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ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

MASTER IN THE ELECTRIC POWER INDUSTRY

ANALYSIS OF COST REDUCTION OPPORTUNITIES IN OFFSHORE WIND

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Supervisor: Paola Núñez Núñez

Madrid
June 2016

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Summary

Offshore wind energy refers to the construction of windfarms in sea or lake waters to generate electricity from wind. It is a relatively new type of renewable source characterised by a number of points that differences it from others technologies, such as more stable energy production and complex logistic and construction. Offshore wind can help to reduce air pollution and greenhouse gases, meet renewable electricity standards, and create jobs and local business opportunities.

Since the beginning of the century, offshore wind has experienced a solid growth, which has intensified in recent years. The European Energy Wind Association expect that, by 2030, once the industry has reached maturity and costs have dropped enough to make this technology competitive, Europe could generate with offshore wind up to 40% of all energy consumed by its citizens. But despite its great potential, there is still a long way until offshore wind achieves competitiveness. Electricity from this technology currently costs significantly more than onshore wind or Combined Cycle Gas Turbines (CCGT), which nowadays is the main alternative technology, albeit with significant carbon emissions.

Offshore wind's position in the future electricity generation mix will be driven, to a large extent, by its cost relative to those of other forms of electricity. The costs will reduce significantly only if the industry as a whole invests in new technologies, large scale automated manufacturing facilities, more effective project management techniques, new installation vessels and methods, and more effective ways of operating and maintaining wind farms. But industry will only invest if it perceives there is a sustainable and viable market for offshore wind. That dilemma reflects the importance of a credible analysis of the future development of the costs of offshore wind energy consistent with a large-scale, viable, long-term market, which is the objective of this thesis.

The starting point of the report is the calculation of the current Levelized Cost of Energy (LCOE) of the technology. To do that, chapter 3 analyses the costs of two representative projects, East Anglia One in UK and Wikinger in Germany, taking into account different assumptions regarding lifetime of the projects, Capex and Opex values, discount rate… After the corresponding calculations, LCOE obtained is 143.80 €/MWh.

The core of the thesis is focused in the analysis of the opportunities and developments that could provide a reduction on costs in the offshore wind technology. The idea is to cover in detail how technology (chapter 4), supply market (chapter 5), finance (chapter 6) and public support (chapter 7) can reduce the cost of energy delivered to the connection point. The respective impact on the LCOE of each measure has been calculated.

In the third part of the thesis (chapter 8), impacts previously evaluated are applied to the current LCOE to obtain a forecast of the offshore wind energy costs towards 2030 horizon. The result reflects an important descend in the LCOE, which is located in 80.82 €/MWh. Finally, it is presented a comparison of offshore wind against other sources of energy, reflecting the position that the technology will have in the future electricity generation mix. In the conclusion it is highlighted that offshore wind could become one of the most competitive sources of energy in the future, even if we compare with non-renewable sources.

Foreword

Weigh anchor, cast off, and feel the wind in our sails…

It was two hours after the midnight of October 12th, 1492 when the maritime expedition led by Cristopher Columbus reached the island of Guanahaní, present Bahamas, after thirty-two days out of sight of land.

The discovery of America is one of the fundamental highlights of the universal history. It represents the meeting of two worlds that had evolved independently from the origin of humanity, and undoubtedly changed the course of events. It was a gift from Europe to the world that would have never been possible without knowing how to take advantage of the wind at sea. Wind that pushed the sails of the three caravels, *La Niña, La Pinta and Santa María,* toward the shores of America, long time before the discovery of other driving forces such as electricity or steam.

Today, more than 500 years after that day, Europe looks back at sea, hoping to find new ways to harness its wind. And, from a few years ago, it seems that it has been found. The offshore wind energy, i.e., electricity generated from wind that blows at sea, where its intensity is higher, and there is much more space available, is emerging as one of the great responses to climate change. It is expected that, by 2030, once the industry has reached maturity and costs have dropped enough to make this technology competitive, Europe could generate with offshore wind up to 40% of all energy consumed by its citizens. Perhaps, history is repeating itself, and again the union of wind and sea allows the old Europe to make another gift to the world.

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INTRODUCTION

1.1 OFFSHORE WIND TECHNOLOGY

In December 2015 it was celebrated the Paris climate conference (COP21), where 195 countries adopted the first universal, legally binding, global climate deal. The agreement sets out a global action plan to limit global warming to well below 2°C, avoiding by this way dangerous climate change. Participant countries also committed to review the objective every 5 years, with the aim to reduce the limit to 1.5°C as soon as possible.

The EU has been at the forefront of international efforts towards a global climate deal. Before the COP21 agreement, EU committed to a legally binding target to meet 20% of its energy consumption through renewable energy by 2020. To achieve this, it is expected that 34% of electricity will need to be generated by renewables. In the longer term, the EU is elaborating targets for 2030 as part of the commitment to decarbonise the economy by 80%.

