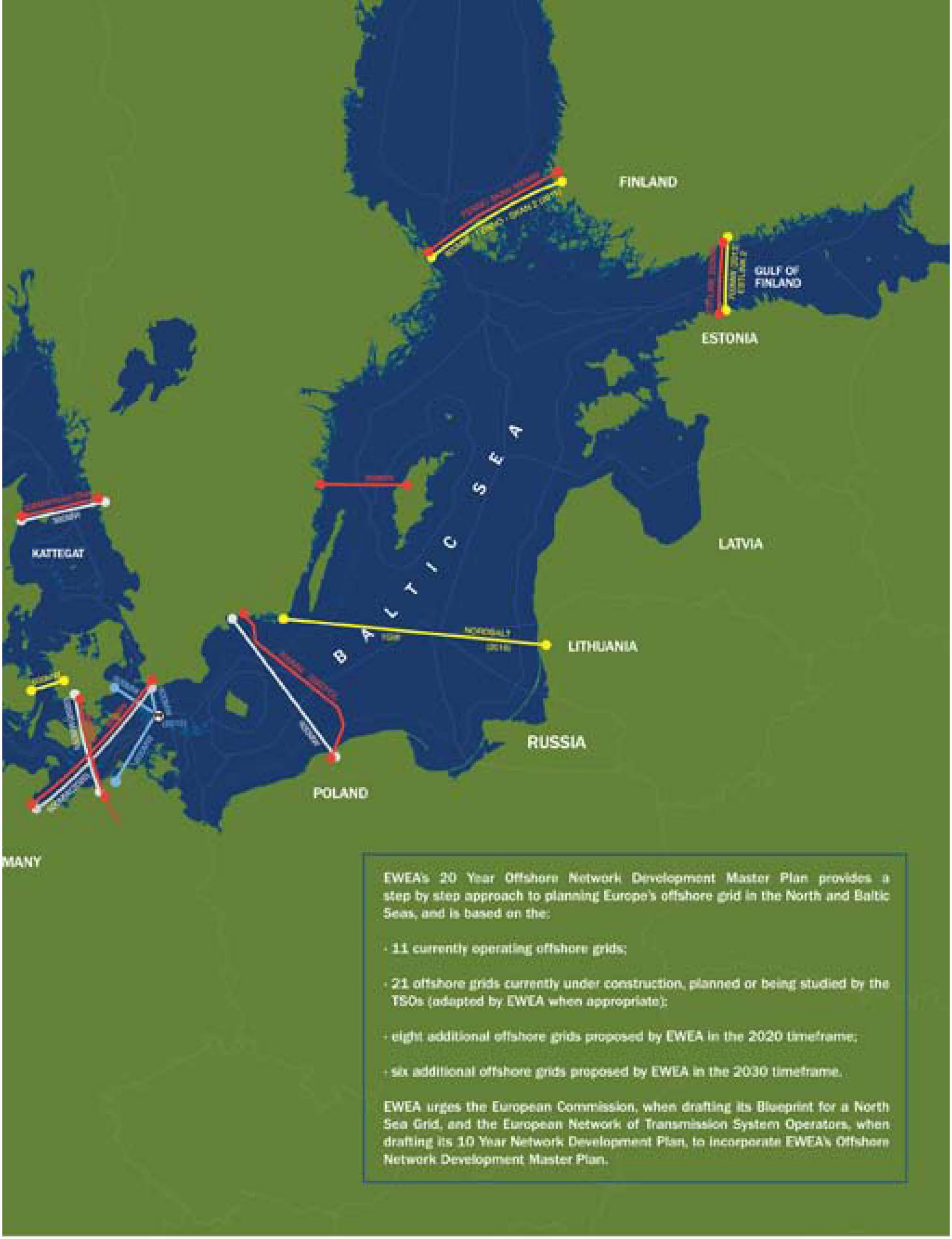
Oceans of Opportunity

Harnessing Europe's largest domestic energy resource

A report by the European Wind Energy Association

Currently operating offshore cable   Under construction or planned offshore ca

Proposed by EWEA in the 2020 timeframe   Proposed by EWEA in the 2030 ti



EWEA's 20 Year Offshore Network Development Master Plan provides a step by step approach to planning Europe's offshore grid in the North and Baltic Seas, and is based on the:

- 11 currently operating offshore grids;
- 21 offshore grids currently under construction, planned or being studied by the TSOs (adapted by EWEA when appropriate);
- eight additional offshore grids proposed by EWEA in the 2020 timeframe;
- six additional offshore grids proposed by EWEA in the 2030 timeframe.

EWEA urges the European Commission, when drafting its Blueprint for a North Sea Grid, and the European Network of Transmission System Operators, when drafting its 10 Year Network Development Plan, to incorporate EWEA's Offshore Network Development Master Plan.

ible   Under study by TSO   Under study by TSO/EWEA recommendation

imeframe   Proposed offshore node   Concession and development zones

Oceans of opportunity

Europe's offshore wind potential is enormous and able to power Europe seven times over.

Huge developer interest

Over 100 GW of offshore wind projects are already in various stages of planning. If realised, these projects would produce 10% of the EU's electricity whilst avoiding 200 million tonnes of CO_2 emissions each year.

Repeating the onshore success

EWEA has a target of 40 GW of offshore wind in the EU by 2020, implying an average annual market growth of 28% over the coming 12 years. The EU market for onshore wind grew by an average 32% per year in the 12-year period from 1992-2004 – what the wind energy industry has achieved on land can be repeated at sea.

Building the offshore grid

EWEA's proposed offshore grid builds on the 11 offshore grids currently operating and 21 offshore grids currently being considered by the grid operators in the Baltic and North Seas to give Europe a truly pan-European electricity super highway.

Realising the potential

Strong political support and action from Europe's policy-makers will allow a new, multi-billion euro industry to be built.

Results that speak for themselves

This new industry will deliver thousands of green collar jobs and a new renewable energy economy and establish Europe as world leader in offshore wind power technology.

A single European electricity market with large amounts of wind power will bring affordable electricity to consumers, reduce import dependence, cut CO_2 emissions and allow Europe to access its largest domestic energy source.

Oceans of Opportunity

Harnessing Europe's largest domestic energy resource

By the European Wind Energy Association

September 2009

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Executive Summary

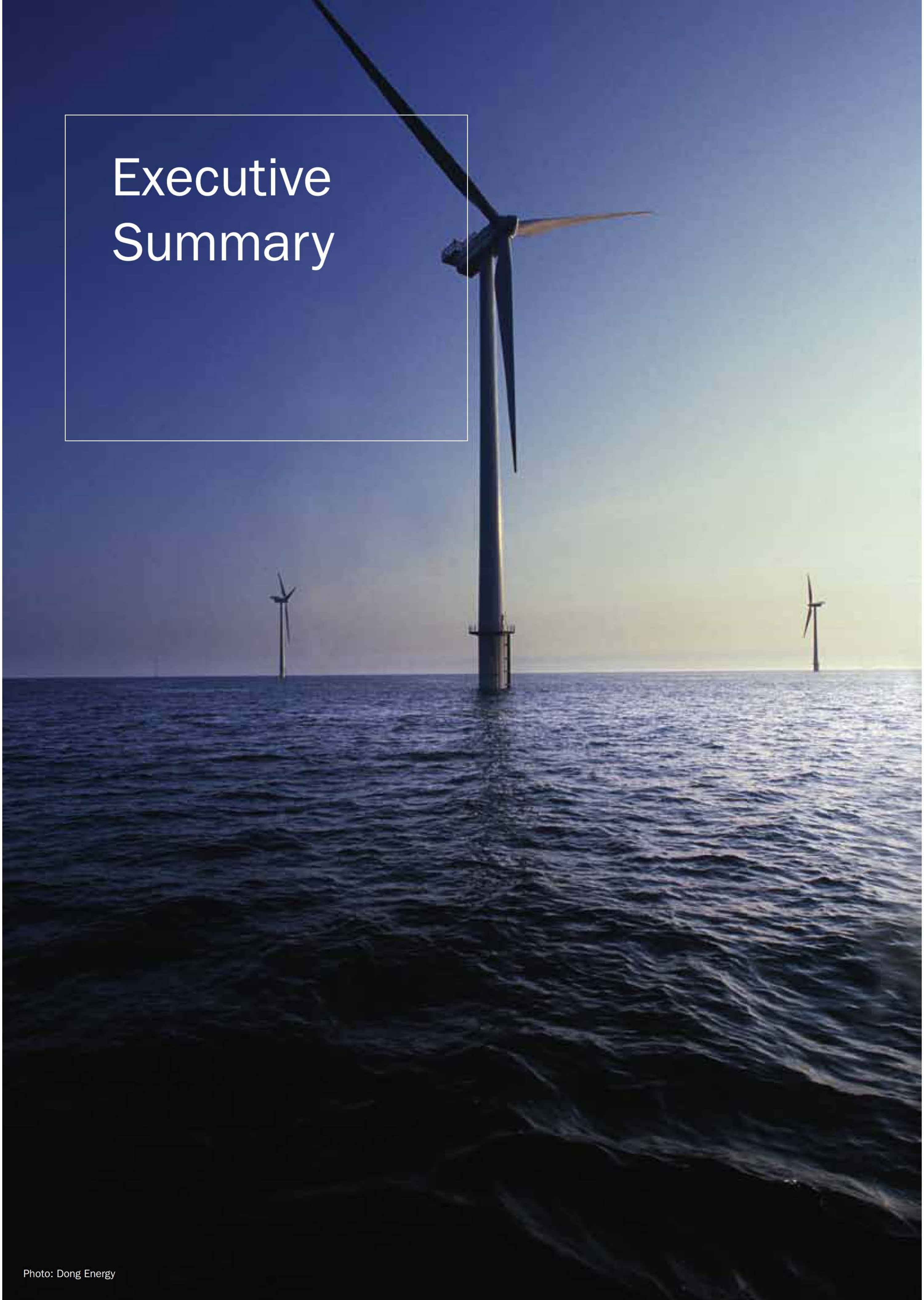


Photo: Dong Energy

Offshore wind power is vital for Europe's future. Offshore wind power provides the answer to Europe's energy and climate dilemma – exploiting an abundant energy resource which does not emit greenhouse gases, reduces dependence on increasingly costly fuel imports, creates thousands of jobs and provides large quantities of indigenous affordable electricity. This is recognised by the European Commission in its 2008 Communication 'Offshore Wind Energy: Action needed to deliver on the Energy Policy Objectives for 2020 and beyond'[1].

Europe is faced with the global challenges of climate change, depleting indigenous energy resources, increasing fuel costs and the threat of supply disruptions. Over the next 12 years, according to the European Commission, 360 GW of new electricity capacity – 50% of current EU capacity – needs to be built to replace ageing European power plants and meet the expected increase in demand. Europe must use the opportunity created by the large turnover in capacity to construct a new, modern power system capable of meeting the energy and climate challenges of the 21st century while enhancing Europe's competitiveness and energy independence.

EWEA target

In March, at the European Wind Energy Conference 2009 (EWEC 2009), the European Wind Energy Association (EWEA) increased its 2020 target to 230 GW wind power capacity, including 40 GW offshore wind. Reaching 40 GW of offshore wind power capacity in the EU by 2020 is a challenging but manageable task. An entire new offshore wind power industry and a new supply chain must be developed on a scale that will match that of the North Sea oil and gas endeavour. However, the wind energy sector has a proven track record onshore with which to boost its confidence, and will be significantly longer lived than the oil and gas sector.

To reach 40 GW of offshore wind capacity in the EU by 2020 would require an average growth in annual installations of 28% - from 366 MW in 2008 to 6,900 MW in 2020. In the 12 year period from 1992-2004, the market for onshore wind capacity in the EU grew by an average 32% annually: from 215 MW to 5,749 MW. There is nothing to suggest that this historic onshore wind development cannot be repeated at sea.

Unlimited potential

By 2020, most of the EU's renewable electricity will be produced by onshore wind farms. Europe must, however, use the coming decade to prepare for the large-scale exploitation of its largest indigenous energy resource, offshore wind power. That the wind resource over Europe's seas is enormous was confirmed in June by the European Environment Agency's (EEA) 'Europe's onshore and offshore wind energy potential'[2]. The study states that offshore wind power's economically competitive potential in 2020 is 2,600 TWh, equal to between 60% and 70% of projected electricity demand, rising to 3,400 TWh in 2030, equal to 80% of the projected EU electricity demand. The EEA estimates the technical potential of offshore wind in 2020 at 25,000 TWh, between six and seven times greater than projected electricity demand, rising to 30,000 TWh in 2030, seven times greater than projected electricity demand. The EEA

[1] European Commission, 2008. 'Offshore Wind Energy: Action needed to deliver on the Energy Policy Objectives for 2020 and beyond'. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0768:FIN:EN:PDF.

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

Photo: Elsam

has clearly recognised that offshore wind power will be key to Europe's energy future.

Over 100 GW already proposed

It is little wonder therefore that over 100 GW of offshore wind energy projects have already been proposed or are already being developed by Europe's pioneering offshore wind developers. This shows the enormous interest among Europe's industrial entrepreneurs, developers and investors. It also shows that EWEA's targets of 40 GW by 2020 and 150 GW by 2030 are eminently realistic and achievable. The 100 or more GW is spread across 15 EU Member States, as well as three other European countries. The rewards for Europe exploiting its huge offshore wind potential are enormous – this 100 GW will produce 373 TWh of electricity each year, meeting between 8.7% and 11% of the EU's electricity demand, whilst avoiding 202 million tonnes of CO_2 in a single year.

In order to ensure that the 100 GW of projects can move forward, and reach 150 GW of operating offshore wind power by 2030, coordinated action is required from the European Commission, EU governments, regulators, the transmission system operators (TSOs) and the wind industry. Working in partnership on developing the offshore industry's supply chain, putting in place maritime spatial planning, building an offshore electricity grid based on EWEA's 20 Year Offshore Network Development Master Plan, and ensuring continued technological development for the offshore industry, are key issues.

By 2020, the initial stages of an offshore pan-European grid should be constructed and operating with an agreed plan developed for its expansion to accommodate the 2030 and 2050 ambitions.

Grids

The future transnational offshore grid will have many functions, each benefitting Europe in different ways. It will provide grid access to offshore wind farms, smooth the variability of their output on the markets and improve the ability to trade electricity within Europe, thereby contributing dramatically to Europe's energy security.

We must stop thinking of electrical grids as national infrastructure and start developing them – onshore and offshore – to become European corridors for electricity trade. And we must start developing them now. The faster they are developed, the faster we will have a domestic substitute if future fuel import supplies are disrupted or the cost of fuel becomes prohibitively expensive, as the world experienced during 2008.

The future European offshore grid will contribute to building a well-functioning single European electricity market that will benefit all consumers, with the North Sea, the Baltic Sea and the Mediterranean Sea leading the way. Preliminary assessments of the economic value of the offshore grid indicate that it will bring significant economic benefits to all society.

Europe's offshore grid should be built to integrate the expected 40 GW of offshore wind power by 2020, and the expected 150 GW of offshore wind power by 2030. It is for this reason that EWEA has proposed its 20 Year Offshore Network Development Master Plan (Chapter 3). This European vision must now be taken forward and implemented by the European Commission and the European Network of Transmission System Operators (ENTSO-E), together with a new business model for investing in offshore power grids and interconnectors which should be rapidly introduced based on a regulated rate of return for new investments.

2010 will be a key year for grid development planning

The European Commission will publish a 'Blueprint for a North Sea Grid'[3] making offshore wind power the key energy source of the future. ENTSO-E will publish its first 10 Year Network Development Plan, which should, if suitably visionary, integrate the first half of EWEA's 20 Year Offshore Network Development Master Plan. The European Commission will also publish its EU Energy Security and Infrastructure Instrument which must play a key role in putting in place the necessary financing for a pan-European onshore and offshore grid, and enable the European Commission, if necessary, to take the lead in planning such a grid.

Supply chain

The offshore wind sector is an emerging industrial giant. But it will only grow as fast as the tightest supply chain bottleneck. It is therefore vitally important that these bottlenecks are identified and addressed so as not to constrain the industrial development. Turbine installation vessels, substructure installation vessels, cable laying vessels, turbines, substructures, towers, wind turbine components, ports and harbours must be financed and available in sufficient quantities for the developers to take forward their 100 GW of offshore wind projects in a timely manner.

Through dramatically increased R&D and economies of scale, the cost of offshore wind energy will follow the same path as onshore wind energy in the past. The technical challenges are greater offshore but no greater than when the North Sea oil and gas industry took existing onshore extraction technology and adapted it to the more hostile environment at sea. An entire new offshore wind power industry and a new supply chain must be developed on a scale that will match that of the North Sea oil and gas endeavour, but one that will have a much longer life.

Technology

Offshore wind energy has been identified by the European Union as a key power generation technology for the renewable energy future, and where Europe should lead the world technologically. The support of the EU is necessary to maintain Europe's technological lead in offshore wind energy by improving turbine design, developing the next generation of offshore wind turbines, substructures, infrastructure, and investing in people to ensure they can fill the thousands of new jobs being created every year by the offshore wind sector.

To accelerate development of the technology and in order to attract investors to this grand European project, a European offshore wind energy payment mechanism could be introduced. It should be a voluntary action by the relevant Member States (coordinated by the European Commission) according to Article 11 of the 2009 Renewable Energy Directive. It is important that such a mechanism does not interfere with the national frameworks that are being developed in accordance with that same directive.

Spatial planning

The decision by countries to perform maritime spatial planning (MSP) and dedicate areas for offshore wind developments and electricity interconnectors sends clear positive signals to the industry. Provided the right policies and incentives are in place, MSP gives the industry long-term visibility of its market, and enables synergies with other maritime sectors. Consolidated at European level, such approaches would enable investments to be planned out. This would enable the whole value chain to seek investment in key elements of the supply chain (e.g. turbine components, cables, vessels, people) while potentially lowering risks and capital costs.

[3] The Council Conclusions to the 2nd Strategic Energy Review referred to the Blueprint as a North West Offshore Grid.

