- Information technology, independent service providers and security services need to be available, as do access to heavy equipment such as cranes and enough parking space (> 50 places).
- Ports and terminals need to comply with health, safety quality and environmental rules and requirements which are standard in the offshore wind industry.

Concerning operation and maintenance, the specific requirements include:

- Full time access for service vessels and service helicopters. This is particularly relevant for the colder areas in northern Europe where ice is a major challenge. If the ports are not ice-free during the whole year the use of an ice-breaking vessel should be ensured;
- Full time and safe access for technicians and service personnel;
- Fresh water, electricity and fuelling facilities;
- General waste disposal and waste water disposal;
- Loading/unloading facilities and transport equipment.

The following diagram provides a map with the location of a selection of ports in northern Europe which have been used as manufacturing and/or mobilisation ports for offshore wind farms to date, or identified as possible future bases for operations.

## FIGURE 7.2 EXAMPLE OF EUROPEAN PORTS FOR OFFSHORE WIND CONSTRUCTION




| No | Port | MP[1] | M[2] | OWE[3] |
|---|---|---|---|---|
| 1 | Aalborg | ● | ● | ✓ |
| 2 | Aarhus | ◎ | ◎ | ✓ |
| 3 | Barrow | ● | ◎ | ✓ |
| 4 | Belfast | ● | ◎ | ✓ |
| 5 | Bremerhaven | ● | ● | ✓ |
| 6 | Brest | ◎ | ◎ | × |
| 7 | Caen | ○ | ○ | × |
| 8 | Cherbourg | ◎ | ◎ | × |
| 9 | Copenhagen | ◎ | ◎ | × |
| 10 | Cape Firth | ◎ | ◎ | × |
| 11 | Cuxhaven | ● | ● | ✓ |
| 12 | Dieppe | ◎ | ◎ | × |
| 13 | Dundee | ◎ | ◎ | × |
| 14 | Dunkirk | ● | ◎ | ✓ |
| 15 | Eemshaven | ● | ◎ | ✓ |
| 16 | Emden | ● | ● | ✓ |
| 17 | Esbjerg | ● | ● | ✓ |
| 18 | Frederikshvn. | ○ | ○ | ✓ |
| 19 | Gdansk | ◎ | ◎ | × |
| 20 | Great Yarmouth | ● | ◎ | ✓ |
| 21 | Hartlepool & tees | ◎ | ◎ | ✓ |
| 22 | Humber | ◎ | ● | ✓ |
| 23 | Hunterston | ◎ | ◎ | × |
| 24 | Le Havre | ◎ | ◎ | × |
| 25 | Zeebrugge | ◎ | ◎ | × |
| 26 | Lubmin | ◎ | ● | ✓ |
| 27 | Malmo | ◎ | ◎ | × |
| 28 | Medway | ◎ | ● | × |
| 29 | Methil | ● | ● | ✓ |
| 30 | Milford H | ◎ | ◎ | × |
| 31 | Montrose | ◎ | ◎ | × |
| 32 | Mostyn | ● | ○ | ✓ |
| 33 | Newhaven | ◎ | ○ | × |
| 34 | Nyborg | ● | ◎ | ✓ |
| 35 | Peterhead | ○ | ○ | × |
| 36 | Portland | ◎ | ○ | × |
| 37 | Ramsgate | ● | ○ | ✓ |
| 38 | Riga | ○ | ◎ | × |
| 39 | Rostock | ● | ● | ✓ |
| 40 | Rotterdam | ● | ● | ✓ |
| 41 | Sassnitz | ● | ◎ | ✓ |
| 42 | Southampton | ◎ | ◎ | × |
| 43 | St Malo | ○ | ○ | × |
| 44 | St Nazaire | ◎ | ◎ | × |
| 45 | Stavanger | ◎ | ◎ | ✓ |
| 46 | Swansea | ◎ | ◎ | × |
| 47 | Tallin | ◎ | ◎ | ✓ |
| 48 | Tyneside | ◎ | ◎ | × |
| 49 | Vlissingen | ◎ | ◎ | ✓ |
| 50 | Wismar | ◎ | ◎ | × |

**Notes:**
1. "MP": suitable as Mobilisation Port
2. "M": Manufacturing infrastructure serving the offshore wind sector
3. "OWE": Offshore Wind Experience

**Legend:**
● Currently or likely in future
◎ Possible in future
○ Unlikely

# 7.3 Announcements and future trends

Considerable investment has already been made in upgrading facilities in a number of northern European port facilities for the offshore wind industry. In some cases, this has been done on top of already impressive existing capabilities and has further enhanced the technical suitability for the requirements of offshore wind.