The offshore wind energy, i.e., electricity generated from wind that blows at sea, where there are less environmental limits due to the absence of population, is expected to play a significant role in meeting COP21 targets, and is emerging as one of the great responses to climate change. It is expected that, by 2030, once the industry has reached maturity and costs have dropped enough to make this technology competitive, Europe could generate with offshore wind up to 40% of all energy consumed by its citizens.

In February 2015 the European Wind Energy Association (EWEA) published its annual statistics, which confirm the fast growth of this technology. A total of 63.5GW of offshore projects are in this moment at the planning phase, in addition to the almost 40GW that are currently online, consented or in construction.

Characteristics of offshore wind

Offshore wind energy refers to the construction of windfarms in sea or lake waters to generate electricity from wind. Wind turbines rely on fixed foundations or floating substructures, and are connected to the transmission network using subsea cables. Two substations, one of them offshore and the other located in the shore, complete the installations.

In essence, the working procedure of an offshore windfarm is the same than on an onshore one. As the wind blows, it flows over the shaped blades of the turbines, causing the turbine blades to spin. The blades are connected to a drive shaft that turns an electric generator to produce electricity. The newest wind turbines are highly technologically advanced, and include a number of engineering and mechanical innovations to help maximize efficiency and increase the production of electricity.

Offshore wind power can help to reduce air pollution and greenhouse gases, meet renewable electricity standards, and create jobs and local business opportunities. It is characterised by a number of points that differences it from others technologies:

- **More stable energy production**: Stronger wind speeds offshore result in higher and more stable generation per megawatt compared with onshore projects, with estimated capacity factors averaging 45% compared with 33% for onshore wind projects. Studies developed by Fitch rating agency understand that simpler topography reduces some of the uncertainties in offshore production estimations.

- **Complex construction:** Completion risk for offshore wind projects is materially higher than for onshore windfarms and thermal power and oil & gas projects. However, the industry is gaining experience and the observed reduction in the number of contracts under which projects are developed is positive.

- **Complex logistics**: The more challenging operating environment and potentially longer unavailability periods may lead to lumpier operating and cost profiles for offshore projects. Dependency on vessels to transport personnel, equipment and perform maintenance is a key differentiating factor that, if not adequately managed, may result in material deviations from budgets. Other key factors are the project's location, the technology used and the project's technical design and scope.

- **Still a very expensive technology**. According to the US Energy Information Agency, offshore wind power is the most expensive energy generating technology being considered for large scale deployment. The low level of development of the industry and the few suppliers of the main components (turbines, foundations...) are the main reasons for the high costs.

Offshore wind is a relatively new industry. Main players appeared during the early years of this century, and nowadays all the activities (turbines manufacture, foundations, installation vessels) are concentrated in three or four players. The same situation applies to the developers of offshore windfarms: the high amount of capital required and other entry barriers, like experience, makes that majority of projects belong to a small group of companies. The four largest developers have in total developed 84% of all wind farms globally and have a total market share of more than 75% if projects under construction are included.

These are the main characteristics of the industry:

- **Offshore wind is a high growth industry**. The global installed capacity of offshore wind farms has almost multiplied by three in the period from 2010 to 2015, reaching a total of 12GW installed in that year. Looking at the official targets for the key European markets, there is clearly material growth to come over the next 5 years.

- **The industry continues on its cost improvement track.** A continuous effort to reduce the LCOE is necessary for offshore wind to remain a relevant renewable. This month, many of the main industry players announced a joint pledge to bring the LCOE down to 80€/MWh for projects taking FID in 2025. This shows the confidence within the industry to get costs down substantially.

- **Profitability still depends on subsidies.** The LCOE of offshore wind is declining continually. However, the industry is still subsidised and thus dependent on various regulation schemes. Different subsidy regimes prevail in the main European countries for offshore wind. Wind farm operators receive, in general, one of two types of subsidies: either a top-up to the market price (ROC), or a fixed price per power unit (feed-in tariff, CfD).

- **Europe is leading the race.** Almost 90% of the installed capacity is distributed among three key countries: UK, Germany and Denmark. Outside Europe, China is the only country with a significant amount of offshore wind installed.

1.2 COST REDUCTION IS REQUIRED TO ACHIEVE COMPETITIVENESS

Despite its great potential, there is still a long way until offshore wind achieves competitiveness. Electricity from this technology currently costs significantly more than onshore wind or Combined Cycle Gas Turbines (CCGT), which nowadays is the main alternative technology, albeit with significant carbon emissions. In addition to this, offshore wind is sometimes foreseen less cost-effective than alternative low carbon technologies that could arrive in the future, such as new nuclear and combinations of Carbon Capture and Storage technologies with fossil fuel plant.

Offshore wind's position in the future electricity generation mix will, to a large extent, be driven by its cost relative to those of other forms of electricity. The costs will reduce significantly only if the industry as a whole invests in new technologies, large scale automated manufacturing facilities, more effective project management techniques, new installation vessels and methods, and more effective ways of operating and maintaining wind farms. But industry will only invest if it perceives there is a sustainable and viable market for offshore wind. That dilemma reflects the importance of a credible analysis of the future development of the costs of offshore wind energy consistent with a large-scale, viable, long-term market.