Chapter 1

The Offshore Wind Power Market of the Future

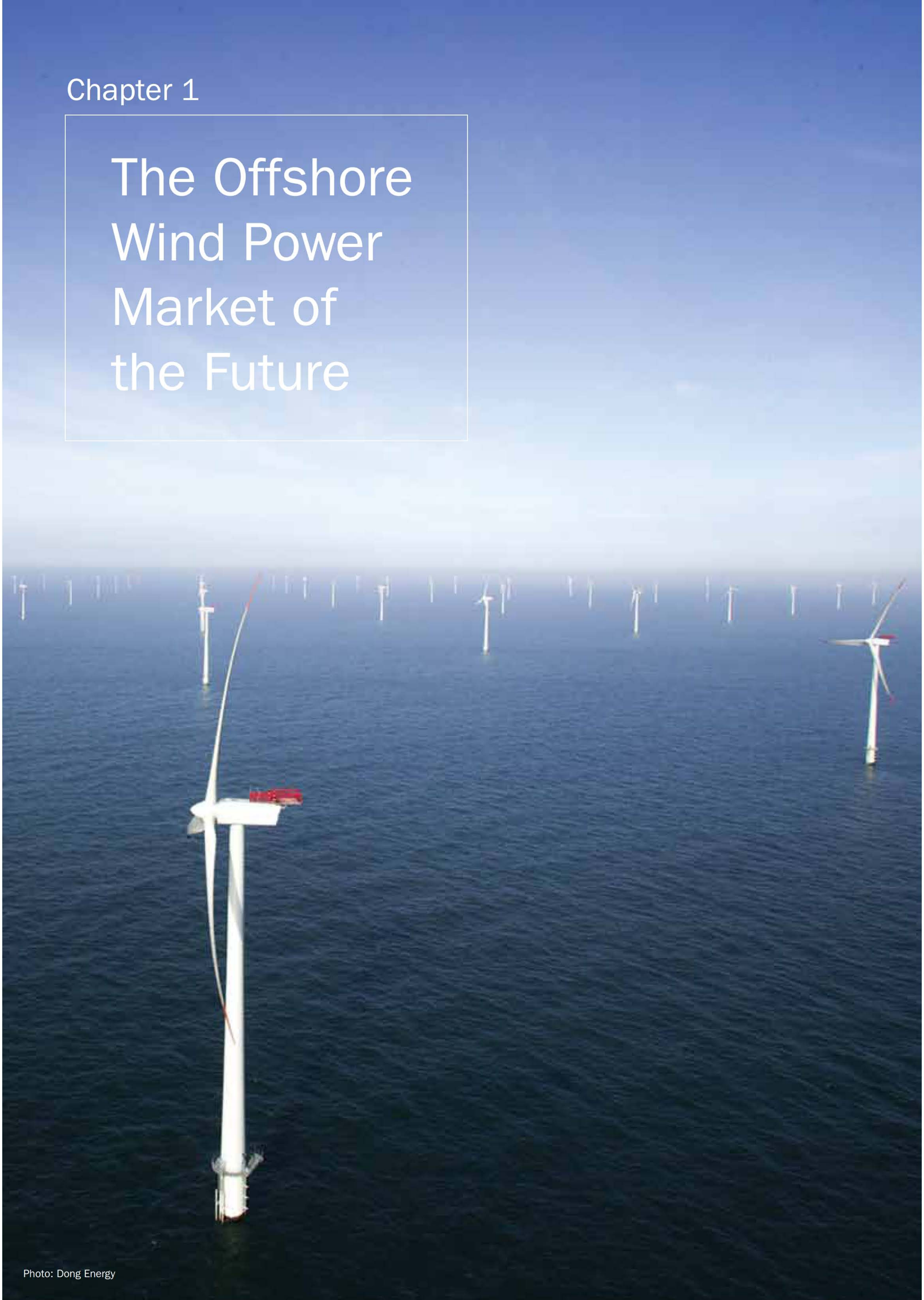


Photo: Dong Energy

2008 and 2009: steady as she goes

2008 saw 366 MW of offshore wind capacity installed in the EU (compared to 8,111 MW onshore) in seven separate offshore wind farms, taking the total installed capacity to 1,471 MW in eight Member States. The UK installed more than any other country during 2008 and became the nation with the largest installed offshore capacity, overtaking Denmark. Activity in 2008 was dominated by ongoing work at Lynn and Inner Dowsing wind farms in the UK and by Princess Amalia in the Netherlands.

In addition to these large projects, Phase 1 of Thornton Bank in Belgium was developed together with two near-shore projects, one in Finland and one in Germany. In addition, an 80 kW turbine (not connected to the grid) was piloted on a floating platform in a water depth of 108m in Italy. Subsequently decommissioned, this turbine was the first to take the offshore wind industry into the Mediterranean Sea, which, together with developments in the Baltic Sea, North Sea and Irish Sea, highlights the pan-European nature of today's offshore wind industry.

2009 has seen strong market development with a much larger number of projects beginning construction, under construction, expected to be completed, or completed during the course of the year. EWEA anticipates an annual market in 2009 of approximately 420 MW, including the first large-scale floating prototype off the coast of Norway.

By the end of 2009 EWEA expects a total installed offshore capacity of just under 2,000 MW in Europe.

2010: annual market passes 1 GW

Assuming the financial crisis does not blow the offshore wind industry off course, 2010 will be a defining year for the offshore wind power market in Europe. Over 1,000 MW (1 GW) is expected to be installed. Depending on the amount of wind power installed onshore, it looks as if Europe's 2010 offshore market could make up approximately 10% of Europe's total annual wind market, making the offshore industry a significant mainstream energy player in its own right.

Summary of the offshore wind energy market in the EU in 2010:

- Total installed capacity of 3,000 MW
- Annual installations of 1,100 MW
- Electricity production of 11 TWh
- Meeting 0.3% of total EU electricity demand
- Avoiding 7 Mt of CO_2 annually
- Annual investments in wind turbines of €2.5 billion

100 GW and counting…

In summer 2009 EWEA surveyed those of its members active in developing and supplying the offshore wind industry, in order to underpin its scenario development for 2030. The project pipelines supplied by offshore wind developers are presented in the Offshore Wind Map and outlined in this report. In all, EWEA has identified proposals for over 100 GW of offshore wind projects in European waters - either under construction, consented, in the consenting phase or proposed by project developers or government proposed development zones. This 100 GW of offshore wind projects shows tremendous developer interest and 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[4].

To see the updated Offshore Wind Map: www.ewea.org/offshore

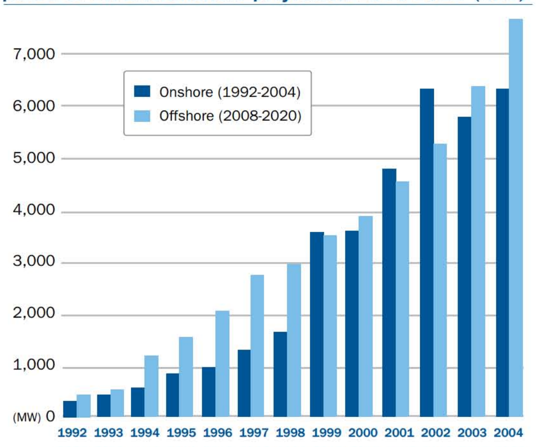
2011 – 2020

(See annex for detailed statistics)

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 expects 34%[5] of electricity to come from renewable energy sources by 2020 and believes 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 should now be increased. EWEA therefore predicts that the total installed offshore wind capacity in 2020 will be 40 GW, up from just under 1.5 GW today.

FIGURE 1: **Historical onshore growth 1992-2004 compared to EWEA's offshore projection 2008-2020 (MW)**

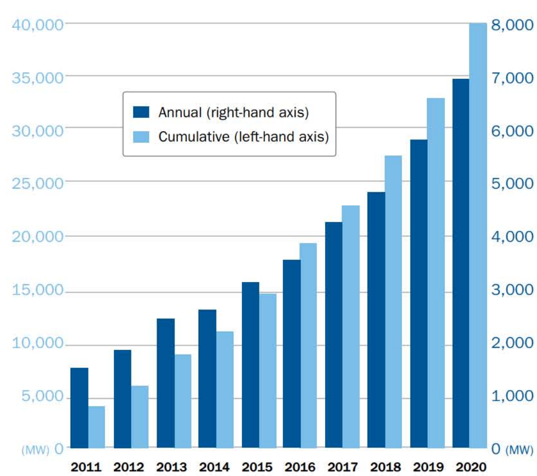


As can be seen in Figure 1, EWEA's offshore scenario can be compared to the growth of the European onshore wind market at a similar time in the industry's development.

ANNUAL INSTALLATIONS

Between 2011 and 2020, EWEA expects the annual offshore market for wind turbines to grow steadily from 1.5 GW in 2011 to reach 6.9 GW in 2020. Throughout this period, the market for onshore wind turbines will exceed the offshore market in the EU.

FIGURE 2: **Offshore wind energy annual and cumulative installations 2011-2020 (MW)**



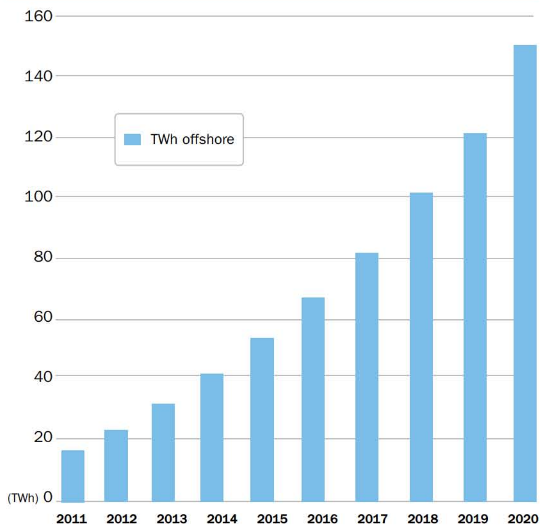
[4] Independently of EWEA's survey of offshore developers which identified 120 GW of offshore wind farms under construction, consented, or announced by companies or proposed development/concession zones (available at www.ewea.org/offshore) New Energy Finance has indentified 105 GW of offshore wind projects in Europe (NEF Research Note: Offshore Wind 28 July 2009).

[5] European Commission, 2006. 'Renewable Energy Roadmap', COM(2006)848 final.

WIND ENERGY PRODUCTION

The 40 GW of installed capacity in 2020 would produce 148 TWh of electricity in 2020, equal to between 3.6% and 4.3% of EU electricity consumption, depending on the development in electricity demand. Approximately a quarter of Europe's wind energy would be produced offshore in 2020[6]. Including onshore, wind energy would produce 582 TWh, enough to meet between 14.3% and 16.9% of total EU electricity demand by 2020.

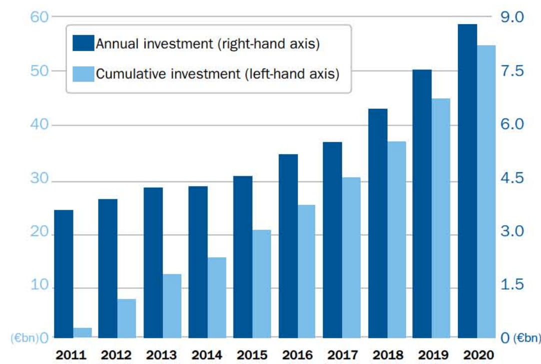
FIGURE 3: **Electricity production 2011-2020 (TWh)**



OFFSHORE WIND POWER INVESTMENTS

Annual investments in offshore wind power are expected to increase from €3.3 billion in 2011 to €8.81 billion in 2020.

FIGURE 4: **Annual and cumulative investments in offshore wind power 2011-2020 (€billion 2005)**



AVOIDING CLIMATE CHANGE

In 2011, offshore wind power will avoid the emission of 10 Mt of CO_2, a figure that will rise to 85 Mt in the year 2020.

[6] The 230 GW of wind power operating in 2020 would produce 582 TWh of electricity, with the 40 GW offshore contributing 148 TWh.

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

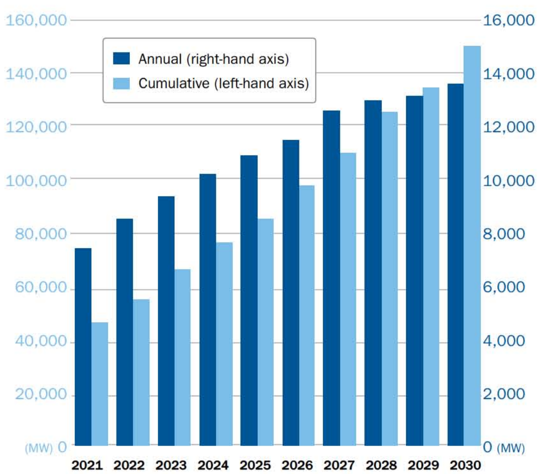
- Total installed capacity of 40,000 MW
- Annual installations of 6,900 MW
- Electricity production of 148 TWh
- Meeting between 3.6% and 4.3% of total EU electricity demand
- Avoiding 85Mt of CO_2 annually
- Annual investments in wind turbines of €8.8 billion

2021 - 2030

ANNUAL INSTALLATIONS

Between 2021 and 2030, the annual offshore market for wind turbines will grow steadily from 7.7 GW in 2021 to reach 13.6 GW in 2030. 2027 will be the first year in which the market for offshore wind turbines exceeds the onshore market in the EU.

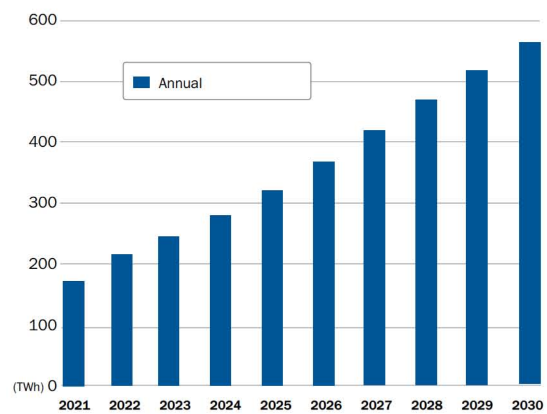
FIGURE 6: **Offshore wind energy annual and cumulative installations 2021-2030 (MW)**



WIND ENERGY PRODUCTION

The 150 GW of installed capacity in 2030 would produce 563 TWh of electricity in 2030, equal to between 12.8% and 16.7% 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[7]. An additional 592 TWh would be produced onshore, bringing wind energy's total share to between 26.2% and 34.3% of EU electricity demand.

FIGURE 7: **Electricity production 2021-2030 (TWh)**



OFFSHORE WIND POWER INVESTMENTS

Annual investments in offshore wind power are expected to increase from €9.8 billion in 2021 to €16.5 billion in 2030.

[7] The 400 GW of wind power operating in 2030 would produce 1,155 TWh of electricity, with the 150 GW offshore contributing 563 TWh.

FIGURE 8: **Annual and cumulative investments in offshore wind power 2021-2030 (€billion)**

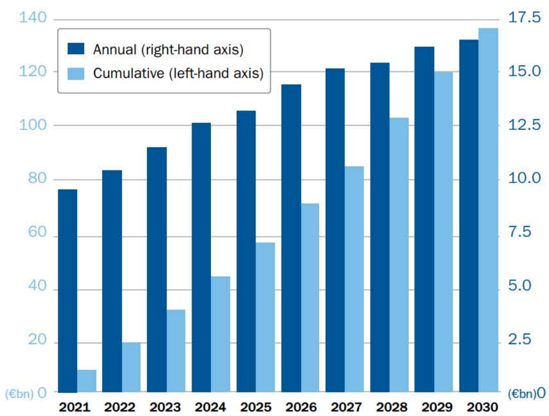
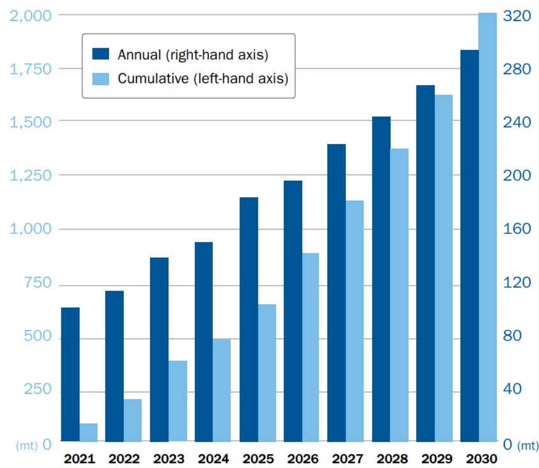


FIGURE 9: **Annual and cumulative avoided CO_2 emissions 2021-2030 (million tonnes)**



AVOIDING CLIMATE CHANGE

In 2021, offshore wind power will avoid the emission of 100 Mt of CO_2, a figure that will rise to 292 Mt in the year 2030.

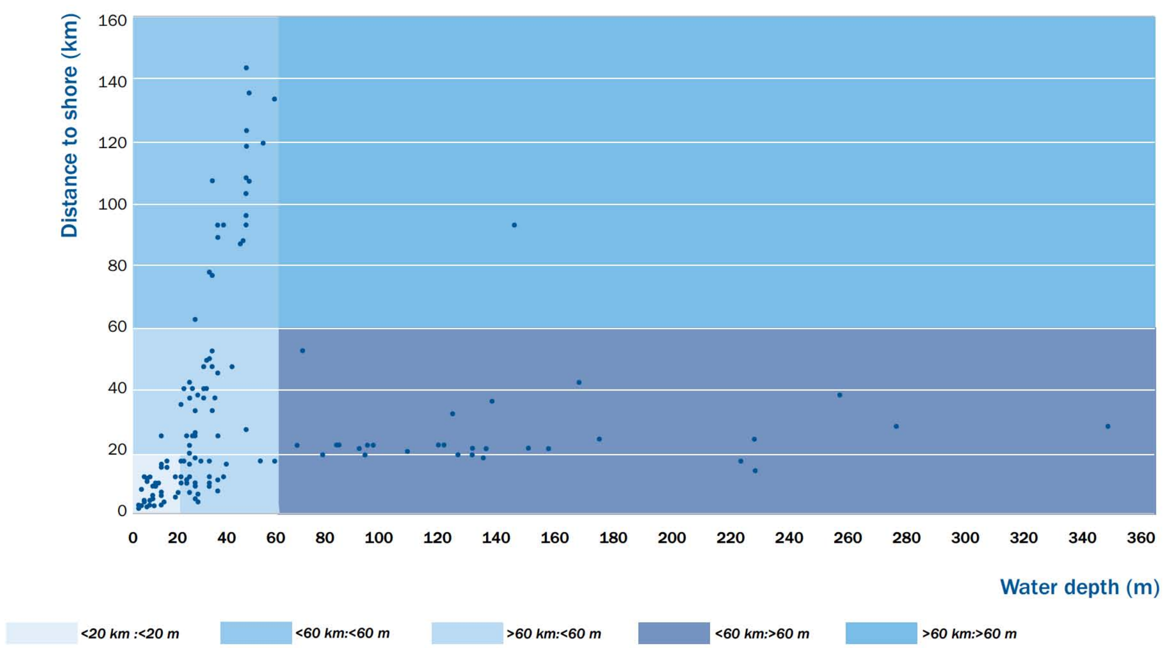
Summary of the offshore wind energy market in the EU in 2030:

- Total installed capacity of 150,000 MW
- Annual installations of 13,690 MW
- Electricity production of 563 TWh
- Meeting between 12.8% and 16.7% of total EU electricity demand
- Avoiding 292 Mt of CO_2 annually
- Annual investments in wind turbines of €16.5 billion

Offshore development – deeper and further

As technology develops and experience is gained, the offshore wind industry will move into deeper water and further from the shore. Looking at the wind farms proposed by project developers, the wind industry will gradually move beyond the so-called 20:20 envelope (20m water depth, 20 km from shore).

FIGURE 10: **Development of the offshore wind industry in terms of water depth (m) and distance to shore (km)**



This scatter graph shows the probable future development trends of the offshore industry in the 2025 timeframe (approximately)[8] .

Identified trends:

<20 km:<20m
At the moment operating wind farms tend to be built not further than 20km from the shore in water depths of not more than 20m.

<60 km:<60m
The current 20:20 envelope will be extended by the majority of offshore farms to not more than 60 km from shore in water depths of not more than 60m.

>60 km:<60m
Far offshore development, which includes current development zones – those illustrated here mainly result from development in Germany – and will include in the future the UK's Round 3, characterised by farms far from shore (more than 60 km) connecting in ideal situations to offshore supernodes, with a water depth generally between 20m and 60m.