Following the substantial success in northwest Germany of its North Sea ports, notably the cluster of Bremerhaven, Cuxhaven and Emden, attention is shifting towards the north-east region of the Baltic coastline. Indeed, the port of Sassnitz in Mecklenburg Vorpommern was selected by EnBW in 2010 as a mobilisation port for the Baltic 2 project. Lower labour costs and strong links to Asia have already allowed a thriving foundation market to be generated in this region. In Germany, substantial capital ownership by local municipal bodies in port infrastructure has allowed close cooperation between industry and public bodies – smoothing the process of creating such clusters. In summer 2011 Bremerhaven ran the first stage of a tender for the financing, planning, construction and operation of a cargo handling and assembly terminal capable of pre-assembling and shipping up to 160 wind turbines per annum for offshore wind projects[19].

In the UK, the government last year pledged a certain amount of investment in offshore wind infrastructure, in order to ensure deployment targets are met. These grants come under the umbrella of the Environmental Transformation Fund (ETF), a budget established to stimulate transition to a low-carbon economy. Examples of funds awarded include a £60 million (€69 million) port infrastructure investment programme, as well as £10 million awarded to individual companies investing in UK facilities. These stimulation measures seem to have helped encourage commitments to invest from some major supply chain players. Siemens, GE, Mitsubishi, Gamesa, Vestas, and Doosan are among those expected to create UK manufacturing facilities. High activity regions in England include Tyneside, Teesside, Humber and East Anglia.

The devolved Scottish administration has also identified port infrastructures as a key component in encouraging industrial development around its ambitious offshore wind plans. The National Renewable Infrastructure Plan (N-RIP) developed by Scotland's economic development agencies identified three potential clusters in Scotland, Forth/Tay, Moray Firth and West Coast in addition to existing expertise focused around Aberdeen and Peterhead. A £70 million public fund has been made available for the required investments with expressions of interest invited from market players at the end of 2010[20].

Ports in Denmark have also been active in seeking opportunities in the offshore wind sector. Lindø Industrial Park is an ongoing conversion of an area of 1 million square metres set up on the closing shipbuilding facilities of Odense shipyard. Smulders Group foundation manufacturer (see Section 4) has entered a conditional agreement to set up extra production capacity at Lindø[21]. Meanwhile the port of Esbjerg has announced plans for significant expansion citing the forthcoming offshore wind market as a primary driver. In preparation of its use for DONG Energy's Anholt offshore wind farm, storage facilities are being rebuilt at the Port of Grenaa.

France is similarly keen to exploit port development opportunities expected to result from its ongoing offshore wind tender and future installation programme, with Saint Nazaire, Brest, Cherbourg, Le Havre and Dunkirk at the forefront of current interest.

While no significant capacity is expected to come online in Eastern European waters prior to 2020,

[19] http://www.bremenports.de/2346_2
[20] http://www.hie.co.uk/highlands-and-islands/key-sectors/energy/n-rip.html
[21] http://www.lindo-industripark.dk/uploadcontent/20110318_Press_Release_Lindo_Smulders_Group_final.pdf

Poland and the Baltic countries of Estonia, Latvia and Lithuania have identified opportunities for supply chain involvement of their ports. Significant labour cost savings in this region present a distinct advantage.

In the Netherlands, Eemshaven already has offshore wind experience and is expected to provide future support to a number of nearby proposed wind farms, the Vlissingen area has recently been extended, and facilities have also been identified for possible use at Ijmuiden and, for O&M operations, at Den Helder.

For Finland the ports of Pori, Vaase and Kristinestad have been earmarked as possible installation bases for its pipeline of projects. Similarly, in Sweden, Halmstad, Uddevalla and Karlshamn offer potential.

In Belgium, Oostende and Zeebrugge ports authorities have been undertaking major developments to service Belwind and Thorton Bank offshore wind farm projects.

Several ports in Spain, particularly those along its north and north-western Atlantic coast, have considerable industrial capabilities which would be well suited to serve any future developments in the area.

## ► KEY FINDINGS

- **The forecast growth of the offshore wind industry in northern Europe is a significant opportunity for ports to counter-balance the economic downturn hitting traditional activities.**

- **There is a general move away from the use of mobilisation ports and instead components are being exported directly from manufacturing facilities to offshore wind farms to save on logistics costs. However potential future production in Eastern Europe to take advantage of lower labour rates may reverse or at least slow this trend.**

- **There is a drive in certain regions towards cluster-building for offshore wind manufacturing in closely located ports. These initiatives are being pursued via cooperation between the public and private sectors, sometimes with facilitation and financial support from the former.**

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EWEA is the voice of the wind industry, actively promoting the utilisation of wind power in Europe and worldwide. It now has over 700 members from almost 60 countries including manufacturers with a 90% share of the world wind power market, plus component suppliers, research institutes, national wind and renewables associations, developers, electricity providers, finance and insurance companies and consultants.

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