Current growth is leaded by political support

The significant growth in Germany and the UK is based on political willingness, but also on fundamental drivers supporting offshore wind. For instance, the UK energy policy is based on the logic of fuel and technology diversification, as well as CO2 emission reduction. The retirement of old fossil plants brings a need for more power plants to be built in the UK. Offshore wind arises as one of the favourable alternatives, as it is not subject to land constraints (contrary to onshore wind). Furthermore, the North Sea is very well suited to offshore wind, with high wind speeds and relatively low water depths. However, it will be difficult to benefit fully from political willingness and the fundamental drivers if the industry cannot meet its cost-cutting targets.

Offshore wind is not yet a mature renewable energy technology and the costs need to come down to legitimate long term success. CfD auction celebrated in 2015 gives a good estimate of current cost level in the UK. The two projects successful in this auction, East Anglia 1 and Neart na Gaoithe, ended up with strike prices of 120 £/MWh and 114 £/MWh respectively. Denmark's latest auction for the Horns Rev 3 windfarm was won by the Swedish Utility Vattenfall with a bid of 103 €/MWh.

Differences between the two countries can be justified if we look at the responsibility of transmission network. In both Germany and Denmark, the transmission system operator (TSO) is responsible for building and operating the offshore transmission lines. This in contrast to the UK, where developers construct the transmission and sell it at cost to the offshore transmission owner (OFTO) before the wind farm begins operation, which means that the developer does not have any risk related to the transmission construction. Delays in transmission construction led to large costs and delays for the first constructed German offshore wind farms.

The risk is lower in Denmark and the Netherlands due to two key regulation characteristics: 1) the TSO builds the transmission line and 2) the regulator performs site tests and eventually selects the site. As the regulator selects the site, the windfarm developer does not need to invest in extensive pre-selection tests and analysis, which in case of a rejection would not be paid back.

On the contrary, investments in UK are more risky. The UK is generally regarded as more risky as developers enter the auctions with separate self-selected locations. The regulator then chooses the developer based on all aspects of the project, including the site features. This type of system demands much more from the developers as they have to perform site analysis before the auction, and also bear the costs of it, without knowing if the project will ultimately benefit from a subsidy. Furthermore, in the UK, the developers are responsible for construction of the transmission line, before selling it to the OFTO as the wind farm is commissioned. However, as all costs are reimbursed, the developer is not taking any construction risk related to the transmission cable.

Industry is committed to reduce costs

On 03 June 2016 a group of European Energy companies and turbine manufacturers pledged to cut the cost of offshore wind farms closer to that of gas and coal power stations in a joint statement to EU policymakers. They declared that they can drive down costs to 80 €/MWh for projects taking FID by 2025. The group stated that offshore windfarms can be fully competitive with new fossil fuel power stations under the right conditions but that a commitment is only possible with a stable and long-term market for renewables in Europe. The group added that there is a “serious question mark” over how much support governments will offer the industry after 2020, when existing EU renewable energy targets are to be replaced by less stringent goals for 2030.

> *“With the right build out and regulatory framework the industry is confident that it can achieve cost levels below €80/MWh for projects reaching final investment decision in 2025, including the costs of connecting to the grid. This means offshore wind will be fully competitive with new conventional power generation within a decade. The offshore wind industry is on track to achieve its cost reduction ambitions and will be an essential technology in Europe’s energy security and decarbonisation objectives.”*
>
> *- Signed by representatives from Adwen, EDPR, Eneco Energie, E.ON Climate & Renewables, GE Renewable Energy, Iberdrola Renovables, MHI Vestas Offshore Wind, RWE Innogy, Siemens Wind Power, Statoil and Vattenfall -*

Figure 1.1 Commitment signed by main developers of offshore windfarms

In 2012, the Department of Energy & Climate Change (DECC) challenged the offshore industry to reach a levelized cost of energy (LCOE) of 100 £/MWh for projects taking FID by 2020 to continue supporting the industry. Moreover, in the most recent UK budget it was announced that support for offshore wind will be capped initially at £105/MWh (in 2011-12 prices), falling to £85/MWh for projects commissioning by 2026. The recent joint pledge from the industry participants seems to give confidence to reach the government targets and secure further financial support of the industry.

Figure 1.2 reflects the comparison of the results of the latest CfD auction in UK (March 2015), where as commented before projects East Anglia 1 and Neart na Gaoiithe were awarded, the latest Danish tender and the industry target for projects taking FID in 2025.