<60 km:>60m
Deep offshore – based on project proposals highlighted to EWEA from project developers using floating platform technologies during the course of the next decade, not further than 60 km from shore.

>60 km:>60m
Deep far offshore – this scatter graph highlights the future long term potential of combining an offshore grid (far offshore) with floating concepts (deep offshore) which is beyond the scope and timeframe of this report.

[8] The data is based on an EWEA spreadsheet containing information on all offshore wind farms that are operating, under construction, consented, in the consenting process or proposed by project developers supplied to EWEA and available (updated) at www.ewea.org/offshore. The scatter graph contains only those farms where both water depth and distance to shore was provided to EWEA, and should therefore be treated with a suitable level of caution.

Europe's first mover offshore advantage

To date, all fully operational offshore wind farms are in Europe. However, two countries outside Europe in particular are determined to exploit their offshore wind potential, providing European companies with significant opportunities for manufacturing and technology exports, experienced developers, project planners, infrastructure experts, and installation equipment.

The United States: hot on Europe's heels[9]

The prospects for wind energy projects off the coasts of the United States brightened in 2008 and 2009. A government report[10] recognised significant potential for offshore wind's contribution. Two states completed competitive processes for proposed projects, one company signed a Power Purchase Agreement with a major utility, and a final regulatory framework was released by the Obama Administration in its first 100 days[11].

In May 2008, the U.S. Department of Energy released "20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply", which investigated the feasibility of wind energy providing 20% of U.S. electricity. The report found that more than 300 GW of wind energy capacity would need to be installed, including 54 GW offshore.

Rhode Island and New Jersey each conducted competitive processes to choose developers to work on projects off their shores, demonstrating that state leadership is driving much of the interest in offshore wind projects in the U.S.

A Delaware utility signed a Power Purchase Agreement with a developer, committing that state to a project in the near future.

The wind industry welcomed the release of a new regulatory framework from the Minerals Management Service (MMS) of the Department of the Interior after much delay. President Bush signed the Energy Policy Act of 2005 setting MMS as the lead regulatory agency for projects in federal waters, but the final rules were not released until April 2009.

And not to be left behind, states surrounding the Great Lakes have also showed interest over the past two years in pursuing projects in America's fresh water. Michigan and Wisconsin both completed major studies regarding the potential for offshore wind, Ohio is conducting a feasibility study for a small project in Lake Erie, and the New York Power Authority asked for expressions of interest for projects in Lake Ontario and Lake Erie in the first half of 2009.

On 22 April 2009, President Barack Obama said "… we are establishing a programme to authorise – for

Photo: Siemens

[9] Contribution from Laurie Jodziewicz, American Wind Energy Association.

[10] U.S. Department of Energy, 2008. '20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply' http://www.20percentwind.org/20p.aspx?page=Report. May 2008.

[11] http://www.doi.gov/news/09_News_Releases/031709.html.


Photo: Siemens

the very first time – the leasing of federal waters for projects to generate electricity from wind as well as from ocean currents and other renewable sources. And this will open the door to major investments in offshore clean energy. For example, there is enormous interest in wind projects off the coasts of New Jersey and Delaware, and today's announcement will enable these projects to move forward."

China: the first farm is developed[12]

With its large land mass and long coastline, China is exceptionally rich in wind resources. According to the China Coastal Zone and Tideland Resource Investigation Report, the area from the country's coastline to 20m out to sea covers about 157,000 km^2. Assuming 10% to 20% of the total amount of sea surface were to be used for offshore development, the total offshore wind capacity could reach 100-200 GW. However, in the coastal zone to the south of China, typhoons may be a limiting factor for the deployment of offshore wind turbines, especially in the Guangdong, Fujian and Zhejiang Provinces.

In 2005, the nation's Eleventh Five Year Plan encouraged the industry to learn from international experience on offshore wind development and to explore the offshore opportunities in Shanghai, Zhejiang and Guangdong Province. The plan also sets a target of setting up one to two offshore wind farms

[12] Contribution from Liming Qiao, GWEC.

of 100 MW by 2010. In the same year, the National Development and Reform Commission (NDRC) also put offshore wind development as one of the major R&D priorities in the “Renewable Energy Industry Development Guideline”.

At provincial level, offshore wind planning also started to take place in Jiangsu, Guangdong, Shanghai, Zhejiang, Hainan, Hebei and Shangdong. Among them, the most advanced is Jiangsu province, with a theoretical offshore potential of 18 GW and a littoral belt of over 50 km, which is an excellent technical advantage for developing offshore wind. In its Wind Development Plan (2006-2010), Jiangsu province stipulated that by 2010, wind installation in the province should reach 1,500 MW, all onshore, and by 2020, wind installation should reach 10 GW, with 7,000 MW offshore. The plan also foresees that in the long term, the province will reach 30 GW of onshore wind installation capacity and 18 GW offshore capacity.

The first offshore wind turbine in China was installed and went online in 2007, located in Liaodong Bay in the northeast Bohai Sea. The test turbine has a capacity of 1.5 MW. The wind turbine was built by the China National Offshore Oil Corp (CNOOC), the country’s largest offshore oil producer, with an investment of 40 million yuan ($5.4 million).

Construction of the first offshore wind farm in China started in 2009, close to Shanghai Dongdaqiao. The first three machines were installed in April 2009. It is expected to be built by the end of 2009 and to provide electricity to the 2010 Shanghai Expo. The wind farm will consist of 34 turbines of 3 MW.

In terms of R&D, the government has put offshore wind energy technology into the government supported R&D programme. Meanwhile, domestic turbine manufacturers are also running their own offshore R&D.

The development of offshore wind in China is still at an early stage. Many key issues need to be addressed. At national level, there is still no specific policy or regulation for offshore wind development. All current policies are for onshore wind. Meanwhile, the approval of offshore wind projects involves more government departments than for onshore wind projects, with a lack of clarity over the different government departments’ responsibility for approving offshore wind projects. Grid planning and construction is another key issue, with grid constraint hindering development.

Chapter 2

Spatial Planning: Supporting Offshore Wind and Grid Development

Photo: Elsam

Maritime spatial planning

Increased activity within Europe's marine waters has led to growing competition between sectors such as shipping and maritime transport, the military, the oil and gas sector, offshore wind and ocean energies, port development, fisheries and aquaculture, and environmental concerns. The fact that the different activities are regulated on a sectoral basis by different agencies, each with its own specific legislative approach to the allocation and use of maritime space, has led to fragmented policy making and very limited EU coordination. In contrast to spatial planning on land, EU countries generally have limited experience of integrated spatial planning in the marine environment, and sometimes the relevant governance structures and rules are inadequate.

In addition to the wide range of sectoral approaches to the use of the sea, there are very different planning regimes and instruments in the different Member States. For example, in Germany there are regional plans for the territorial seas and national EEZ (Exclusive Economic Zones) plans, whereas in France, sea "Enhancement Schemes" have been used in some areas as the main instrument.

Only a few European countries currently have defined dedicated offshore wind areas, including the UK, Germany, Denmark, Belgium and the Netherlands, each of which has its own approach. A few countries, such as the UK, Germany and Denmark, have integrated the deployment of offshore wind energy into a global approach that encompasses industrial, research and policy aspects, and they are seen as the most promising markets.

Most other countries use existing marine planning laws, which can delay projects considerably as offshore wind is a newly developing and unique energy resource. Drawn out and imprecise planning can increase the costs of offshore projects significantly.

With no integrated approach, offshore wind energy deployment is caught between conflicting uses, interest groups and rules from different sectors and jurisdictions (both at inter-state and intra-state level). This creates project uncertainty, increases the risk of delays in, or failure of offshore wind projects, and impairs the sector's potential for growth.

These barriers are further aggravated by the absence of an integrated and coordinated approach to maritime spatial planning (MSP) between the different Member States and regions. There are potential synergies between offshore projects and cross-border inter-connectors that are currently not being exploited and taken into consideration in MSP regimes. Without

TABLE 1: **Overview of the different planning methods**

Process	Country	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Single-window Application Process	UK	**Crown Estate (CE):** Tenders right to develop site	**Department of Trade and Industry's (DTI) Offshore Renewables Consents Unit (ORCU):** Food and Environment Protection License for works at sea	**ORCU:** Permit for construction/operation of a generating station	**ORCU:** Coast protection permit	**Secretary of State for Trade and Industry:** Permit for construction of onshore substation/overhead line	
Single-window Application Process	Denmark	**Danish Energy Authority (DEA):** Site pre-screening	**DEA:** Site tender/permit to survey for Environmental Impact Assessment (EIA)	**DEA:** Building permit	**Developer:** Construction of wind plant	**DEA:** Permit to exploit site and generate electricity	
Single-window Application Process	Spain	**Developer:** Expression of interest in site	**General Directorate for Energy Policy and Mines (DGPEM):** Site pre-screening, evaluation of environmental/tourism/fishing/shipping impact/ grid conection	**DGPEM:** Site tender	**DGPEM:** Coordinate application review with govt. agencies	**DGPEM:** Lease agreement	**Developer:** Project planning, feasibility studies; **DGPEM:** Adm. Authorization and construction permit
Single-window Application Process	Netherlands	**Developer:** Application for location incl. EIA to **Ministry of Transport and Water Resources (MTW)**	**MTW:** Consultation with stakeholders (EIA, defense, shipping, fishing, etc.)	**MTW:** Invitation to submit building application	**MTW:** Draft building permit	**MTW:** Final building permit	
Single-window Application Process	Belgium	**Developer:** Presents concessions application, incl. detailed site plan/EIA to **Ministry of Marine Environment (MME)**	**MME:** Consultation with stakeholders	**MME:** Publishes initial concession application, opens concession process to competitors	**MME:** Building and exploitation authorization (plant/cabling)		
Single-window Application Process	Germany	**Developer:** Notice of intention to construct communicated to **BSH** (federal marine authority)	**Developer:** Public and stakeholder consultation	**Developer:** Two years environmental study, shipping risk analysis	**BSH:** Project approval	**BSH:** Cable approval EEZ	**Länder (state government):** Cable approval 12 nm zone for the Transmission System Operator
Single-window Application Process	Norway	**Developer:** Intention to apply for permits communicated Energy Regulator	**Developer:** Informal public and stakeholder consultation	**Developer:** Formal application presented to Energy Regulator	**Energy Regulator:** Formal public and stakeholder consultation	**Energy Regulator:** Application approval	**Oil and Energy Ministry:** Final project approval if appeal
Multiple-window	Ireland	**Department of Communications, Energy, and Natural Resources (CENR):** Foreshore license to explore site	**Developer:** Public and stakeholder consultation preparation of EIS	**CENR:** Foreshore lease	**Commission for energy regulation:** Construction, generation, and supply permit		
Multiple-window	Sweden	**Ministry of Industry:** Permit for explotation of seabed	**Ministry of Sustainable Development:** Environmental permit	Building permit, **Municipality** if in 12 nm zone, **Ministry of Industry** if in EEZ	**Network Authority (part of Energy Administration):** Concession for cabling and grid access		
Application Guidelines being defined/finalized	Italy	**Maritime Authority:** Site consent dependent on MoT Authorization	**Ministry of Transport (MoT):** Consultation with Economic and Environment Ministries and stakeholders	**MoT:** Authorization to build and operate wind plant			
Application Guidelines being defined/finalized	France	**Competent Authority TBD:** Declaration of Zone Development Eolien (ZDE)	**Competent Authority TBD:** Environmental Impact Statement (EIS)	**Prefect Maritime:** Concession for use of public land	**Competent Authority TBD:** Construction permit		
Application Guidelines being defined/finalized	Poland	**No current protocol**					

Different ministry involved | *Developer* | *National authority* | *Local authority* | *To be defined*

SOURCE: *Emerging Energy Research, 2008. 'Global Offshore Wind Energy Markets and Strategies 2008 – 2020'.*

cross-border coordination, grid investments in particular risk being sub-optimal because they will be made from an individual project and national perspective, rather than from a system and transnational perspective. This harms both the deployment of offshore wind energy projects and the development of a well-functioning Europe-wide market for electricity.

The lack of integrated strategic planning and cross-border coordination has been identified as one of the main challenges to the deployment of offshore power generation by the recent European Commission Communications:

- 'Offshore Wind Energy: action needed to deliver on the Energy Policy Objectives for 2020 and beyond'[13];
- 'An Integrated Maritime Policy for the European Union'[14]; and
- 'Roadmap for Maritime Spatial Planning: achieving common principles in the EU'[15].

[13] COM (2008) 768. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0768:FIN:EN:PDF.
[14] COM (2007) 575. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0575:FIN:EN:PDF.
[15] COM (2008) 791. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0791:FIN:EN:PDF.

Recommendation:

If Member States decided to perform maritime spatial planning (MSP), and dedicate areas for offshore wind developments and electricity interconnectors, it would send clear positive signals to the industry. Provided the right policies and incentives are in place, MSP gives the industry long term visibility of its market. Consolidated at European level, such approaches would enable investments to be planned out. This would enable the entire value chain to seek investment in key elements of the supply chain (e.g. turbine components, cables, vessels, people) while potentially lowering the risks and capital costs.

Maritime spatial planning approaches should be based on a common vision shared at sea basin level. In this regard, cross border cooperation on MSP is key for building a common and streamlined planning approach and making optimal use of the maritime space. Cross-border cooperation on MSP would aid projects crossing several Economic Exclusive Zones such as large-scale offshore wind projects, and the interconnectors of the future pan-European grid.

Offshore wind synergies with other maritime activities

Offshore wind parks cover large areas as the project size must be sufficient to ensure the financial viability of the project, and as a minimal distance between the turbines is needed to avoid or minimise the wake effects. It is therefore possible to optimise the use of the space by developing synergies with other activities. For example, a project has started in Denmark to combine offshore wind parks with aquaculture. Offshore wind parks could also be combined with large desalination plants, or be used as artificial reefs to improve fish stocks. Since the foundation structure in an offshore wind turbine is large and stable it may in the future be combined with ocean energies to give additional power production at a given offshore site. This last point was also promoted by the European Commission through the recent 2009 FP7 call.

Photo: Eneco

Chapter 3

Building the European Offshore Grid

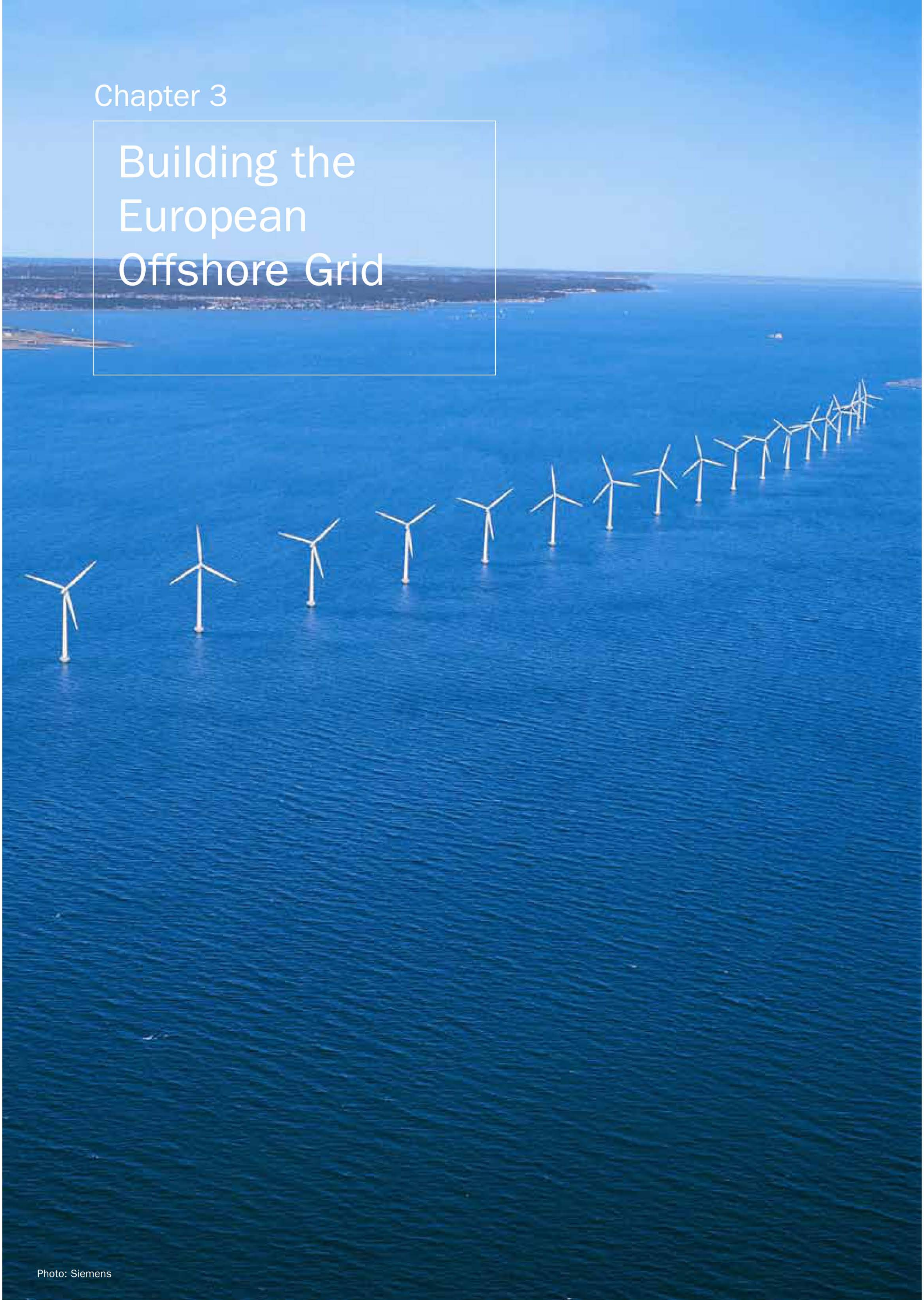


Photo: Siemens

Introduction

The deployment of offshore wind energy requires a dedicated offshore electricity system. Such a system will provide grid access for the more remote offshore wind farms, and additional interconnection capacity to improve the trading of electricity between the differing national electricity markets. The transnational offshore grid of the future will have many functions, each benefitting Europe in different ways:

- the geographically distributed output of the connected offshore wind farms will be aggregated and therefore smoothed, increasing the predictability of the energy output and diminishing the need for additional balancing capacity[16];
- wind farm operators will be able to sell wind farm output to more than one country;
- power trading possibilities between countries will increase;
- it will minimise the strengthening of onshore (mainland) interconnectors' high-voltage networks, which can be difficult due to land-use conflicts;
- connecting offshore oil and gas platforms to the grid will enable a reduction of their GHG emissions;
- it will offer connection opportunities to other marine renewable energy sources;
- shared use of offshore transmission lines leads to an improved and more economical utilisation of grid capacity and its economical exploitation;
- European energy security will be improved, due to a more interconnected European grid;
- increased interconnection capacity will provide additional firm power (capacity credit) from the offshore wind resource.

The future European offshore grid will therefore contribute to building a well-functioning single European electricity market that will benefit all consumers. Because of the prominent concentration of planned offshore wind farms in the North Sea, the Baltic Sea and the Mediterranean Sea, a transnational offshore grid should be built first in those areas. In many of the offshore grid designs that have already been proposed, an offshore grid has branches reaching as far as Ireland, France and Spain.

This section will address planning issues, technology aspects, possible topologies, and the consequences for the European network in general. Furthermore it will briefly discuss the operational, regulatory and economic aspects of an offshore grid.

Mapping and planning the offshore grid

DRIVERS FOR PLANNING

Building an offshore grid is different from building an onshore grid in many ways – not least technically and economically. Perhaps the greatest challenge is the international aspect. The two basic drivers throughout the planning (and later in the implementation stage) of a transnational offshore grid are its role in international trade and the access it provides to wind power and other marine energy sources.

[16] TradeWind, 2009. "Integrating Wind - Developing Europe's power market for the large-scale integration of wind power." Available at: http://www.trade-wind.eu.

The basis for planning the offshore grid is therefore a combination of an ambitious - but realistic - vision of future offshore wind power capacities and a common stakeholder vision on the future necessary expansion of the European transmission network. This report seeks to develop and implement such a vision.

The future projections for offshore wind power capacity are discussed in Chapter 1.

The future development of the European transmission grid is described in different publications (TDP UCTE 2008, Nordic Grid Master Plan 2008) and various national studies (the Netherlands, the UK, Denmark). Some international studies (TradeWind) have explored the implications of offshore wind for grid requirements. At present, issues related to the joint planning of offshore wind power development and grid reinforcement arise in markets with significant offshore wind development (Germany, the UK). Finding practical solutions for these issues will be very helpful for the process of international joint planning.

PLANNING IN THE DIFFERENT MARITIME AREAS

At present, offshore grid ideas are being developed above all for northern Europe, especially for the North Sea and the Baltic Sea. However, offshore wind farms are expected to be developed in most European waters, and so the grid aspects of developments along the Atlantic Coast and in the Mediterranean area also have to be considered in pan-European planning. In the longer term, and depending on further technological developments enabling the industry to reach deeper waters, the offshore network should be expanded to areas that have not yet been investigated, including the northern part of the North Sea.

PLANNING APPROACH

A realistic schedule for a transnational offshore grid should:

- closely follow existing plans and ideas from national transmission system operators (TSOs) to enable a smooth start, for example the different planned connections between the Nordic area and UK, the Netherlands and Germany;
- ensure the network is conceived and built in a modular way, i.e. that it is made up of modules that can feasibly be exploited;
- take into account time-dependent aspects such as realistic implementation scenarios for wind power development, supply chain issues and financing possibilities;
- coordinate the implementation of the offshore network with the upgrade of the onshore network;
- present a coordinated approach to implementing the common vision shared by the relevant stakeholders throughout the process.

Partners in the planning and work process are the TSOs, governments, regulators, technical suppliers, wind farm developers, consultants and financing bodies.

POLICY PROCESSES SUPPORTING THE PLANNING

Because of the complexity of transnational planning processes, the planning of an offshore grid requires strong policy drivers and supra-national control mechanisms. In the present political framework, transmission lines through different marine zones are forced to seek regulatory and planning approval with the relevant bodies of each Member State through which the line passes. Multiple country reviews impose delays of years to an approval process that is already complex enough.

Offshore grid topology and construction

NO LACK OF IDEAS

There is no shortage of ideas from academics, grid companies and various industries on how to construct a dedicated offshore transmission grid. Because of the concentration of planned offshore wind farms in the North Sea and the Baltic Sea, a transnational offshore grid will be constructed in those areas first.

Proposals have been put forward by several different bodies, including the following:

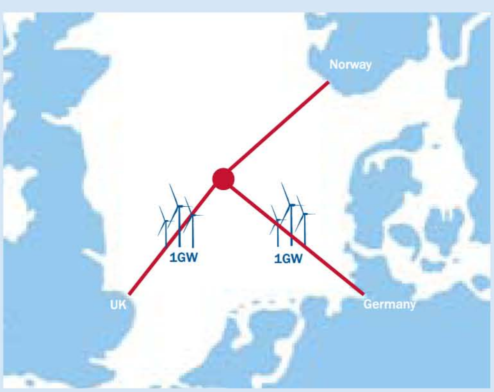
- TradeWind
- Airtricity (see Figure 11)
- Greenpeace
- Statnett
- IMERA
- Mainstream Renewable Power (Figure 12)

FIGURE 11: **Airtricity Supergrid concept**

SuperNode (Mainstream Renewable Power)

The SuperNode configuration, developed by Mainstream Renewable Power, is a first step for the development of the European Supergrid. It would allow the three-way trading of power between the UK, Norway and Germany, and include two 1 GW offshore wind farms, one in the UK and one in Germany. Depending on the wind farm output at any given time, the capacity for trade would go up to 1 GW between each pair of countries in the combination.

FIGURE 12: **Mainstream Renewable Power**



This report seeks to build on these approaches and propose an optimal long-term development plan for the future pan-European offshore electricity grid.

OFFSHORE GRID TECHNOLOGY

The utilisation of HVDC (High Voltage Direct Current) technology for the offshore grid is very attractive because it offers the controllability needed to allow the network both to transmit wind power and to provide the highway for electricity trade, even between different synchronous zones. Moreover, HVDC offers the possibility of terminating inside onshore AC grids, and thus avoiding onshore reinforcements close to the coast.

There are two basic types of HVDC transmission links: HVDC-LCC (conventional HVDC) and the recent HVDC-VSC (Voltage Source Convertor). HVDC-LCC has been extensively used worldwide, operating over 6 GW per line, at voltages of up to 800 kV. 60 GW had been installed by the end of 2004[17].

Today, the drivers for the offshore grid favour HVDC VSC as the best option[17b] for the following reasons:

- the technology is suitable for the long distances involved (up to 600 km), with minimal losses;
- the compactness (half the size of HVDC LCC) minimises environmental impact and construction costs, for example of the HVDC platforms;
- the system is modular. A staged development is possible, and stranded investments can more easily be avoided;
- the technology – because of its active controllability - is able to provide flexible and dynamic voltage support to AC and therefore can be connected to both strong and weak onshore grids. Moreover, it can be used to provide black start[18], and support the system recovery in case of failure;
- multi-terminal application is possible, which makes it suitable for meshed[19] grids.

In this way the HVDC VSC technology seems to offer the solution for most of the offshore grid's technical challenges.

There are two major manufacturers of HVDC VSC technology. ABB uses the brand name HVDC Light, whereas Siemens has branded its technology HVDC

[17] & [17b] European Academies Science Advisory Council, 2009. 'Transforming EU's Electricity Supply – An infrastructure strategy for a reliable, renewable and secure power system'.

[18] Black start is the procedure for recovering from a total or partial shutdown of the transmission system.

[19] Meshed topology offshore grids are able to cope with the failure of a line by diverting power automatically via other lines.

Photo: Elsam

Plus. The technologies are not identical, and efforts are needed to make them compatible and jointly operable, when used together in the future offshore grid. For that purpose, two major conceptual decisions have to be taken – namely, to agree to standardise the DC working voltage levels and to agree on the largest possible plug and play boundary. In addition, other players such as Areva are also developing HVDC VSC technology.

Although all technologies for the offshore grid already exist in principle, there are several aspects of HVDC VSC technology which require technical development in the short term in order to achieve the necessary technical maturity - such as the availability of ultra fast HVDC circuit breakers, load flow control concepts and very fast protection schemes. Also, operational experience has to be collected to optimise the interface with wind power generation in the HVDC environment.

OFFSHORE GRID TOPOLOGY

There are three basic elements which will form the backbone of the future offshore transmission network. These are:

- lines/branches: these consist of submerged cables characterised by transmission capacity;
- offshore nodes (hubs or plugs): these offshore nodes consist of offshore platforms containing

HVDC conversion equipment, switchgear and other electrical equipments, and will serve as:
  - common connection points for a number of offshore wind farms;
  - common connection points for a number of other marine generators; and
  - intersections (junctions) of network branches allowing the electricity to be dispatched to the different electricity markets.
- Onshore nodes: connection points between the offshore transmission grid to the onshore transmission grid.

The offshore grid topology basically builds upon the following types of transmission highways:

- A. interconnectors developed by TSOs (in principle through bilateral cooperation) for the purpose of cross border exchange between electricity markets (current state of play);
- B. lines specifically developed for connection of offshore wind farms, and offshore facilities (current state of play); and
- C. lines developed in a coordinated effort for the purpose of connecting offshore wind, marine technologies and the promotion of cross border trade.

The capital costs of the HVDC converter stations are higher than corresponding substations in AC, while the cost of cables is lower for DC than for AC.

Regarding electricity loss, HVDC has significant losses at converter station level, but lower losses per km than AC. There is thus a trade off in the use of DC versus AC. Therefore, the nodes of the grid should be located near spatially clustered wind farms, as in this way a few nodes per country can be determined, but offshore wind clusters not too far from the coast should be directly connected to shore with an AC line.

EWEA's 20 Year Offshore Network Development Master Plan

EWEA's 20 Year Offshore Network Development Master Plan is based on the necessary grid upgrades that would allow all planned, proposed, under construction and operating offshore wind farms to transport all the electricity produced to European electricity consumers in an economically sound way. It is underpinned by the TradeWind study and existing TSO plans, and is designed, in addition to connecting offshore wind farms to the grid, to increase electricity trading opportunities and improve Europe's energy security.

EWEA urges other stakeholders, particularly the European Commission in its Blueprint for a North Sea Grid and ENTSO-E's System Development Committee, to incorporate EWEA's 20 Year Offshore Network Development Master Plan, taking into account the results of European-funded projects such as WindSpeed (www.windspeed.eu) and OffshoreGrid (www.offshoregrid.eu).

Spotlight on specific EU-funded projects

OffshoreGrid will develop a scientifically-based view on an offshore grid in northern Europe along with a suitable regulatory framework that takes all the technical, economic, policy and regulatory aspects into account. The project is targeted at European policy makers, industry, transmission system operators and regulators. The geographical scope is firstly the regions around the Baltic and North Sea, the English Channel and the Irish Sea. Secondly, the results will be transferred by qualitative terms to the Mediterranean region.

The main objective of the WINDSPEED project is to identify a roadmap to the deployment of offshore wind power in the central and southern North Sea. The roadmap includes the definition of an offshore wind energy target and a set of coordinated policy recommendations for the deployment of offshore wind in this specific sea basin. WINDSPEED delivers a decision support system for the evaluation of the physical potential for offshore wind, having inputs such as policy targets for all users of the sea, allocation rules and calculation rules for the assessment of impacts on offshore wind economics.

EWEA's 20 Year Offshore Network Development Master Plan[21]

The starting point of EWEA's 20 Year Network Development Master Plan is the offshore wind power scenarios presented in Chapter 1 of this report.

The map also shows the offshore nodes and possible onshore connection points (see inside cover for larger map).

FIGURE 13: **Current status of all existing offshore transmission lines and development and concession zones**

The offshore grid map (Figure 13) shows all existing offshore transmission lines (red lines) and all existing offshore concession zones.

FIGURE 14: **Offshore transmission lines in 2020 based on current TSO plans and studies, amended by EWEA as appropriate**

The offshore grid map (Figure 14) shows all existing offshore transmission lines (red lines), all planned transmission lines (yellow lines) and those being studied by TSOs (green lines) - in some cases as amended by EWEA (light blue) - together with the concession zones.

FIGURE 15: **Offshore transmission lines in 2020 as recommended by EWEA**

The offshore grid map (Figure 15) shows all existing offshore transmission lines, all planned offshore transmission lines and those being studied by TSOs, and the first 10 years of EWEA's 20 Year Offshore Network Development Master Plan (grey lines), together with the concession zones.

FIGURE 16: **Offshore transmission lines in 2030 as recommended by EWEA**

The offshore grid map (Figure 16) shows all existing offshore transmission lines, all planned offshore transmission lines and EWEA's 20 Year Offshore Network Development Master Plan, together with the concession zones.

[21]Despite a high theoretical potential, the Mediterranean area is not analysed here, due to lack of substantial data. Such data should come from the OffshoreGrid project (see p.29).

HOW AN OFFSHORE GRID WILL EVOLVE

In northern Europe the offshore grid spans around Great Britain and Ireland, the North Sea including the Channel and the Baltic Sea.

North Sea and Irish Sea

The topology in this area links the countries bordering the North Sea: the UK, Norway, Denmark, Germany, the Netherlands, Belgium and the north of France.

The future North Sea offshore grid will evolve out of existing TSO plans. Improving Norway's connection to the European grid will allow offshore wind farms in the North Sea to connect to these interconnectors, and will at the same time improve the connection of Nordic hydro to northern Europe. EWEA therefore proposes to take the best practice example of Kriegers Flak in the Baltic Sea and apply this principle to the interconnectors already being studied - NorGer, Nord Link and Norway/UK. EWEA proposes a three-legged solution for each of the planned lines:

- NorGer: planned as a link between Norway and Germany but EWEA proposes also linking it to Denmark and having a trajectory and node in the German EEZ[21] to enable offshore wind farms to be connected.
- Nord Link: planned as a link between Norway and Germany but EWEA proposes also linking it to the UK and having a trajectory and node in the German EEZ to enable offshore wind farms to be connected;
- Norway/UK: planned as a link between Norway and the UK but EWEA proposes also linking it to Germany via a node, which would also allow UK Round 3 farms to connect in UK waters and provide an additional node for Norwegian offshore wind farms (and oil and gas platforms).

EWEA also proposes additional three-legged solutions and other lines for the 2020 timeframe:

- a link between Ireland, Northern Ireland and Wales;
- a link between Belgium, the UK and the Netherlands;
- a cable off Northern Norway linking to an offshore node;
- an upgrade between Denmark and Sweden

In the 2030 timeframe the UK link to Ireland will be improved, as will its link to the node off the coast of Norway via the Shetland Islands; Ireland will be directly connected with France, and the nodes off the coast of Belgium and the Netherlands are interconnected with German and UK nodes.

Baltic area

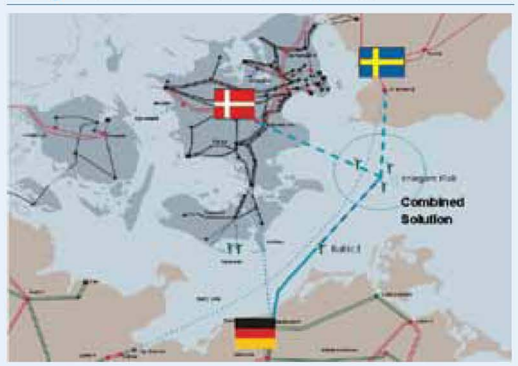
In the Baltic Sea the main offshore grid elements are the following:

- on the western side, the Kriegers Flak 1,600 MW wind farms will be considered to be the first nucleus for an international offshore grid once it is successfully connected to three markets (Germany, Denmark, Sweden);
- further main grid elements are the NordBalt Interconnection between Sweden and Lithuania, preferably built with HVDC-VSC technology, together with a second line between Finland and Estonia (Estlink II) and a reinforcement of the Swed-Pol line;
- further strengthening between Germany/Sweden, Germany/Denmark, and Denmark/Sweden.

Kriegers Flak

Kriegers Flak is seen as a flagship project at European level. It is located on a sandbank (Kriegers Flak) in the Baltic Sea, and is likely to consist of a combination of three wind farms connected to Sweden, Germany and Denmark, for a total capacity of 1.6 GW. Three different TSOs are involved: Vattenfall, Energinet.dk and Svenska Kraftnätt.

FIGURE 17: **Vattenfall Europe Transmission, Energinet.dk, Svenska Kraftnät, 2008**



SOURCE:"Kriegers Flak progress report".

[21] EEZ: Exclusive Economic Zone

TABLE 2: **EWEA's 20 Year Offshore Network Development Master Plan (North and Baltic Seas)**

Name, description and timeframe	Status	Capacity (MW)
Existing - 11 offshore grids		
NorNed linking Norway and the Netherlands	Operating	700
Skagerrak linking Norway and Denmark	Operating	940
HVDC linking France and the UK	Operating	2,000
Kontek linking Germany and Denmark	Operating	600
HVDC linking Germany and Sweden	Operating	600
Konti-Skan linking Denmark and Sweden	Operating	300
SwePol linking Sweden and Poland	Operating	600
HVDC Linking Swedish mainland and Gotland	Operating	260
Estlink linking Finland and Estonia	Operating	350
Fenno Skan linking Sweden and Finland	Operating	500
Moyle Interconnector linking N. Ireland and Scotland	Operating	500
In the 2020 timeframe		
Planned/under construction - seven offshore grids		
Great Belt, internal Denmark	Planned by 2010	600
Fenno Skan II linking Sweden and Finland	Planned by 2011	800
BritNed linking the UK and the Netherlands	Planned by 2011	1,000
East-West Interconnector linking Ireland and north Wales	Planned by 2012	500
Estlink II linking Finland and Estonia	Planned by 2013	700
Upgrade linking Norway and Denmark (Skagerrak)	Planned	350
NordBalt linking Sweden and Lithuania, possibly as HVDC-VSC (formerly SwedLit)	Planned by 2016	700 to 1,000
Under study - 14 offshore grids		
Internal HVDC between Scotland and England	Under study	1,800
Internal HVDC between Scotland and Wales	Under study	1,800
Internal HVDC between Scotland and Shetland Islands	Under study	600
Internal HVDC between Scotland and Isle of Lewis	Under study	600
Internal HVDC in Scotland	Under study	600
Nemo HVDC linking Belgium and UK	Under study	1,000
Upgrade linking UK and France (EFA)	Under study	2,000
Skagerrak 4 linking Norway and Denmark	Under study by 2014	600
Cobra Cable linking the Netherlands and Denmark	Under study by 2016	700
NorNed 2 linking Norway and the Netherlands	Under study 2015 - 2016	700

Name, description and timeframe (North and Baltic Seas)	Status	Capacity (MW)
(Under study with EWEA recommendation – four offshore grids)		
Kriegers Flak linking Denmark, Sweden and Germany. EWEA recommendation: The EU and countries involved should push forward with the project for a three-legged solution as outlined by the recent TSO pre-feasibility study[22]	Under study	600 each
NorGer linking Norway and Germany. EWEA recommendation: NorGer should be developed as a three-legged HVDC-VSC line linking Norway, Germany and Denmark, as a modular connection with a higher capacity potential. With appropriate financial support from the Commission it should be able to plug in offshore wind farms in Norwegian EEZ waters bordering the Danish EEZ, and offshore wind farms in the northern part of the German EEZ	Under study 2017 - 2018	1,400
Nord Link linking Norway and Germany. EWEA recommendation: Nord Link should be developed as a three-legged HVDC-VSC line linking Norway, Germany and the UK), as a modular connection with a higher capacity potential. With appropriate financial support from the Commission it should be able to plug in offshore wind farms in Norwegian EEZ waters bordering the Danish EEZ and offshore wind farms in the norther-western part of the German EEZ	Under study 2016 - 2018	700 to 1,400
Norway/UK linking Norway and the UK. EWEA recommendation: This line should be developed to become a three-legged HVDC-VSC linking the UK, Norway and Germany with possibly three nodes as a modular connection, with a higher capacity potential and with appropriate financial support from the Commission. The node in the Norwegian EEZ could allow offshore wind farms to plug in, together with the Ekofisk and Valhall platforms, and could link to the north-western node in German EEZ	Under study 2017 – 2020 (characterised by Statnett as low+ maturity)	1,000 to 5,000
EWEA recommendation - eight offshore grids		
Three-legged HVDC-VSC line linking Ireland, Northern Ireland and Wales	EWEA recommendation	1,000
Three-legged HVDC-VSC line linking Belgium, UK and the Netherlands	EWEA recommendation	1,000
HVDC Netherlands linking to offshore node	EWEA recommendation	2,000 to 5,000
HVDC North Norway linking to offshore node	EWEA recommendation	2,000
Upgrade linking Denmark and Sweden (Konti-Skan II)	EWEA recommendation	360
Upgrade linking Germany and Sweden	EWEA recommendation	600
Upgrade linking Poland and Sweden	EWEA recommendation	600
Upgrade linking Germany and Denmark	EWEA recommendation	550

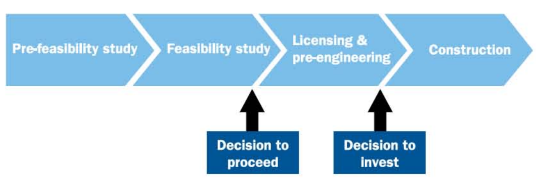
[22] Energinet.dk, Svenska Kraftnät, Vattenfall Europe Transmission, 2009. 'An analysis of Offshore Grid Connection at Kriegers Flak in the Baltic Sea'.