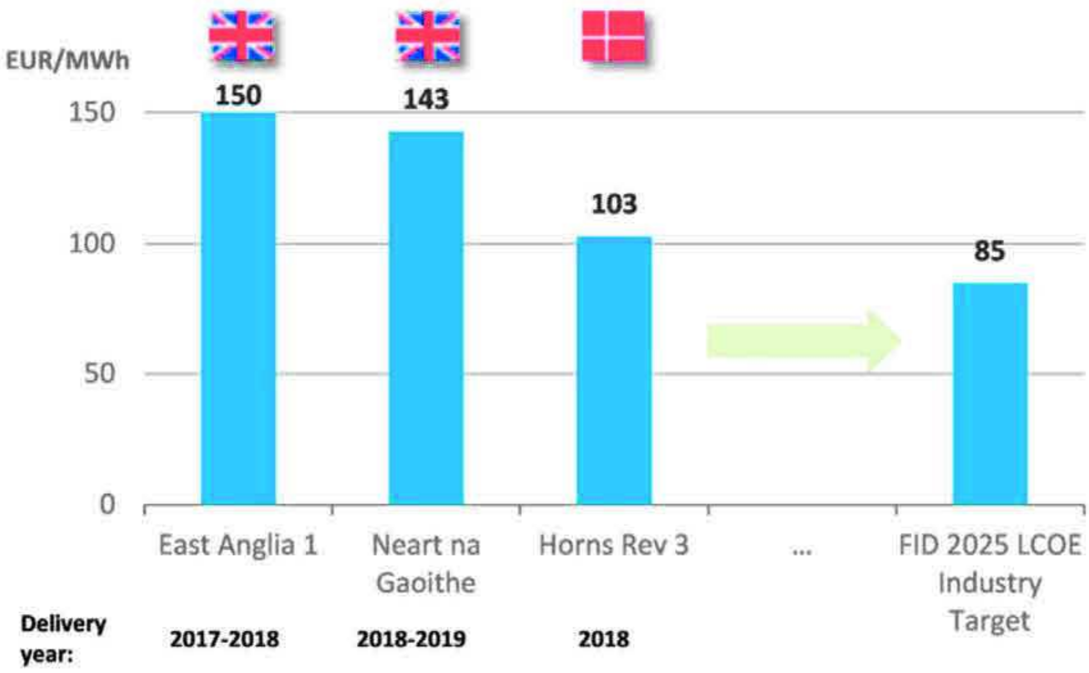


Figure 1.2 Comparison of the results of the latest CfD auction in UK, the latest Danish tender and the industry target for projects taking FID in 2025.

The main objective of this master thesis is to make a research of the alternatives, opportunities and improvements that can lead the offshore costs to achieve the committed LCOE of 80 €/MWh.

1.3 Objectives of this Master Thesis

The objective of this thesis is to analyse the opportunities and developments that could provide a reduction on costs in the offshore wind technology. The idea is to cover in detail how technology, supply market and finance can reduce the cost of energy delivered to the connection point. The alternatives to be studied are classified in three groups:

- Opportunities that affect the efficiency in the supply chain.
- Opportunities based in the technology development.
- Opportunities based on financing alternatives.

Apart from these three groups, chapter 7 analyses the measures that European governments could implement to favour the reduction in the cost of energy of the offshore wind, although the impacts associated to these measures are not computed to avoid overlapping with the other three categories. All the opportunities analysed in the other three categories assume that every political or public measure needed will be implemented, and in consequence they are taken into account in the LCOE impact calculated.

Once calculated the impact on the LCoE of each opportunity, the information obtained is then applied to the current costs scenario to obtain a forecast of the future development of the costs towards 2030.

Next is detailed a scheme of the objectives that will cover the report:

1) **Analysis of the current LCOE of the offshore wind technology.**
    a. Cost evaluation of offshore wind projects reaching the Final Investment Decision (FID) in present years, including Capex and Opex analysis, taxes consideration, and terminal value of the windfarm.

       Two projects have been selected as representative of the current costs of the total offshore capacity installed in Europe, located in UK and Germany.
    b. Use of this LCOE as a reference of the potential reductions that generate the opportunities analysed in the next part of the report.

2) **Analysis of cost reduction opportunities.**
    a. Identification and study of the key developments, dependencies and actions that could result in a reduction in costs.
    b. Detailed description of each alternative, explaining the concept and the target dates when the improvement will be available in the market.
    c. Calculation of the approximate impact that each alternative could have on the reference LCoE, using the information available to calculate it.

3) **Application of the impacts previously evaluated to the current costs of the technology.**
    a. Calculation of a forecasted LCoE towards 2030 horizon applying the findings analysed in the alternatives to the reference LCoE calculated in the first point.
    b. Comparison of offshore wind costs with different technologies, reflecting the position that the offshore wind will have in the future electricity generation mix.

2

OFFSHORE WIND POWER MARKET

2.1 INITIAL DEVELOPMENT OF THE MARKET

The first offshore wind farm was inaugurated in 1991, 2.5 km off the Danish coast at Vindeby. Developed by DONG Energy, it features eleven 450 kW turbines for a total capacity of 4.95 MW. 20 years later, by the end of 2010, 2.946 MW of offshore wind capacity in 45 wind farms spread across nine countries were feeding an estimated 10.6 TWh of electricity into the European grid.

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

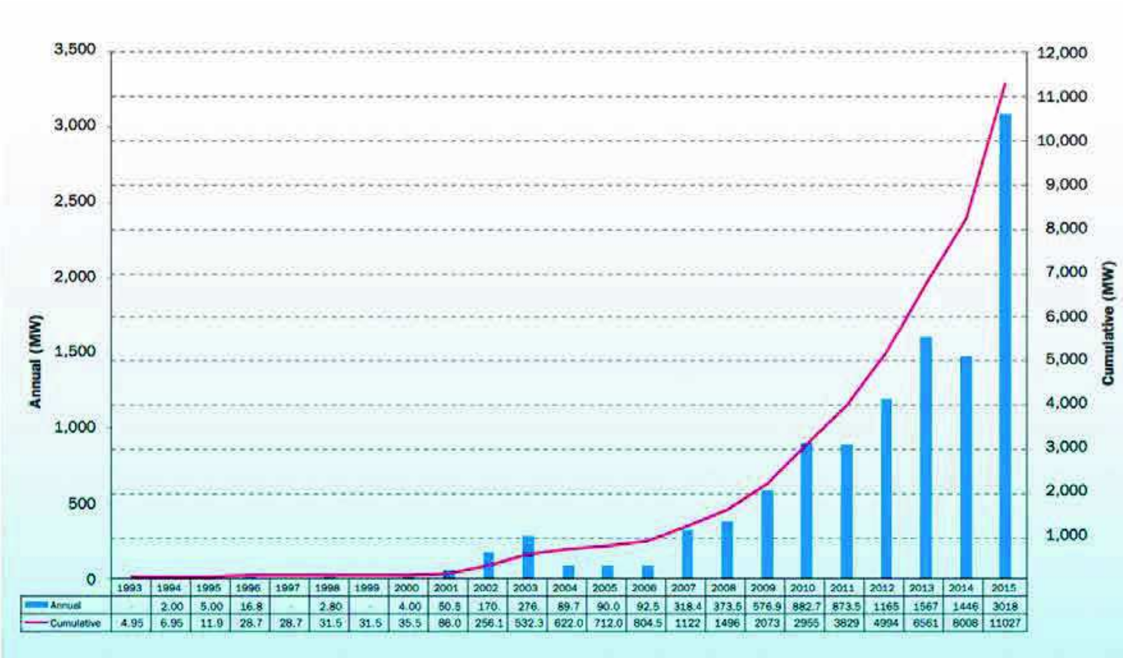


Figure 2.1 Cumulative and annual offshore capacity installed in Europe. Source: EWEA

With 20 turbines and a total capacity of 40 MW, in 2001, the Middelgrunden project in Danish waters became the first “utility-scale” offshore wind farm. That same year, seven 1,5 MW turbines were grid connected off Utgrunden in Sweden.

Since the beginning of the century, new offshore wind capacity has been going online every year. Moreover, the share of new offshore wind capacity in total wind capacity additions has been increasing. In 2001 the 50,5 MW of installed offshore capacity represented 1% of total new European annual wind capacity, the 883 MW installed in 2010 represented 9.5% of the annual European wind energy market.

This increase accelerated in this decade. Since 2010, despite the global financial crisis, the growth in the amount of capacity installed has been rising, starting with 882 MW in 2010 and finishing with 3.018 MW in 2015.

Europe´s advantage

Currently all major operational offshore wind farms are European. The reason of this predominance are different: it was the first zone of the world in building windfarms at sea, it has lot of space available, good meteorological an ocean conditions…

The development of offshore wind energy globally creates significant opportunities for European companies, from manufacturers to developers, to expand their activities beyond European waters.