Name, description and timeframe (North and Baltic Seas)	Status	Capacity (MW)
In the 2030 timeframe		
EWEA recommendation – six offshore grids		
Upgrade linking the UK and Ireland	EWEA recommendation	1,000
HVDC linking the UK (Shetland Islands) and north Norway node	EWEA recommendation	2,000
HVDC linking the UK and the Netherlands (as a modular connection, possibly also linking Belgian node)	EWEA recommendation	2,000 to 5,000
HVDC linking the Netherlands with NorGer node	EWEA recommendation	1,000 to 5,000
HVDC linking the Netherlands node with Nord Link node	EWEA recommendation	1,000 to 5,000
New HVDC linking Ireland and France	EWEA recommendation	1,000

OFFSHORE GRID CONSTRUCTION TIMELINE - STAGED APPROACH

Most of the electricity grids in the world have been put together from the bottom up, connecting local producers with nearby off-take points, and this will not be different with the offshore grid. The construction of an offshore grid is a process that will take many years to be fully accomplished. Even the implementation process of a single line is very lengthy (around 10 years), involving several stages (Figure 18).

FIGURE 18: **Stages in a typical timeline for building an offshore interconnector total process duration is around 10 years**



SOURCE: Statnett, 2009

A possible timeline for the construction of a transnational offshore grid is sketched in Figure 18. The timeline falls naturally into three main stages:

STAGE I: LOCAL (NATIONAL) GRIDS

Countries establish and implement coordinated connection for offshore wind power at national level. Onshore connection points are identified. Dedicated (HVDC) offshore lines are built by TSOs to interconnect clustered wind power capacity. Dedicated regulatory regimes are established for offshore transmission, enabling TSOs to recover investments via the national electricity market. The process starts towards the internationalisation of regulatory regimes. The necessary onshore transmission reinforcements are identified. The multilateral grid planning process is prepared. Work on the standardisation and technical development of HVDC VSC technology speeds up.

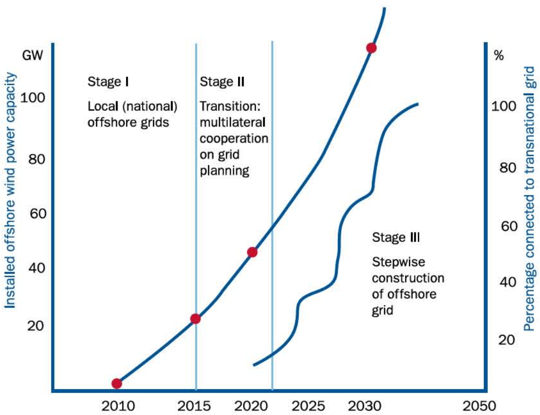
STAGE II: TRANSITION TO TRANSNATIONAL GRID

A process of multilateral grid planning is in place. Long-distance lines dedicated to offshore wind are planned and implemented. Implementation of pilot projects for connecting offshore wind power to different markets (Kriegers Flak, super-node). HVDC VSC technologies are optimised, based on operational experience. Adaptation of trajectories of planned offshore interconnectors to connect offshore wind power.

STAGE III: TRANSNATIONAL GRID

Step by step implementation of the transnational offshore grid. The planned lines are built. The maps illustrate a proposed grid scenario for the short term (present situation to 2010), the medium term (2020) and the long term (2030 and beyond).

FIGURE 19: **Stages in the development of a transnational offshore grid. The actual rate of development of offshore wind power capacity might follow a more step by step development**



SOURCE: XPWind, EWEA

Onshore grid upgrade

The offshore grid cannot be isolated from the rest of the network. The rational development of such a grid for the purposes of promoting trade and connecting offshore renewable power has to be part of an overall planning process for the European networks.

The consequence in the short to medium term is that onshore reinforcements have to be implemented on specific transmission corridors and lines. The exact locations of corridors and lines to be upgraded need to be identified by detailed studies[23].

One of the first studies that looked into this issue was the TradeWind project. On the basis of wind power scenarios, the study identified upgrades that would significantly alleviate the congestions in the European grid for wind power scenarios up to 2030.

The operational and regulatory aspects of offshore grids

NETWORK OPERATION: CLOSE COOPERATION WITHIN ENTSO

The principal operational tasks concerning the offshore grid are:

- operating and maintaining the grid in a secure and equitable way, whilst granting fair access to the connected parties; and
- scheduling the HVDC lines for the predicted amounts of wind power and the nominated amounts of power for trade.

The operation of the offshore grid will, however, be an integral part of the operation of the interconnected European grid and therefore very close coordination is required between the various connected power systems, which is a challenging task for the newly formed ENTSO-E. It is therefore vital that ENTSO-E establishes a structure that is suited to such cooperation, for example through the North Sea Regional Group, as well as within the System Operations and Market Committees.

Photo: Siemens

[23]Such as the German study: DENA, 2005. 'Integration into the national grid of onshore and offshore wind energy generated in Germany by the year 2020'. Available at: http://www.dena.de/en/topics/thema-esd/publications/publikation/grid-study.

Beside these organisational developments, one of the first tasks for the TSOs and industries involved is to set up a system of standards and grid connection requirements. New standardisation efforts are needed in the field of HVDC, more specifically to agree on a common system of voltage levels. Furthermore, in order to enable a smoothly and efficiently constructed grid, it will be essential that parties agree on a system of plug and play and standard – interchangeable building blocks.

COMBINING TRANSMISSION OF OFFSHORE WIND POWER AND POWER TRADING

The capacity of the offshore grid should be sufficient to transport the maximum expected output of the connected offshore wind farms. However, this maximum is only produced for a certain amount of hours each year. On average (annual basis or longer), the capacity factor of the offshore wind farms, and so the capacity usage of the line by the wind farm, is approximately 40%. The offshore wind farms should have first call on the rights to use the grid connection, as:

- in a properly functioning electricity market, wind power's very low marginal cost will ensure it is the cheapest (and environmentally most benign) electricity at any time on the market place; or
- in the absence of a properly functioning electricity market (as is currently the case) priority access would need to be granted to wind power, as stipulated in the EU Renewable Energy Directive 2009/28/EC.

Either way, wind farm operators would specify their grid requirements to the grid operator on a day-ahead basis, together with functioning intra-day markets. The remaining capacity would then be available for interconnection users at day-ahead nomination, together with functionioning intra-day markets.

The benefits of the operation of such a grid for the market have been outlined by the TradeWind project. The offshore grid enables the different electricity markets to be interconnected in a much better way and with a significant surplus, with markets relying on import and at the same time providing access to cheap balancing power to deal with the added variability introduced by the offshore wind resource. As an example, north-west Germany is identified as an energy surplus area with high internal congestions on the mainland grid. Taking into account the fact that the Netherlands and Belgium will benefit from increased imports, and that Norway has large amounts of controllable and storable hydro power, an offshore grid which linked these countries together would bring considerable economic, environmental and system benefits[24].

In the Baltic Sea, linking the wind farm clusters in the Kriegers Flak together would enable flexibility for transporting higher amounts of offshore wind power to areas with higher electricity prices. Furthermore, such a link would make it possible to trade power effectively between Sweden, east Denmark and Germany in periods with low wind speeds.

REGULATORY FRAMEWORK ENABLING IMPROVED MARKET RULES

At present, there are significant barriers in the electricity market in Europe, which hamper an efficient combination of trade and offshore wind power transmission via a transnational offshore grid:

- the differences in regulatory regimes and market mechanisms of the countries involved;
- a lack of proper rules with respect to priority feed-in for wind power versus nomination of day-ahead and intra-day trade.

These issues should be taken up in the ongoing Regional Initiative for the integration of European power markets as pursued by ERGEG. In order to ensure that sufficient grid capacity is built in time, a common regulatory regime should be put in place to incentivise the organisations responsible for wind farm connection (TSOs) and organisations responsible for planning interconnection (TSOs, market parties) to plan and construct the most economically efficient grid system.

It is necessary to establish a legal and regulatory framework that enables an efficient use of the different lines of the offshore grid in all its stages. In order to ensure an efficient allocation of the interconnectors for cross-border trade, they should be allocated directly to the market via implicit auction.

[24] TradeWind, 2009. 'Integrating Wind - Developing Europe's power market for the large-scale integration of wind power.' Available at: http://www.trade-wind.eu.

Photo: Siemens

Further market integration and the establishment of intra-day markets for cross border trade are of key importance for market efficiency in Europe when integrating large amounts of offshore wind power. In this way, the market will respond more adequately to the characteristic properties of wind energy[25]:

- its predictability, which improves with a shorter forecasting horizon and as the size of the area for which the forecast is organised increases;
- its variability, which decreases as the size of the geographical area increases due to spatial de-correlation;
- its low marginal costs and low CO_2 emissions which favour the use of wind power whenever wind is available, even at times which can be challenging in situations of low load, near minimum generation level.

Taking these properties into account, TradeWind used market models to help estimate the economic benefits at EU level of market mechanisms favouring wind power integration, leading to the following results:

- *flexibility of rescheduling dispatch decisions in the generation mix:* accepting intraday wind power forecasts by shortening gate-closure times would result in a reduction in the total operational costs of power generation of at least €260 million per year;
- *flexibility of cross-border exchange* (assuming sufficient transmission capacity): allowing the intraday rescheduling of cross border exchange would lead to annual savings in system operation costs of €1-2 billion per year.

Economic value of an offshore grid

INTRINSIC VALUE OF OFFSHORE GRID

There are several ways of evaluating the economic value of an offshore grid. A basic distinction can be

[25] TradeWind, 2009. 'Integrating Wind - Developing Europe's power market for the large-scale integration of wind power.' Available at: http://www.trade-wind.eu.

made between the purely market orientated approach which looks at economic benefits for specific interested parties (for example investors) and the 'regulated' approach, which looks at the benefits to society.

A preliminary assessment of the costs/benefits of a transnational offshore grid in the regulated approach indicates that it brings high economic value to society. This can be concluded from the TradeWind analysis, with an estimated reduction in operational cost of power generation at the European level of €326 million per year, as brought about by a meshed offshore grid. The benefits are to a great extent due to the added flexibility introduced when including an HVDC network that links many countries (Norway, Denmark, Germany, the Netherlands, Belgium and the UK in the North Sea and Sweden, Denmark and Germany in the Baltic Sea). Because HVDC connections are controllable, bottlenecks in the AC grid can be avoided when transporting offshore wind power to consumers in areas with an energy deficit or high local generating costs.

As demonstrated by TradeWind, a €326 million reduction in annual total power generating costs can be interpreted as a very conservative estimate of the break-even cost for the extra investments needed to realise a meshed transnational offshore network, compared to a more nationally orientated approach.

Taking into account factors that are not covered in the TradeWind cost model, such as the start-up cost of thermal generators, internal grid constraints and the balancing of wind power, the operational benefits of a meshed offshore grid could very well be significantly higher than estimated by the model. It is also important to note that the offshore grid structure was by no means optimised in the TradeWind study.

This conclusion is in line with findings of the study by Veal[26], which looked into the economics of combining offshore connections with interconnectors for trade. The combination appears to be cost-effective in many scenarios, depending on the distance from the offshore wind farm cluster to shore. Certainly for distances of more than 90km from shore, there is always some economic benefit gained from integrating those wind farms that lie among the interconnector's route, or where this route can easily be diverted to pass through the wind farm area.

Photo: GE

Apart from the economic benefits highlighted above, the actual implementation will create high social benefits in terms of economic growth, industrial development and employment.

THE VALUE OF AN OFFSHORE GRID IN THE CONTEXT OF A STRONGER EUROPEAN TRANSMISSION NETWORK

On a European level, the benefits of the transmission network upgrades – such as building subsea interconnectors linking offshore wind farms - are even more significant. A preliminary evaluation has been made within the TradeWind project, which calculated the

[26] C. Veal, C. Byrne, S. Kelly, 2007. 'The cost-benefit of integrating offshore wind farm connections and subsea interconnectors in the North Sea'. Proc. European Offshore Wind Conference and Exhibition, Berlin, Germany.

reduction in the operational costs of power generation caused by dedicated grid upgrades.

For TradeWind's 2020 grid and wind power scenario, the savings in operational costs amount to €1.5 billion per year, allowing for an average investment cost of €490 million for each of the 42 transmission upgrade projects that were proposed, including several offshore HVDC lines. Because this estimate assumed a less strong interconnection between the countries around the North Sea than the one proposed in this report, it should be considered as conservative.

Investments and financing

INVESTMENT COST ESTIMATES

Until now, few studies have published estimates on investment costs for a Europe-wide offshore grid. Two recent reports made some preliminary calculations which allow ballpark figures to be estimated for the total investment cost of a transnational offshore grid.

- Greenpeace[27]: this study proposed a grid in the North Sea for 68 GW of offshore wind power, to be in place by around 2025. The topology considered for the study has a total single line length of 6,200 km. Assuming 1 GW capacity per line, the proposed grid would cost €15-20 billion;
- TradeWind[28]: the additional investment costs were estimated for a meshed offshore grid connecting the "far" offshore wind farm clusters with a total installed capacity of 80 GW in the North Sea to those in the Baltic Sea, according to the 2030 high scenario. The additional investment costs for the topology were estimated to be around €9 billion, taking into account specific cable lengths and transmission capacities (not including the costs of the interconnectors envisaged already now for trading purposes);
- for comparison purposes: the UK's East Coast Transmission study[29] looked at an offshore network along the east coast of GB linking in the Shetland and Orkney Islands in 2020. It estimated a total investment cost of €5.5 billion.

Taking into account the fact that the offshore network discussed in this chapter is more extensive than the topologies used in the studies mentioned above, a safe bottom line assumption for investments in offshore transmission up to 2030 is in the range of €20-30 billion. This number would include both the 'trade' interconnectors and the dedicated lines for wind power connection. For comparison, the International Energy Agency (IEA) estimates total investments in European electricity transmission grids of €187 billion in the period 2007-2030[30]. The economic projections and budgeting should be made within the framework of a total upgrade of the European transmission network, which also comprises the required onshore upgrades. It is evident that a detailed assessment has to be based on detailed network designs. Furthermore in

[27] Greenpeace, 2008. 'A North Sea Electricity Grid [R]evolution'. Available at: http://www.greenpeace.org/belgium.
[28] TradeWind, 2009. 'Integrating Wind - Developing Europe's power market for the large-scale integration of wind power.' Available at: http://www.trade-wind.eu.
[29] Seanergy: East Coast Transmission (January 2008).
[30] International Energy Agency, 2008. 'World Energy Outlook'.


Photo: Vestas

the assessment of the economics, the cost of electrical losses and operation and maintenance costs should be taken into account.

FINANCING THE EUROPEAN ELECTRICITY GRID

The financing of the future pan-European offshore grid will involve significant investments. Therefore a good understanding of the transiting electricity volumes, which will come from the production of the offshore wind parks and the development of trading, is necessary to ensure a sustainable return on investment.

Investments in regulated interconnectors, performed and operated by TSOs should prioritise meshed grids. In this respect, the regulators should allow these investments with higher risks and longer return rates. Upfront guarantees are needed, possibly in combination with regulated returns. Such guarantees should be based on the cumulative number of consumers on the interconnected markets. The final cost for the consumers, however, would be lowered by the fees collected by the network operators through the use of the interconnector. Therefore, as the European electricity market becomes fully operational, trading develops, and the grids are used at full capacity, the cost for the final consumer would be minimal.

If allowed by regulators, merchant interconnectors could represent additional profits for TSOs, which would incentivise their construction. Private companies investing in these face higher risks, in particular for the connection of large offshore wind arrays, as the profitability of the interconnector would then depend on the development speed in the area. In these cases, the investment could be guaranteed by a specific instrument, for example by the European Investment Bank Risk Sharing Finance Facility (RSFF).

As described previously, the bankability of the future pan-European electricity grid seems ensured, but investments should happen in a timely manner. In order to speed up the process, and in addition to dedicated streamlined legislation, support should be provided to the investments. In this respect, the European Economic Recovery Plan is a welcome small step in the right direction. But existing EU instruments, such as the funds for Trans-European Networks, or the forthcoming 'Marguerite fund', managed by the European Investment Bank, should be directed towards offshore wind power, key components of the value chain, and electricity infrastructure for offshore wind power. At regional level, structural funds should also be directed towards the development of electricity infrastructures.

Recommendations:

It is recommended that a transnational offshore grid infrastructure be built to connect the predicted 40 GW by 2020, 85 GW by 2025 and 150 GW of offshore wind power by 2030, together with the promotion of trade between electricity markets. A realistic planning schedule for the offshore grid should closely follow existing initiatives for offshore interconnectors, and would conceive a grid in a modular and methodical way. The transnational offshore grid must be planned as an integral part of the European transmission system and involve onshore reinforcements where necessary.

An ambitious European vision must be established using EWEA's 20 Year Offshore Network Development Master Plan; the planning and implementation process should involve close cooperation and efficient coordination between the stakeholders (European TSOs). ENTSO-E should provide the appropriate forum for cooperation, should a sufficiently ambitious vision emerge in ENTSO's 10 Year Network Development Plan.

HVDC VSC is a promising technology and R&D should be accelerated to address the remaining technical issues. Appropriate standardisation work should be carried out in the short term.

Preliminary topologies will be presented, including possible time frames (short, medium and long term). Ongoing studies like the European Commission funded OffshoreGrid project are expected to provide more detailed analyses in the short term. These proposals should be taken up as soon as possible in the planning process of ENTSO.

A common regulatory regime should be put in place to incentivise the organisations responsible for wind farm connection (TSOs) and the organisations responsible for planning interconnection (TSOs, market parties) to plan and construct the most economically efficient grid system.

Preliminary assessments of the economic value of the offshore grid indicate that it will bring significant economic benefits to all society.

Chapter 4

Supply Chain

Photo: Vestas

Building a new European offshore industry

In the last few years, the offshore wind energy sector has emerged as a distinct sector of the wind industry. In terms of technology, the onshore market is approaching maturity, with well established processes and reliable mass-produced products. Onshore, technological improvements are focused on delivering large numbers of wind turbines and ensuring cost competitiveness through the optimisation of the manufacturing process and supply chain management. Research is focused on further improving the products' reliability and efficiency.

The offshore wind energy sector is at a much earlier stage of development. In terms of annual installations, offshore wind energy is where onshore wind was in the early 1990s. With 1.5 GW installed today, the sector will shortly leave the demonstration phase to enter a phase of strong industrial growth. In the coming years, the main focus will be on standardising the installation processes and developing dedicated offshore turbines from a dedicated supply chain, just as it was for onshore wind 15 years ago.

Whereas the size of onshore wind turbines, and onshore turbine technology, seem to be reaching an optimum, offshore wind turbine technology is still progressing and evolving fast, to reflect the requirements of conditions specific to offshore, such as market evolution and economies of scale. In this field, incremental technology innovations are taking place, but technological breakthroughs are sought in parallel. In the development of offshore, the door is still wide open for innovative concepts and designs.

Therefore, the European offshore wind industry should be seen as a specific industry, distinct from onshore wind industry development. Reaching 40 GW of offshore wind energy by 2020 will mean manufacturing, installing and operating approximately 10,000 wind turbines, which corresponds to an average of three to four offshore turbines being installed per working day over the next 12 years. Currently, the wind power industry installs 20 onshore wind turbines in the EU per working day. Developing a new European offshore industry is a challenge, but the development of onshore technology and markets serves as a strong indicator and benchmark for what can be achieved.

This industry will also develop in partnership with related industries, such as the oil and gas sector, the shipbuilding industry and the steel sector, and be a driver for their future development. Offshore wind energy provides an historic opportunity to create a new heavy industry in which Europe is a technology leader, uniting existing heavy industries in a common effort to tackle climate change and improve the security of Europe's energy supply, whilst reducing energy imports, creating new jobs and ensuring European technology leadership.

Cost reductions for the offshore wind energy sector will arise in particular from higher market volumes and longer production series from the industry. The project scale will increase, and the trend will continue towards larger offshore wind farms in the 200-300 MW range and beyond, using dedicated and standardised offshore turbines. This will enable streamlined, repeatable installation processes, and provide incentives to build the necessary installation vessels and access technologies. Regarding access, dedicated harbours will be necessary to support the implementation of a large number of offshore wind turbines and foundations.

In the following sections, some of the major cost drivers are addressed: turbine supply, the available substructures, vessels and harbours.

Supply of turbines

Today, six turbine manufacturers are already supplying the offshore market: Siemens, Vestas, REpower, BARD, Multibrid and Nordex.

Most current offshore turbines are adaptations of onshore designs. The production capacity for offshore wind turbines is therefore dependent on the growth in the onshore market. Given that the onshore market is less risky than the offshore market for turbine manufacturers and developers, this causes bottlenecks in periods of high onshore demand.

MAKE consulting[31] (Figure 20) indicates that there is currently more production capacity in Europe than is needed to fulfill European demand. Total onshore and offshore demand is forecast to reach 10 GW in 2010, compared to a production capacity of approximately 12 GW, if castings are considered as the limiting elements. That would leave room for production capacity to be available for offshore manufacturing.

In addition, offshore wind turbine manufacturers are increasing their capacity. A minimum offshore turbine capacity of 5,750 MW by 2013 (Table 3), will be sufficient to supply the increase in the offshore market demand from 1.7 GW in 2011 to 6.8 GW in 2020.

2008 was characterised first by component and then turbine supply shortages which led to growth in wind turbine prices, partly due also to an increase in the price of raw materials. The market will now see signs of relaxation, including offshore turbine availability, and increased competition, which may drive the costs down in the medium term.

TABLE 3: **Turbine supply estimates four years ahead**

Manufacturer	Turbine supply 2008 (MW)	Offshore capacity 2008 (MW)	Projected production (MW) and timeline	Offshore capacity (MW)
Siemens	1,947	649[32]	6,000	2,000
Vestas	5,581	-	10,000 by 2010	2,000[33]
REpower	943	-	2,600 by 2010[34]	850[35]
BARD Engineering	-	-	400 by 2010	400
Multibrid	50	50	505	505
Nordex	1,075	150	4,450 by 2011	n.a.

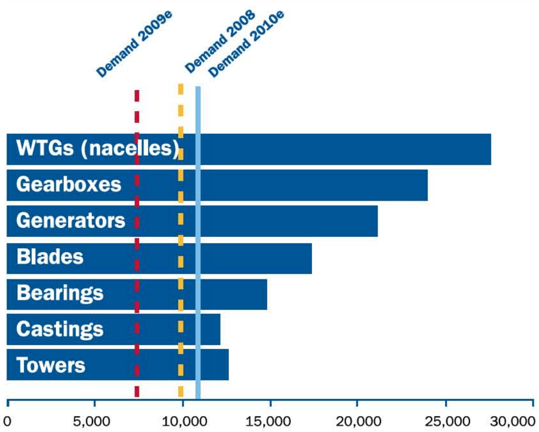
Source: BTM Consult, 2008. "World market update 2008" for the supplied capacity in 2008, and EWEA.

The economics of offshore wind tends to favour larger machines. The offshore environment may allow the relaxation of a number of constraints on turbine design, such as aesthetics and sound emission level. However, addressing marine conditions, corrosion and reliability issues creates new challenges in the offshore sector. In the near term this will lead to a significant modification of onshore machines by the offshore sector, and in the medium and long term, to the development of specific offshore turbine designs.

This trend is reflected by the new generation of offshore wind turbines which are coming on the market. These larger designs (in the 5 MW range) are dedicated to the

[31]MAKE Consulting, 2009. 'The wind forecast, supply side'.
[32]Siemens reserved one third of its capacity for offshore wind.
[33]No data available. Estimate assumes Vestas delivers as much as Siemens.
[34]Based on Reuters Article Repower Plans Capacity Expansion April 2, 2008.
[35]Assume 1/3 of capacity.

FIGURE 20: **Domestic production capacity in Europe compared to demand (MW)**



Source: MAKE Consulting, 2009. 'The wind forecast. Supply side.'

offshore environment, and are aimed at addressing its major challenges, such as marinisation, corrosion, reliability and maintainability.

There is no consensus within the sector regarding the optimal size of an offshore wind turbine as the main focus is reliability and cost efficiency. In this regard, a global approach to the value chain is needed. In the past, upscaling was a major cost driver for the wind industry. However, while large wind turbine designs (up to 10 MW) are often cited, this raises the issue of the availability of the installation vessels and cranes able to install and operate these machines. The main driver for offshore wind technology continues to be economic efficiency, rather than generator size.

For future applications, the key element will be to further improve turbine reliability, as the accessibility of offshore wind farms for repair and maintenance is lower than for offshore. Two philosophies are currently emerging in this regard:

1. improving wind turbine intelligence, implementing redundancy, advanced control algorithms, condition monitoring, and preventive maintenance algorithms;
2. developing simple, robust wind turbines including as few moving parts as possible to limit the risk of failure (two-bladed, downwind, direct-drive turbines, variable speed with new generator concepts).

Photo: Dong Energy

TABLE 4: **Offshore wind turbine manufacturers**

Manufacturer	Power output	Record
Siemens	3.6 MW	Siemens Wind Power has stated that it is prepared to reserve up to one third of its production capacity for offshore wind turbines. In offshore development, Siemens has taken a lead position, with the SWT3.6 107. This position was further strengthened in 2008, when the company signed an agreement with Denmark's DONG Energy for the supply of up to 500 offshore turbines. Bonus – now Siemens Wind Power - pioneered the offshore installation of wind turbines with the world's first offshore wind farm at Vindeby, Denmark, installed in 1991. Since then, its track record includes Nysted Havmøllepark, Burbo Offshore Wind Farm and Greater Gabbard. Siemens Energy will supply 175 of its SWT-3.6-107 (3.6 MW) wind turbines to the 1 GW London Array offshore windfarm owned by DONG Energy, E.ON and Masdar. Siemens is currently developing its next generation of offshore turbines, and testing 3.6 MW direct drive concept, suitable for offshore applications, with the aim to improve reliability and reduce costs.
Vestas	3 MW	Vestas is one of the few players that has experience in the offshore sector. In late 2008 the company won a large order of 300 MW for Warwick Energy's Thanet project in the UK. Vestas will increase its total production capacity (onshore and offshore) to 10 GW in 2010. No reservation of capacity has been announced for offshore. The offshore turbine supply will rely on the developments of the onshore market.
Nordex	2.5 MW	The N90 offshore is an adaptation of the onshore design. This turbine is designed for offshore use.
REpower	5 and 6 MW	REpower manufactures some of the largest wind turbines in the world suitable for offshore use, the 5M (5 MW) and the 6M (6 MW). REPower will install six 5M in 2009 at the test project Alpha Ventus. The 5M serial production begun in autumn 2008 in a new construction hall in Bremerhaven. In the beginning of 2009, the first three 6M turbines were erected close to the Danish-German border, where they are to be tested for offshore operation and where they will be subjected to a type certification. REpower is participating in the "Beatrice Demonstrator Project" to test the performance of the 5 MW turbine on the open sea 25 km off the east coast of Scotland and at a water depth of over 40m. REpower recently signed an agreement with Vattenfall to supply 150 MW to the Ormonde wind farm. Delivery is scheduled to start in 2010.
BARD Engineering	5 MW	BARD has developed a specific offshore design. Their development focuses on the Deutsche Bucht. In the first phase BARD has planned three wind farms each with 80 turbines of 5 MW. The permit for the project "Bard Offshore 1" has already been obtained.
Multibrid	5 MW	Multibrid developed a specific offshore design based on a 5 MW permanent magnet generator and a single stage planetary transmission, currently being tested at Alpha Ventus. Multibrid will supply 80 M5000 turbines for the offshore Global Tech 1 wind farm (400 MW). Global Tech 1 is located 90 kilometres from the coast in the German North Sea. Delivery is scheduled for 2011-2012.

SOURCE: MAKE Consulting, own elaboration.

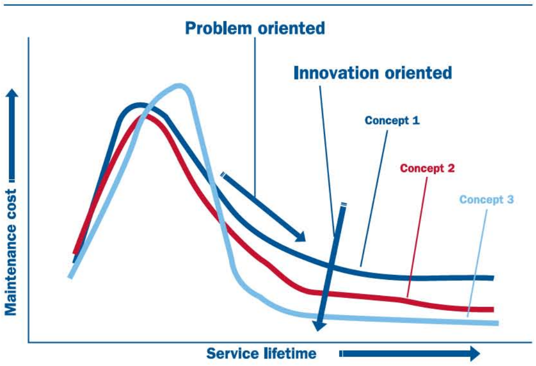
In addition to the current market players, newcomers are taking an interest in the market, such as Acciona, which is participating in the UK's Round 3 with a marinised 3 MW turbine[36], and Gamesa, which may produce a 3.5 MW offshore turbine before 2015, depending on market dynamism. In addition, the upcoming large market volumes may also attract non-European newcomers.

The future for wind turbine designs

In order to establish large production volumes, several pressing demands have to be met. This can be realised through a strategy focused on producing continuous, incremental improvements in the current basic concepts of wind turbine systems. Besides this strategy of incremental improvement, offshore project designers and operators, for instance, are requesting the development of completely new concepts. This second approach is also an opportunity to make significant reductions in the cost of energy by developing innovative concepts. These two strategies should be developed in parallel.

This dual approach is illustrated Figure 21, through the evolution of maintenance costs as a function of concept lifetime. A typical learning process demonstrates an increase of maintenance and repair cost immediately after putting a new concept into operation. Through incremental technological improvements, the maintenance and repair costs decrease. For an innovative concept, it is likely that a new learning trajectory with the same characteristics will be followed.

FIGURE 21: **Illustration of problem-solving and innovation orientated research**



Courtesy: Jos Beurskens, ECN.

This dual approach applies for offshore wind energy. On the one hand, manufacturers focus on incremental innovation by improving product reliability, increasing component lifetime and developing preventive maintenance strategies. On the other hand, breakthrough concepts are discussed, with the objective to make offshore turbines as simple and robust as possible.

Offshore operation and maintenance of wind turbines is still very much in its infancy with each project having its own approach. As the amount of operational offshore units increases, the operation and maintenance (O&M) function will have to be certified and unified to create a unified O&M industry. Some ideas that may be introduced into the O&M market are as follows:

- swing off systems enabling a spare nacelle to replace a nacelle in need of service;
- preventive and automatic systems that can carry out oil, brush and filter changes independently of human presence;

[36]Recharge, 12 June. 'Taking our turbines offshore will be a breeze says Acciona'.

Photo: Stiftung Offshore Windenergie

- multi–coated blades keeping blade maintenance to a minimum;
- modular drive trains should be introduced making heavy part replacement easier. Service schedules should be modelled on those from the conventional power industry with proper life time analysis of the different components.

Improving the reliability of offshore wind turbines is paramount to the success of offshore wind energy in the future. The larger the machine and further away from the coast, the larger the economic loss for non-operation and associated maintenance. Vintage wind turbines often have the same gearbox for their entire working lives. Modern wind turbines are much larger and optimised by weight and efficiency. They need a number of major overhauls during their lifetimes to ensure efficient operation, as does any conventional power generation plant. Wind turbines are currently designed in such a way that the exchange of main components or sub assemblies is difficult. More efficient and newer drive train concepts are needed to bring turbine reliability up to the required level. A more modular build up of drive trains with more built in redundancy could help faster, cheaper and more efficient turbine maintenance. The need for extremely reliable machines offshore can also be an extra driver for the reliability of onshore machines.

Innovative concepts, such as variable speed, direct-drive offshore wind turbines are currently emerging, with the aim of limiting the number of moving parts and lowering maintenance costs, as gearboxes are expensive to replace offshore. A multi-pole gearless machine also operates at lower drive train speeds and thus creates less stress on components. A main challenge for these concepts is to reduce the weight on top of the tower, in order to optimise the use of material and limit the transport and installation costs. So far, gearless machines have been heavier and more expensive to produce than their geared equivalent. Lighter gearless technology is now being tested onshore.

Larger machines (5 to 10 MW), specifically designed for offshore could bring benefits in terms of economies of scale by placing fewer larger machines on fewer foundations, or increasing the wind farm's power output. For example, economies of scale could also be realised by increasing the lifetime to 30 years, provided it does not negatively affect the design.

Concepts such as two-bladed downwind turbines could emerge in the medium term. Two-bladed machines are louder in operation making them less appropriate onshore, but not offshore. A two-bladed machine would be easier to install as nacelles can be stacked with the full rotor mounted, whereas the single blade lifts of the third blade for the bunny eared configuration are highly dependent on calm weather. No large two-bladed offshore turbine is currently in operation.

Supply of substructures

The offshore manufacturing industry was originally developed by the oil and gas industry to supply a limited quantity of bespoke structures. It established a number of facilities around Europe to manufacture these structures, and over the last 40 years it has built several hundred of them. However, as oil and gas technology has moved towards subsea developments, offshore manufacturing capacity has been significantly reduced.

Today the main actors in the offshore wind industry are civil marine engineering firms such as MT Højgaard, Per Aarsleff, Bilfinger and Berger, Hochtief, Züblin, Dredging International, Van Oord and Ballast Nedam. The same goes for the vessels used: Buzzard, Jumping Jack, Vagant, Excalibur, Eide, Rambiz and Svanen are mainly used for marine works.

The offshore wind industry will need to deploy upwards of 10,000 structures by 2020. The offshore manufacturing industry cannot deliver this in its current form. The industry currently has insufficient capacity, and the processes adapted from oil and gas manufacturing are not capable of delivering the volumes required. Therefore the offshore wind industry must take urgent steps to rectify this situation. In addition, the supply of substructures should not been seen as independent from their transport and installation as an integrated approach is taken, taking into account unique site conditions and the location of the wind farm.

Substructures represent a significant proportion of offshore development costs. In the case described by Papalexandrou[37], the foundation represents 25% (5 MW turbine) to 34% (2 MW turbine) of investment costs in 25m water depth. Thus, novel sub-structure designs and/or improved manufacturing processes that reduce costs will be critical to improving the economics of offshore developments.

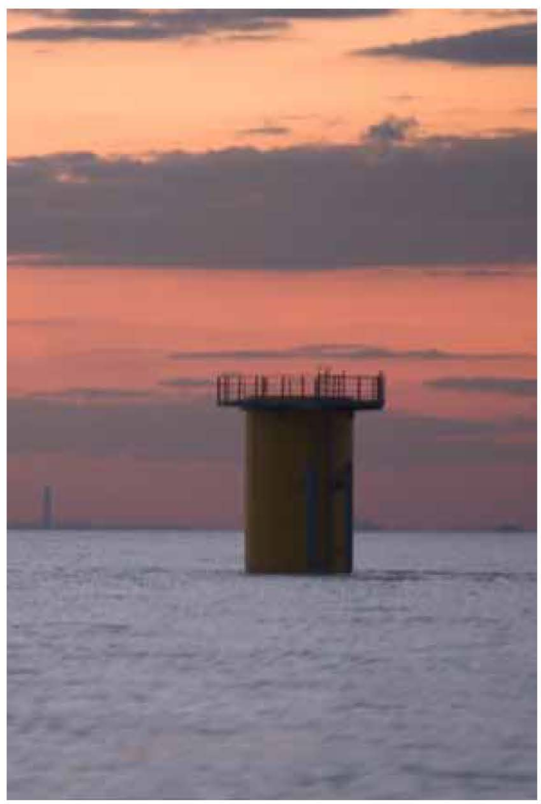


Photo: Elsam

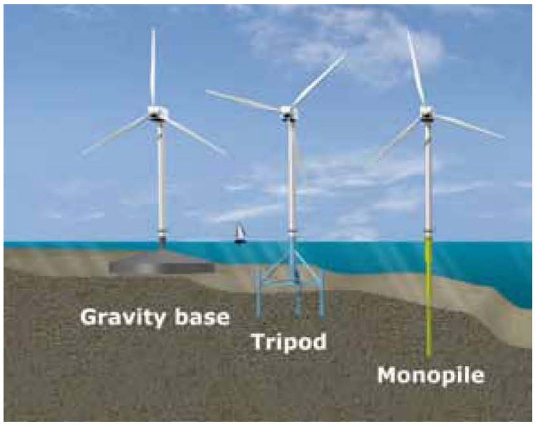
[37]Papalexandrou, 2008. 'Economic analysis of offshore wind farms. KTH School of Energy and Environment, in partnership with Ecofys'.