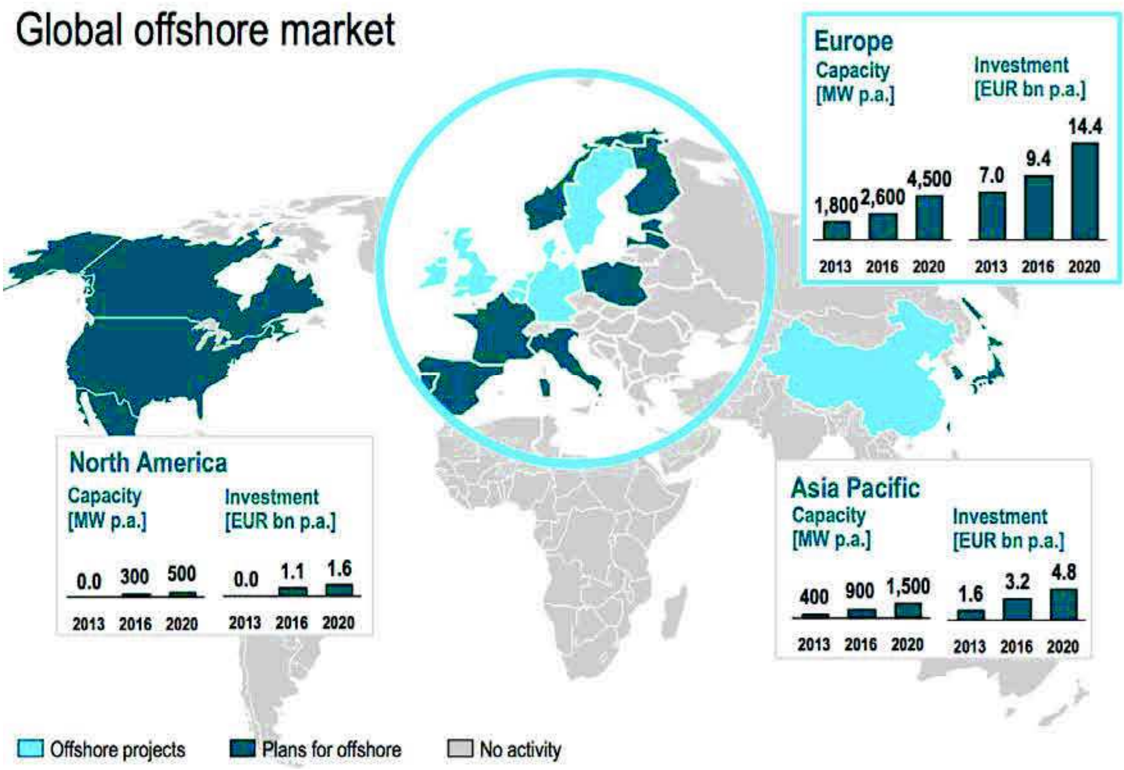


Figure 2.2 Global offshore market in 2013. Source: EER, BTM, Roland Berger.

As can be seen in the picture, Europe is, by far, the zone where the Offshore Wind power has reached a higher level of development. It has ambitious growth rates and annual increments of 4,5GW in 2020. Asia Pacific occupies the second position, with annual additions of 1,5GW in 2020. Finally, North America follows the other two zones with lower level of investments.

2.2 OFFSHORE WIND POWER MARKET TODAY

Capacity in Europe

Taking into account the importance of the European Offshore Wind market with respect to the rest of the world, and considering that it is our continent, from now on, our report will be focused in this zone.

Europe's cumulative installed capacity at the end of 2015 reached 11.027,3 MW, across a total of 3.230 wind turbines. Including sites under construction, there are now 84 offshore wind farms in 11 European countries.

With installed capacity now capable of producing approximately 40,6 TWh in a normal wind year, there is enough electricity from offshore wind to cover 1,5% of the EU's total electricity consumption.

As can be seen in figure 2.3, the UK has the largest amount of installed offshore wind capacity in Europe (5.060,5 MW) representing 45,9% of all installations. Germany follows with 3.294,6 MW (29,9%). With 1.271,3 MW (11,5% of total European installations), Denmark is third, followed by Belgium (712,2 MW, 6,5%), the Netherlands (426,5 MW, 3,9%), Sweden (201,7 MW, 1,8%), Finland (26 MW), Ireland (25,2 MW), Spain (5 MW), Norway (2 MW) and Portugal (2 MW).

Country	BE	DE	DK	ES	FI	IE	NL	NO	PT	SE	UK	Total
No. of farms	5	18	13	1	2	1	6	1	1	5	27	**80**
No. of turbines	182	792	513	1	9	7	184	1	1	86	1,454	**3,230**
Capacity installed (MW)	712	3,295	1,271	5	26	25	427	2	2	202	5,061	**11,027**

Figure 2.3 Europe Offshore Market. Distribution by country. Source: EWEA.

In terms of the number of grid-connected wind turbines in Europe, the UK leads the market with 1.454 turbines (45%), followed by Germany (792 wind turbines, 24,5%), Denmark (513 turbines, 15,9%), Belgium (182 turbines, 5.6%), the Netherlands (184 turbines, 5,7%), Sweden (86 turbines, 2,7%), Finland (nine turbines, 0,3%) and Ireland (seven turbines). Norway, Portugal, and Spain all have one wind turbine each.

The 11.027,1 MW of offshore wind capacity are mainly installed in the North Sea (7.656,4 MW, 69,4%). 1.943,2 MW or 17,6% are installed in the Irish Sea, and 1.420,5 MW (12,9%) in the Baltic Sea, and 7 MW in the Atlantic Ocean.

The average capacity rating of the 754 offshore wind farms under construction in 2015 was 4.2 MW, 12.9% larger than in 2014. Larger capacity turbines were deployed by all manufacturers in 2015. The average size of wind farms in construction in 2015 was 337.9 MW, an 8.2% decrease from 2014.

Financial situation

The financial markets in 2015 continued to support the offshore wind sector across a variety of instruments and actors. The record level of commercial debt that was raised in 2015 through project finance, green and/ or non-recourse bonds indicates that financial markets are willing to back well-structured projects.

Ten projects worth €13.3bn in total reached final investment decision in 2015, compared to €6.5bn, a doubling from 2014. In total, 3 GW of new gross capacity were financed across four countries, 66% of which was in the United Kingdom.