TABLE 5: **Overview of the different types of substructures**

Type of substructure	Brief physical description	Suitable water depths	Advantages	Limitations
Monopile steel	One supporting pillar	10 – 30m	Easy to manufacture, experience gained on previous projects	Piling noise, and competitiveness depending on seabed conditions and turbine weight
Monopile concrete, installed by drilling	One supporting pillar	10 – 40m	Combination of proven methods, Cost effective, less environmental (noise) impact. Industrialisation possible	Heavy to transport
Gravity base	Concrete structure, used at´ Thornton bank	Up to 40m and more	No piling noise, inexpensive	Transportation can be problematic for heavy turbines. It requires a preparation of the seabed. Need heavy equipment to remove it
Suction bucket	Steel cylinder with sealed top pressed into the ocean floor	n.a.	No piling, relatively easy to install, easy to remove	Very sensitive to seabed conditions
Tripod / quadropod	3/4-legged structure	Up to 30m and more	High strength. Adequate for heavy large-scale turbines	Complex to manufacture, heavy to transport
Jacket	Lattice structure	> 40m	Less noise. Adequate for heavy large-scale turbines	Expensive so far. Subject to wave loading and fatigue failure. Large offshore installation period (first piles, later on placing of structure and grouting) therefor sensitive for weather impact
Floating	Not in contact with seabed	> 50m	Suitable for deep waters, allowing large energy potentials to be harnessed	Weight and cost, stability, low track record for offshore wind
Spar buoy *Hywind being tested*	Floating steel cylinder attached to seabed	120 - 700m	Very deep water, less steel	Expensive at this stage
Semi submersible	Floating steel cylinder attached to seabed	Blue H Prototype being tested in 113m	Deep water, less steel	Expensive at this stage

Source: Carbon Trust, EWEA, Companies

FIGURE 22: **Shallow water and medium depth foundations**



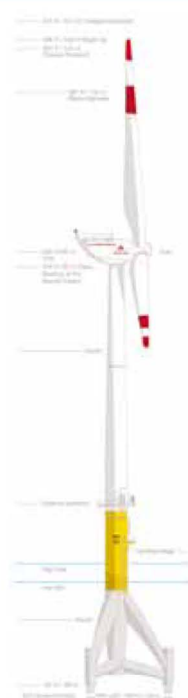
SOURCE: Carbon Trust as published in Recharge 26/06/09.

Today, there is no standard offshore substructure design, and at depths of over 25m the foundation costs start to increase dramatically. Most offshore structures developed to date use 2–3 MW turbines in water depths of up to 20m, and most of those to be developed in the near future will do the same. These will be largely based on monopile technology and gravity-based structures (Figure 22). However, as turbine size increases and the industry migrates into deeper waters, additional sub-structure designs will be required. Different concepts will compete, such as fixed structures with three or four legs (tripods/quadropods) (Figures 22, 23 and 24), gravity structures or jackets. Such technologies are suitable for water depths of up to 50-60m, depending on the project economics, and site conditions and would be therefore well adapted to countries with medium depth waters.

In order to harness the offshore wind potential of deeper waters such as those off the Norwegian coast, the Atlantic Ocean, or the Mediterranean Sea, floating designs are required (Figure 23). Three demonstrators are available in Europe today:

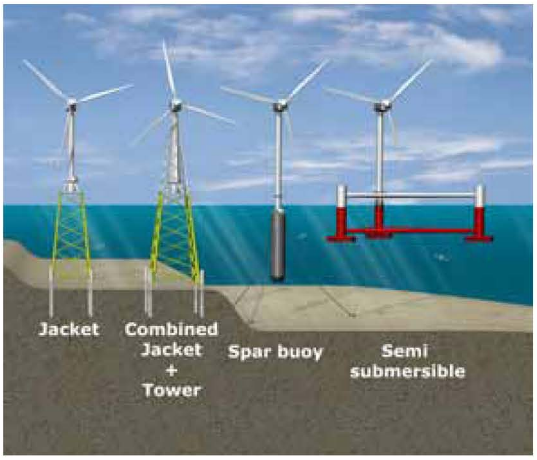
- the Hywind concept from Statoil Hydro (Figure 26), consists of a steel jacket filled with ballast. This floating element extends 100 metres beneath the surface and is fastened to the seabed by three anchor piles. The turbine itself is built by Siemens. The total weight is 1,500 tonnes. The first prototype has been built and has been operational since June 2009;
- the Blue H concept (Figure 25), recently tested in Italy, has been selected by the UK's Energy Technology Institute (ETI) as one of the first projects to receive funds as part of its £1.1 billion initiative. This UK based project aims to develop an integrated solution for a 5 MW floating turbine deployed offshore in waters between 30 and 300 meters deep. In addition, Blue H was recently selected under the Italian framework "Industria 2015" to develop a hybrid concrete/steel 3.5 MW floating wind turbine ideal for the deep waters of the Mediterranean Sea;
- the Sway concept is developed in partnership with Statkraft and Shell in particular. It is based on a floating elongated pole far below the water surface, with ballast at the bottom part. The centre of gravity being far below the centre of buoyancy, the system remains stable. It is designed for turbines of up to 5 MW and water depth from 80 to 300m.

FIGURE 23: **Tripod foundation for the Multibrid turbines at the RAVE test site**

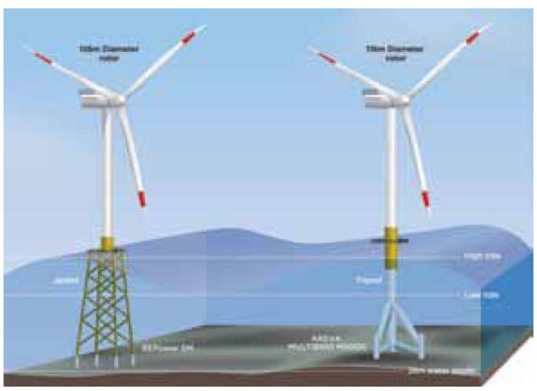


SOURCE: www.alpha-ventus.de

FIGURE 24: **Medium and high depth foundations**



SOURCE: Carbon Trust as published in Recharge 26/06/09.



SOURCE: Recharge Simon Bogle and Offshore Stiftung / Jan Oelker.

FIGURE 25: **Blue H technology**

In the short term, standard, easy to manufacture sub-structure design is essential for large-scale offshore wind deployment. However, to reduce the unit cost of substructures, new and improved materials and manufacturing technologies are required for welding, casting and pouring concrete. These must be coupled with more efficient manufacturing processes and procedures, making use of automation and robotics, for example. Unique concrete/steel hybrids may also be developed in the future.

In the near term, the major deployment issue is the development of the production facilities and equipment for manufacturing the sub-structures in the necessary quantities, on schedule and to the required standards, at an acceptable price. This will require significant investment in new manufacturing yards and in the associated supply chain. It will also mean the deployment of new and improved manufacturing processes, procedures and equipment to increase production efficiency and reduce costs.

FIGURE 26: **The Hywind concept**

Vessels - turbine installation, substructure installation and other vessels

The current market for offshore wind turbine installation makes use of a number of different vessels for different projects, and also draws on some vessels from the oil and gas sector and civil marine sector. A critical element of the offshore supply chain will be the availability of installation vessels to facilitate the installation of 10,000 offshore wind turbines, together with the necessary substructures and cables by 2020.

Compared to existing offshore sectors (oil and gas, marine installation), the installation processes for the offshore wind industry are extremely demanding, due to a higher number of operation days, and repetitive installation processes. Many installation vessels are not ideal for such conditions. Their equipment is often not up-to-date[38] as most up-to-date vessels are booked by the oil and gas industry.

The installation of offshore wind turbines has fostered the creation of specialised jack up vessels to ensure the turbines can be quickly and efficiently installed. Initially the firm A2SEA converted two feeder vessels to install the Horns Rev I wind farm, which were again used for the major repairs. The record for putting up the tower, nacelle and blades of one turbine on Horns Rev was close to eight hours. The second generation of offshore wind installation ships was pioneered by the MPI Resolution. This vessel is also able to install foundations and lay cables. Currently there are three factors which are driving the current development of Turbine Installation Vessels (TIV):

- wind turbine size, as larger turbines imply larger ships;
- water depth, as the deeper the water, the more expensive and larger a turbine installation ship needs to be;
- distance from shore, as the further a site is from the supply harbour (and the larger the capacity of the turbines) the higher the transport costs to site;
- optimisation of installation in a given weather window.

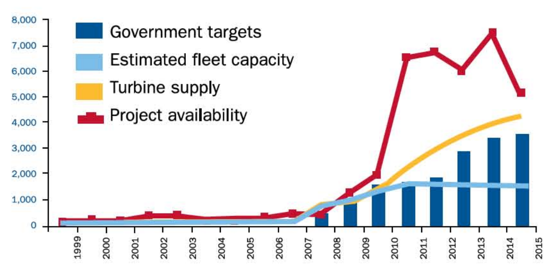
The current technology trend will favour large-scale vessels able to carry multiple pre-assembled wind turbines. Turbine installation vessels have the advantage of being custom built, fast-moving, self-propelled, multi-turbine vessels that can fully exploit the available weather windows. A number of ambitious plans exist to build new large capacity ships. The Gaoh Offshore vessel (Figure 32 on p.58) is an ideal example, as it has a planned capacity of 18 x 3.6 MW wind turbines including towers and rotors. However many of the planned vessels lack sufficient finance to build due to the increased reluctance of banks to take risks due to the financial crisis and the lack of support work in the oil and gas industry.

New Energy Finance (Figure 27) forecasts a shortage of installation capacity after 2011, with an installation capacity of 2 GW per year.

In addition to the turbine and tower installation vessels, only a few vessels are available for heavy foundation installation[39]. Heavy lift vessels from the oil and gas industry are not suited to serial installation of foundations, largely because of their cost. The industry will therefore rely on scarce equipment to achieve its objectives.

An additional barrier to offshore wind deployment will be having sufficient offshore personnel trained to operate these boats at the required security level. Another factor that can complicate the use of vessels is the need to be able to operate in different jurisdictions.

FIGURE 27: **Project, turbine and vessel supply forecasts compared to annual government targets (MW)**



Note: Turbine demand derived from developers' estimates after 2011.

SOURCE: New Energy Finance.

The type of vessel to be developed depends greatly on the strategy to be chosen for deploying the future parks. A key conclusion of the Beatrice project is that

[38] Dynamic positioning systems are of vital importance for the precise positioning of wind turbines and safe installation offshore.

[39] http://www.bnoffshore.com.

most of the offshore assembly should be done on land. Previous experience has led to the bunny ear configuration whereby nacelles have the hub and two blades mounted on shore and the third blade stacked onboard a ship for installation. However, as installing the third blade at sea is a sensitive and time consuming element of the lifting operation, a trend should emerge towards the 'one lift concept' of fully erected turbines. This means that the offshore wind industry should be located near harbours, in order to optimise operation and lower costs (see harbours section).

Three installation strategies are illustrated below:

PRE-ASSEMBLY AT HARBOUR

Turbines, substructures and towers are shipped to a support harbour[40]. At this support harbour final fitting and assembly takes place. When the pre-assembly work is finished the turbines are transported and installed at site by a turbine installation vessel. This was the installation configuration used for Horns Rev 1, for example.

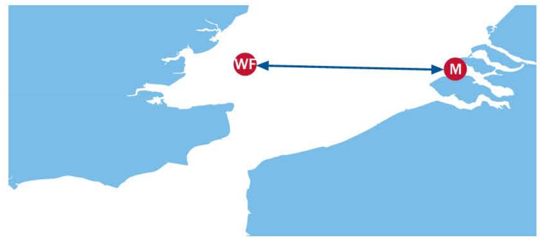
FIGURE 28: **Ship turbines to local construction port, jack-up vessel shuttles from there**

SOURCE: BVG Associates [40b]

MANUFACTURE AND PRE-ASSEMBLY AT HARBOUR

This approach entails the setting up of an assembly operation close to the site. A second approach is shipping the pre-assembled turbines directly from the turbine manufacturer to the site. Suppliers based in Bremerhaven, for example, are able to deliver this type of service.

FIGURE 29: **High speed jack-up vessel shuttles from manufacturing site**

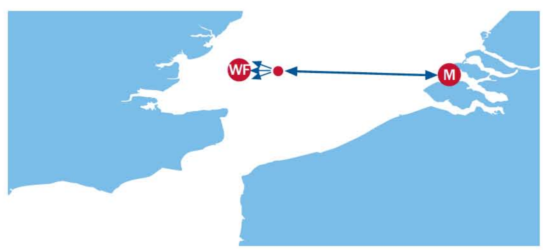


SOURCE: BVG Associates

ASSEMBLY OFFSHORE

Using this method, feeder vessels supply an offshore jack-up vessel to the installation site. The advantage of this method is that the installation vessel does not need to be used for transport. However, an extra loading operation has to be used to load the feeder vessels or barges.

FIGURE 30: **Feeder barge shuttles from manufacturing site to jack-up at wind farm site**



SOURCE: BVG Associates

The choice of a given installation strategy depends on the economic balance between the number and type of ships used, the distance to the coast, and the transportation / operation risks involved. For instance, the third strategy limits the transition times of the installation vessel. However, it requires a second ship, and means the wind turbines have to be handled a second time from the feeder to the installation vessel. A2SEA demonstrated that such a strategy could be economically viable compared to the first and second options for UK Round 3, involving longer distances to the coast.

[40 & 40b] BVG Associates for UK Department of Energy and Climate Change, 2009. 'UK Ports for the Offshore Wind Industry: Time to Act'.

In addition to installation vessels, effective access systems will be essential for the operation of the offshore facilities and the safety of personnel involved in the installation, hook-up, commissioning and operations and maintenance (O&M) of the turbines. These systems must be capable of transferring people and equipment safely to the turbine. They must provide a suitable means of escape and casualty rescue and be robust in northern European weather conditions.

A variety of access solutions will be needed. These will range from helicopters through to an array of different-sized boats and jack-ups capable of lifting the heaviest components into and out of the nacelle. This will require the development of specialist vessels that can replace and repair major equipment, such as gearboxes and blades.

Figure 31 shows two of the access systems developed: the access catamaran developed by Windcat Workboats and the Ampelmann system by TU Delft.

FIGURE 31: **Two new access systems, Windcat Workboat (top) and Ampelmann (below)**

Recommendations:

The installation of 40 GW by 2020 will require dedicated offshore installation vessels for the offshore wind energy sector. Such vessels should be able to install offshore wind farms in medium water depths (30-40m and beyond), and operate in harsh conditions, in order to increase the number of days of operation from an estimated 180 days a year to 260-290 days. Ideally, these vessels should be able to carry assembled subsystems, or even a set of assembled turbines in order to limit the number of operations performed at sea.

On the basis of a minimum capacity of 10 turbines, 10 sets of blades and 10 tower sections, 12 installation vessels will be required. Each vessel could cost in the region of €200 million, with a total investment of €2.4 billion. Accessing capital to build such vessels requires strong and stable market conditions to guarantee return on investments. To speed up the process and enable the timely delivery of the necessary number of installation vessels, specific financial measures are required. The European Investment Bank in particular should take the necessary measures to support the risk related to these significant investments. Through the European Investment Bank, the necessary financing instruments exist for renewable energies. As key elements for the deployment of offshore wind power, installation vessels should be eligible for such instruments, expanded accordingly.

A brief introduction to some vessels used in turbine installation

The tables below present a non-exhaustive list of vessels that can be used for foundation and turbine installation. In addition to those presented, heavy-lift vessels when suited can be used for foundation, turbine, and cable installation, such as Eide (installation at Nysted I, II and Lillegrunden), Rambiz (Beatrice, Thornton Bank), or HLV Svanen (Egmond aan Zee, Gunfleets Sand and Rhyl Flats).

TABLE 6: **A selection of vessels and jack-up barges currently active in wind installation with an operating depth of >30m[41]**

	JB-109	SEA Jack	Resolution	LISA	JB-114 and JB-115	Kraken	Titan 2
Owner	A2SEA	A2SEA	MPI Vroon	SMIT	Jack-up barge NV	Seajacks int	
Operation depth	50m	35m	Max 35 with leg extensions	50m	50m	40m	50m
Crane max.	280t	600t	300t	600t	280t	700t	180t
Configuration	Jack-up barge	Self propelled jack-up barge	Jack-up crane ship	Jack-up barge	Jack-up barge	Self propelled vessel	Self ropelled jack-up barge
Accommodation	160 optional	38 standard	50 incl. crew	Max 60	160 optional	60 optional	na

The MPI Resolution and the Kraken are the only dedicated turbine installation vessels currently capable of working at more than 30m water depth. The Kraken is currently working in the oil and gas sector. The Kraken is to return to wind installation shortly and is to be joined by a new sister ship.

TABLE 7: **Selection of vessels currently active in wind turbine installation with an operating depth of <30m**

Attribute	Sea Energy	Sea Power	Excalibur
Owner	A2SEA	A2SEA	Seacore
Operation depth	27m	14.3m	30m
Crane max	120t	120t	220t
Configuration	Jack-up crane ship	Jack-up crane ship	Jack-up barge
Accommodation	36 incl. Crew	36 incl. crew	20 plus crew

Sea Energy and Sea Power are the original turbine installation vessels used at Horns Rev 1. The Excalibur, though optimised for wind, is not self propelling.

[41] The Bard Wind Lift vessel is not included as this will be used by BARD Engineering themselves.

TABLE 8: **Some vessels due to enter service in the near term**

Attribute	Adventure	Discover	Shamal	Scirocco	Wind Carrier	Inwind	Gaoh	Blue Ocean
Owner	MPI	MPI	Seajacks Int	Seajacks Int	Wind carrier	Inwind	Gaoh	
Operation depth	40m	40m	40m	40m	na	na	40m	60m
Crane max.	1,000t	1,000t	700t	200t	na	na	1,600t	1,200t
Configuration	Self propelled jack-up crane ship	Self propelled jack-up ship	Self propelled jack-up ship	Self propelled jack-up ship	na	na	Self propelled jack-up ship	Self propelled jack-up ship
Accommodation	120 incl. crew	Max 120	60 incl. crew	52 incl. crew	na	na	121 incl. crew	na
In service	Q1 2011	Q3 2011	na	na	na	na	Awaiting finance	Q3 2011

TABLE 9: **Vessel availability (for European offshore wind installation) by type of application**

Vessel type	Vessel supply
Survey vessels Used to survey the sea floor in preparation for the installation of an offshore wind farm. Smaller survey vessels are used to perform Environmental Impact Assessment studies and post-evaluation.	Currently sufficient for market.
Turbine Installation Vessels Custom built self propelled installation vessels that can carry multiple turbines at a time.	Three out of four in operation, three being built, 12 needed in total. Extremely difficult to finance in the current climate.
Construction support vessels Used to assist in the construction of offshore wind parks. Includes motorised and non-motorised jack up barges, barges, pontoons and platforms.	Sufficient but supply dependent on demand from oil and gas sector.
Work boats Support the work of other vessels by providing supplies of tools and consumables to other boats.	Sufficient vessels.
Service vessels	Sufficient for scheduled maintenance work. Construction and installation vessels are often used for major service work.
Crew transfer vessels	Sufficient vessels and quick to build.

SOURCE: own elaboration, EWEA members' expertise.

Future innovative installation vessels

As previously described, the installation of 40 GW by 2020 will require dedicated offshore installation vessels for the offshore wind energy sector. On the basis of a minimum capacity of 10 turbines, 10 sets of blades and 10 tower sections, 12 installation vessels will be required.

These vessels should be able to install offshore wind farms in medium depths (30-40m and beyond), and operate in harsh conditions, in order to increase the number of days of operation to 260-290 days. In the best configuration, these vessels should be able to carry assembled sub-systems, or even a set of assembled turbines, in order to limit the number of operations performed at sea.

Such vessels are currently under development, such as the concepts illustrated in Figures 32 and 33. A market visibility over five years is required to secure the financing. In the current financial situation, the financing of these major supply chain components is problematic.

FIGURE 32: **Example of the Gaoh concept. This boat is designed to lift 18 3.6 MW turbines in 45m depth, including seabed penetration**

SOURCE: Ole Steen Knudsen AS.

FIGURE 33: **Blue Ocean Ships multiple carrier concept**

Ports and harbours

A number of specially adapted ports is critical for supplying the offshore market. These facilities should possess deep water and reinforced quaysides to take the large weight of turbines, and large storage areas with low premium fees and suitable space to move foundations and cranes.

Within the next 10 years, manufacturers will have moved close to or located outlets at port facilities, as is the case in Bremerhaven (see Showcase: Bremerhaven's success story on p.60). In the near future, the Bremerhaven facilities will produce 1 GW of offshore wind turbines every year. The success of Bremerhaven is built on a strong political push for economic diversification, such as an integrated approach towards offshore wind energy: this approach is based on a strong manufacturing capacity, testing facilities, demonstration sites, research and training facilities, and a dedicated harbour. Such an integrated approach enables offshore wind turbines to be tested and demonstrated in near-offshore conditions, manufactured on site, and shipped directly to the offshore site. If this development continues then large transport and installation vessels could collect foundations and turbines directly from a manufacturing facility quayside and install them directly.

HARBOUR REQUIREMENTS

One of the main conclusions of the DOWNVInD[42] project is a strong recommendation to perform pre-assembly

[42] The objective of DOWNVInD (Distant Offshore Windfarms with No Visual Impact in Deepwater) is to make the step change in techniques, technologies and processes needed to enable the development of large capacity windfarms offshore in deep water (http://www.downvind.com).

activities onshore (see section on vessels). In order to do this suitable ports and harbours need to be able to fulfil the following requirements[43], including:

- an area of storage of 6 to 25 ha (60,000 to 250,000m^2);
- a private dedicated road between storage and quay side;
- quay length: approximately 150m to 250m;
- quay bearing capacity; 3 to 6 tons/m^2;
- a seabed with sufficient bearing capacity near the pier;
- draft of minimum 6m;
- warehouse facilities of 1,000 to 1,500m^2;
- access for smaller vessels (pontoon bridge, barge etc);
- access for heavy/oversize trucks;
- potentially license/approvals for helicopter transfer;
- being available for the project installation.

Concerning operation and maintenance, the specific requirements include:

- full time access for service vessels and service helicopters;
- water, electricity and fuelling facilities;
- safe access for technicians, and
- loading/unloading facilities.

EXISTING FACILITIES

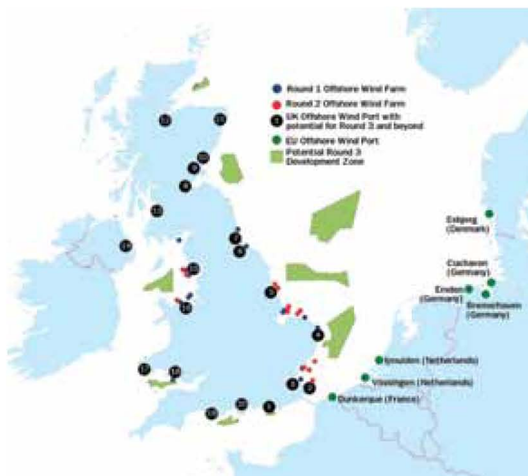
Ports able to service offshore wind power developments in the North Sea are illustrated in Figure 24. A total of 27 harbours are identified, which could be adapted to the specific needs of the offshore wind sector. Only a few, however, would be suitable for the installation of substructures.

Germany and the UK, in particular, are very active in port development, which is considered as a way to diversify harbour activities, attract companies and create local employment. In the case of Bremerhaven, Germany, an integrated industrial approach was implemented, leading to promising successes (see showcase on Bremerhaven on p.60). Such an approach bases the developments in port activities on strong local partnerships with wind turbine manufacturers, component suppliers, research institutes and developers.

The same trend is emerging in the UK, where initiatives are underway to improve the "offshore readiness" of UK ports. The UK Department of Energy and Climate Change's recent report[44] identifies UK harbours as potential candidates for the large-scale deployment of offshore wind energy. This brochure also proposes supporting wind turbine manufacturers and developers that wish to launch activities in these areas, thereby promoting an integrated industrial approach.

In Greater Yarmouth, for instance, which is one of the main UK facilities for the offshore oil and gas industry, specific actions are being taken to adapt and extend the harbour infrastructures and services to support offshore wind development.

FIGURE 34: **Identified harbours suitable for future offshore wind developments**



1. Newhaven
2. Ramsgate
3. Medway (Sheemess and Isle of Grain)
4. Great Yamouth
5. Humber
6. Hartlepool and Tees
7. Tyneside
8. Methil (Fife Energy Park)
9. Dundee
10. Montrose
11. Peterhead Bay
12. Cromarty Firth (Nigg Bay and Highland Deephaven)
13. Hunterston
14. Belfast (Harland & Wolff)
15. Barrow-in-Furness
16. Mostyn
17. Milford Haven
18. Swansea/Port Talbot
19. Portland
20. Southampton

[43] UK Ports and offshore wind Siemens´Perspective, Presentation by Chris Ehlers, MBA, MD Renewables Division, Siemens plc - 30 March 2009.

[44] UK Department of Energy and Climate Change. 'UK Offshore Wind Ports Prospectus'.

Showcase: Bremerhaven's success story[45]

Bremerhaven has attracted half of the €500 million invested in offshore wind power development along the German North Sea coastal region during the past years. Its economy, based on shipping, shipbuilding, and a commercial fishery faced a strong economic downturn in the 1990s. In the early 2000s, the local authorities evaluated possible means of economic diversification. The historical strengths of this area included comprehensive maritime technology know-how and a skilled workforce specialised in shipbuilding, heavy machinery design and manufacture. Offshore wind energy was chosen as an alternative development.

So far, Bremerhaven has attracted (see Figure 35):

- two offshore wind turbine manufacturers REpower and Multibrid;
- two onshore wind turbine manufacturers, PowerWind and Innovative wind;
- powerBlades, which is manufacturing blades up to 61.5m long for REpower 5 and 6 MW turbines;
- WeserWind Offshore Construction weorgsmarienhütte, specialised in the design and manufacturing of heavy steel offshore foundation structures. It has designed the tripod support structures for Multibrid turbines, the jacket-foundations for REpower, and tripods for BARD Engineering.

Regarding the harbour's facilities, an additional terminal is planned for 2011. This terminal will be capable of directly handling large, heavy and bulky components, and/or complete assemblies – like nacelles weighing over 250 tonnes and large rotor blades with lengths of 61.5 metres and up.

The industrial development is supported by research facilities such as Deutsche Windguard, which operates one of the largest wind tunnels in the world, with special acoustical optimisation for rotor blades. Another example is the Fraunhofer Institute, which operates a new rotor blade test facility for blades up to 70m long. In future this blade testing capability will be expanded to include 100m long blades.

Specific support was provided for wind turbine demonstration, with fast and streamlined permitting processes (6 weeks for the Multibrid M5000 prototype). Today five 5 MW turbines (four Multibrid M5000s and one REpower 5M) are demonstrated within the Bremerhaven city limits, with specific foundations designed for offshore implantations.

The success of Bremerhaven is said[46] to be due to a clear and integrated industrial strategy, public ownership of land, and significant clustering of competencies. Bremerhaven's companies have already created some 700 new jobs in the past three years, this is expected to rise to 1,000–1,200. In order to continue this growth, these established and newer companies require new workers in both blue and white collar positions. Dedicated training schemes were put in place internally in the companies themselves, through the Fachhochschule Bremerhaven, or the co-operation between the technical universities of Oldenburg, Bremen and Hannover, involved in ForWind, or the Bremerhaven Economic Development Company through the POWER Cluster project[47].

FIGURE 35: **Bremerhaven site description**

Source: Windenergie Argentur

(45) Based on Renewable Energy World, 13 March 2009.

(46) The role of the RDAs and the Devolved Administrations, March 2009, DECC port seminar.

(47) http://www.power-cluster.net.

Photo: Dong Energy

HARBOURS OF THE FUTURE

As discussed in this chapter, offshore manufacturing capacities are likely to be increasingly located near the harbour facilities, in order to facilitate transport and installation, in particular for large machines.

New concepts are emerging for servicing the future offshore wind farms, such as the Dutch 'harbour at sea' concept. This concept is currently being developed to service the future large offshore arrays implemented far from shore. Such multi-purpose platforms could allow sailing times to be reduced for installation and maintenance. They could also allow host crews and technicians on site, spare parts storage, and provide for offshore installation of transformer stations.

For wind energy:

- a station for transporting, assembling and maintaining offshore wind turbines;
- accommodation for personnel (hotel);
- storage of spare parts;
- workplaces;
- foundations for commissioning of assembled wind turbines;
- test site for new offshore wind turbines (five places),
- transformer station;
- electrical substation for connections on land (electrical hub);
- heliport.

Other functions:

- aquaculture of raw materials for food, energy and materials;
- shelter in emergency situations;
- recreation (yachting marina);
- 'gas-to-wire' units;
- logistics centre for the fishing sector;
- coastguard service;
- lifeboat service;
- harbour for offshore.

SOURCE: We@Sea

FIGURE 36: **Harbour at Sea concept. Courtesy of We@Sea**

SOURCE: www.haveneilandopzee.nl.

Photo: Elsam

Future trends in manufacturing for the offshore wind industry

- Production of offshore wind turbines can be expected to remain in the established clusters in the short term as a stable and reliable supply chain is in place;
- as offshore machines increase in size, more manufacturers will be relocated directly to or close to harbour facilities to ease transportation of machines and delivery of components;
- as offshore foundations increase in size and complexity they will be built closer to offshore wind sites;
- as offshore installations increase, a large number of offshore-ready personnel will be needed for the installation and later for the O&M of the offshore wind farms;
- independent offshore O&M companies will emerge as soon as the market is large enough to support them;
- the predominant offshore market is planned for the North and Baltic Seas in the short to medium terms. Countries in this area can expect to reap the benefits of offshore wind development.

Bremerhaven has attracted a large number of offshore players due to its integrated approach towards offshore wind energy[48] (see Harbour section on p.58). A similar trend may emerge in Dutch and UK ports. The current schemes will however not be sufficient to supply the necessary number of workers to deliver 40 GW offshore wind by 2020, as the market already faces shortages of project managers and electrical engineers in particular.

In this chapter, some of the major cost drivers of offshore wind energy were addressed: turbine supply, available substructures, vessels and harbours. Cost reductions for the offshore wind energy sector will be brought about above all from higher market volumes and a more established track record from industry.

[48] Bremerhaven has put nine separate initiatives in place to encourage offshore wind turbine manufacturers to relocate there. Green Jobs ippr, page 39. 2009.

Project scale will increase, and the trend will continue towards larger offshore wind farms in the 200-300 MW range and beyond, using dedicated and standardised offshore turbines and installation processes. This will enable the industry to implement streamlined, repeatable installation processes, and build the necessary installation vessels and access technologies.

Chapter 5

Main Challenges

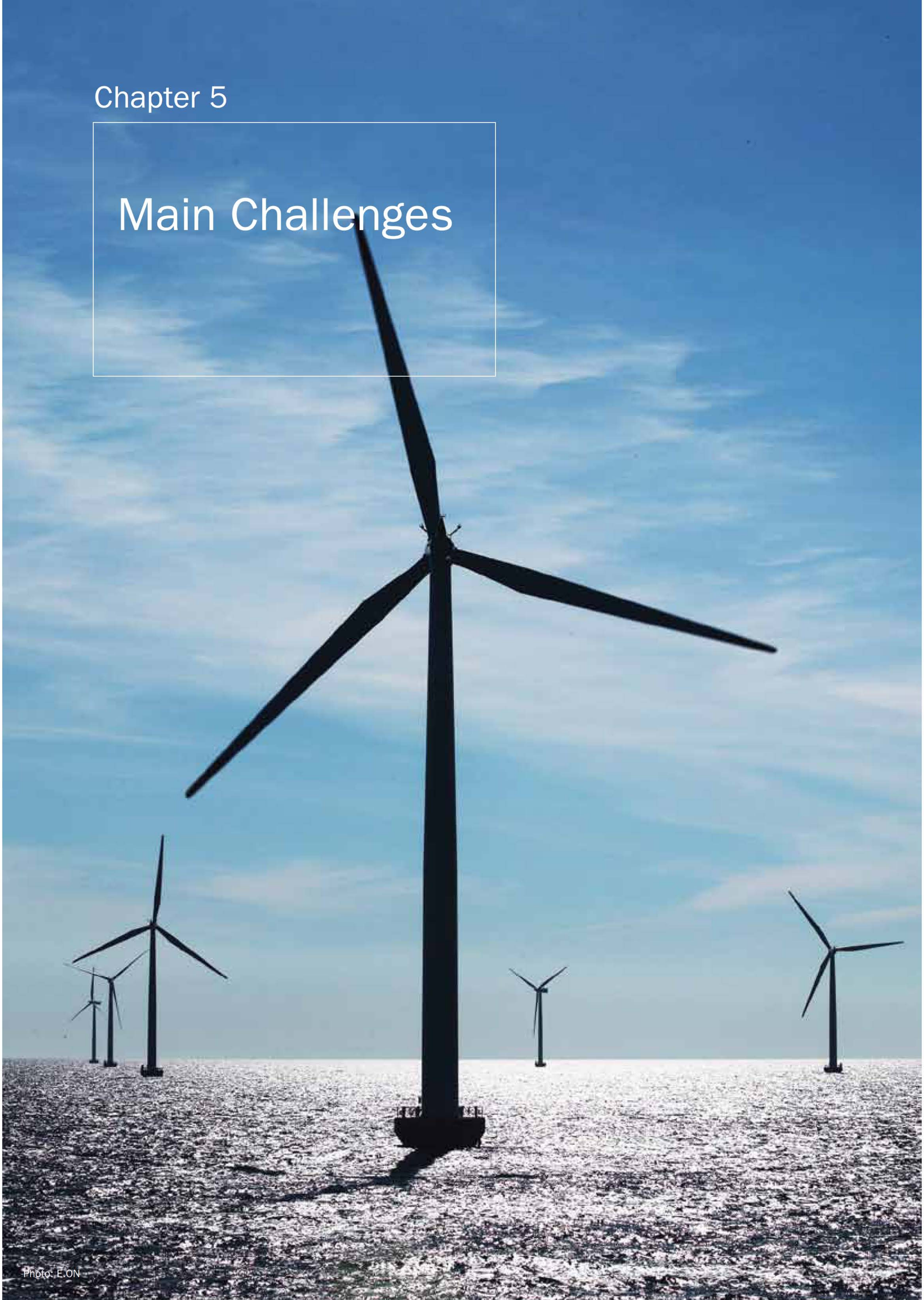


Photo: E.ON

Wind energy is one of six "European Industrial Initiatives" proposed by the European Commission to accelerate innovation and deployment of strategically important technology. These initiatives are intended to facilitate European leadership in energy technologies.

The offshore wind energy resource will never become a limiting factor. There is enough energy over the seas of Europe to meet total European electricity demand several times over. In a recent study, the European Environment Agency (EEA) estimates the technical potential of offshore wind energy in the EU to be 30,000 TWh annually. The European Commission estimates total EU electricity demand of between 4,279 TWh and 4,408 TWh in 2030.

It would require eight areas of 100 km times 100 km (10,000 km^2.) to meet all of the EU's electricity demand, or less than 2% of Europe's sea area not including the Atlantic. The combined area of the North, Baltic and Irish Seas and the English Channel is more than 1,300,000 km^2. The Mediterranean is an additional 2,500,000 km^2.

Although the offshore wind energy resource will never become a limiting factor, it will be a challenge to develop a new offshore wind industry in the EU. Some of the main challenges are:

- **wind measurements and characteristics:** acquiring more detailed knowledge of the wind on complex structures for improving wind turbine designs; gathering detailed knowledge of wind characteristics through the development of advanced measurement techniques and systems, and developing a high resolution offshore wind atlas;
- **next generation of wind turbines:** developing the next generation of offshore wind turbines, including exploring concepts of very large scale turbines in the 10-20 MW range; and optimising manufacturing processes and developing the necessary test facilities;
- **manufacturing**: supporting the take-off of offshore by developing the necessary substructure concepts and corresponding manufacturing processes and capacities, including boats and harbours; developing standard and replicable installation and operation processes; improving knowledge of the physical environment to reduce development risks and uncertainty;
- **maritime spatial planning:** developing spatial planning instruments, in particular offshore, to facilitate the planning of the future offshore wind energy developments. A foreseen benefit of maritime spatial planning is to provide guarantees to the supply chain on the future market volumes at European level. Therefore, investments in the corresponding manufacturing capacities, harbours, boats, testing capacities, or human resources could be performed in advance, while providing guarantees to investors, lowering the risk, and potentially the cost of capital;
- **personnel:** making sure a sufficient number of people are trained to supply the demand of the offshore market.

Annex: Offshore Wind Energy Installations 2000-2030

Year	Cumulative capacity (MW)	Annual installations (MW)	Wind energy production (TWh)	Wind energy's share of electricity demand (EC ref. scenario)	Wind energy's share of electricity demand (EC New Energy Policy)	Annual offshore wind power investments (€ billion)	CO_2 avoided annually (Mt)
2000	35.35	3.8	0	0.0%	0.0%	0.007	0
2001	85.85	50.5	0	0.0%	0.0%	0.089	0
2002	255.85	170	1	0.0%	0.0%	0.306	1
2003	515.05	259.2	2	0.1%	0.1%	0.480	1
2004	604.75	89.7	2	0.1%	0.1%	0.175	2
2005	694.75	90	3	0.1%	0.1%	0.185	2
2006	895.25	200.5	3	0.1%	0.1%	0.431	2
2007	1,105.25	210	4	0.1%	0.1%	0.483	3
2008	1,471.33	366.08	5	0.2%	0.2%	0.879	4
2009	1,901	430	7	0.2%	0.2%	1.032	4
2010	3,001	1,099	11	0.3%	0.3%	2.529	7
2011	4,501	1,500	16	0.5%	0.5%	3.300	10
2012	6,459	1,958	24	0.6%	0.7%	3.916	15
2013	8,859	2,400	32	0.9%	0.9%	4.320	20
2014	11,559	2,700	42	1.1%	1.2%	4.320	26
2015	14,659	3,100	54	1.4%	1.6%	4.573	33
2016	18,259	3,605	67	1.7%	2.0%	5.047	40
2017	22,375	4,116	82	2.1%	2.4%	5.557	49
2018	27,240	4,865	101	2.5%	2.9%	6.315	59
2019	33,090	5,852	122	3.0%	3.6%	7.526	71
2020	40,000	6,915	148	3.6%	4.3%	8.810	85
2021	47,700	7,717	177	4.3%	5.2%	9.779	100
2022	56,200	8,500	209	5.0%	6.1%	10.713	117
2023	65,500	9,303	244	5.8%	7.1%	11.662	135
2024	75,600	10,100	282	6.6%	8.2%	12.593	155
2025	86,500	10,904	323	7.5%	9.5%	13.521	176
2026	98,100	11,650	366	8.5%	10.8%	14.367	198
2027	110,400	12,470	413	9.5%	12.2%	15.293	221
2028	123,200	13,059	461	10.6%	13.6%	15.927	244
2029	136,400	13,290	511	11.7%	15.1%	16.118	268
2030	150,000	13,690	563	12.8%	16.7%	16.510	292