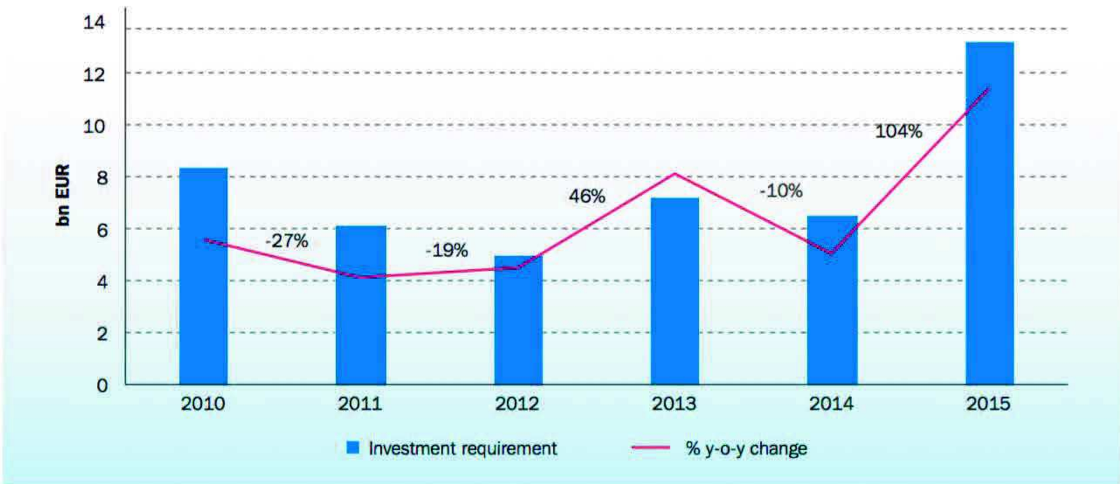


Figure 2.4 Investment requirements in Offshore Wind Power in years 2010 – 2015. Source: EWEA

In 2015 the UK had the largest level of investment in new offshore wind farms, at €8.9bn. Cumulatively, over the last 5 years, Germany has received the most investment, attracting €19.8bn for the construction of new offshore wind projects, or 43% of the total funds committed to the sector for the same period.

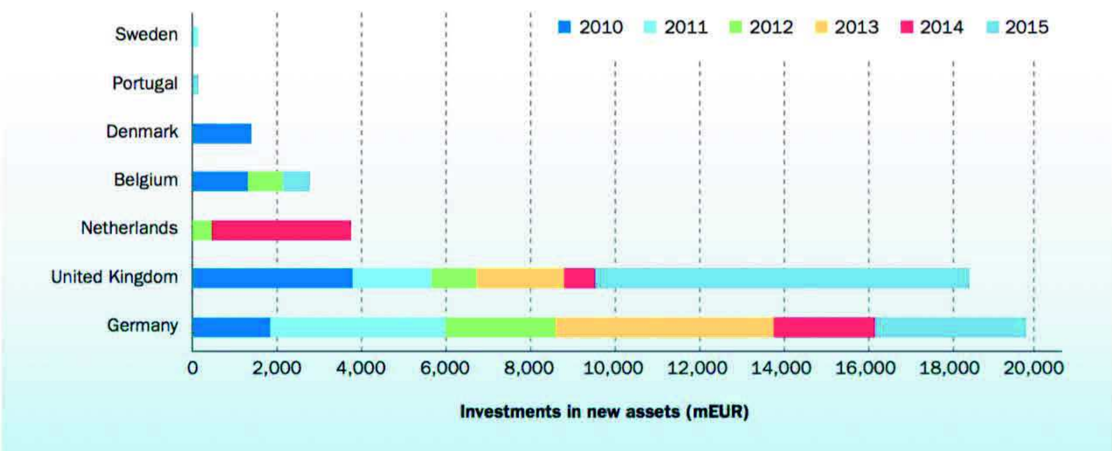


Figure 2.5 Cumulative investments by country during the years 2010 – 2015.

Main players in the supply chain

The supply chain of offshore wind power is composed by several markets, all of them providing components, technology or services needed to complete a windfarm. In this part it has been done a review of the companies that plays a relevant role in the European market, looking at the accumulated market share since year 2010. To make the analysis it has been used the information published quarterly in the market Overview Report by 4C Offshore.

Turbine manufactures

Siemens is, with difference, the world leader in the fabrication of offshore turbines. It has more than 2.144 turbines installed (8.2GW) and the 69% of the market share. Is followed by MHI-Vestas, with 391 turbines installed and 1,3GW of capacity. Then, Senvion (198 turbines) and Adwen (190 turbines) compete for the third position.

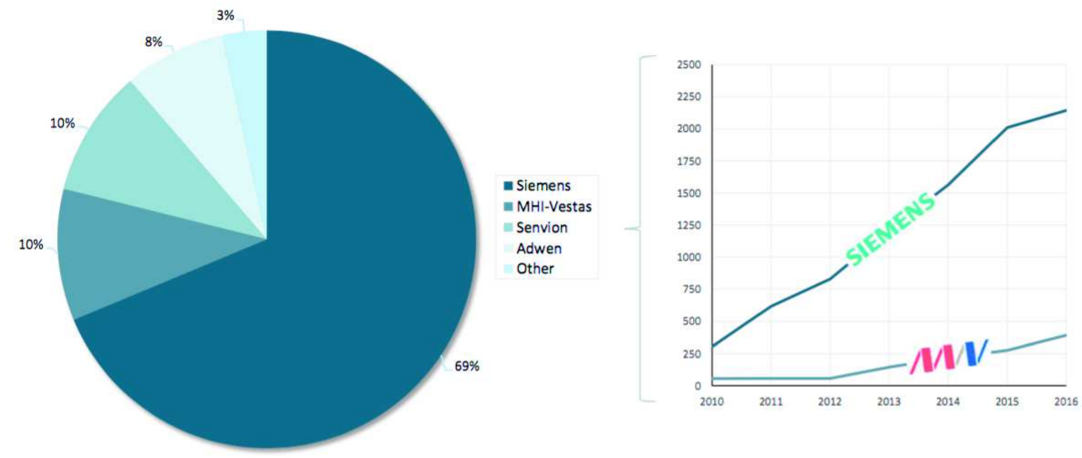


Figure 2.6 Accumulated market share of turbine manufactures since 2010. Source: 4C Offshore.

Turbine installers

In the turbine installation market the competence is higher. There are three main companies with represent together more tan 70% of the market share. A2Sea is the first company in the sector, with 974 turbines installed since 2010. MPI offshore, with 654 turbines, and Seajacks, with 309 turbines, are the second and third players in the sector.

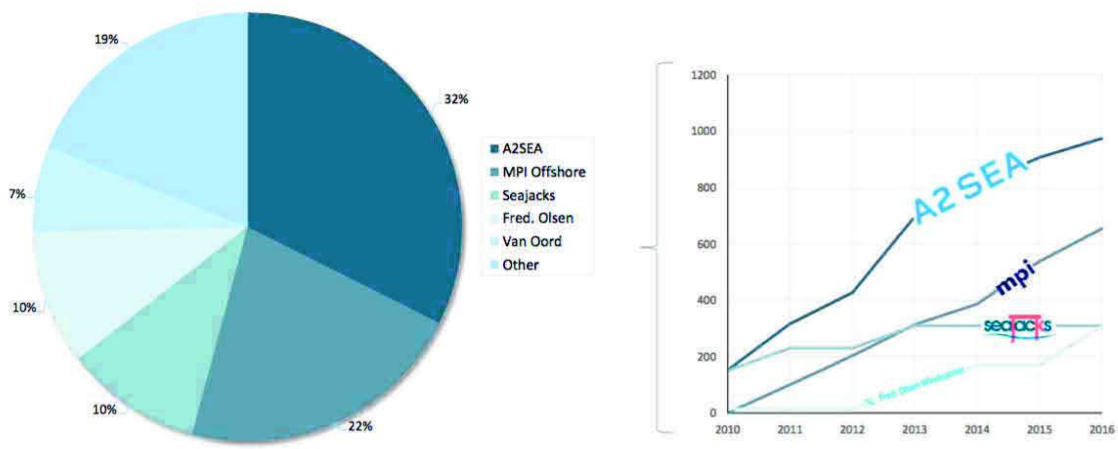


Figure 2.7 Accumulated market share of turbine installers since 2010. Source: 4C Offshore.

Foundations design

The foundations design market is clearly dominated by Ramboll, that has designed 1.250 foundations an represents near 50% of the market share. Secondly, DONG Energy has also an important market share, after having installed 284 foundations since 2010. COWI – IMS JV is located on the third position, with 245 foundations designed.

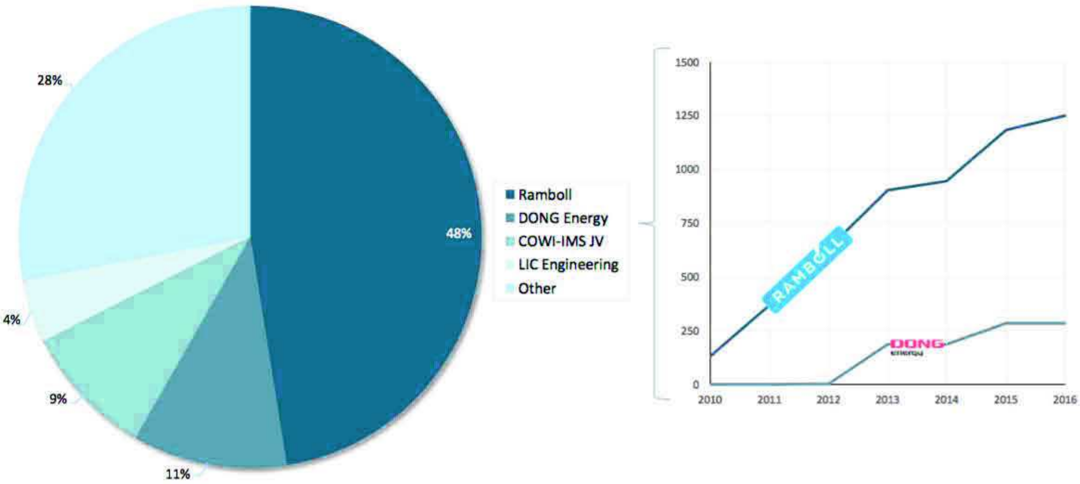


Figure 2.8 Accumulated market share of foundations design since 2010. Source: 4C Offshore.

Foundation installers

As it happens in the turbine installation market, the foundation installers market is also more diversified. There are two main players: Van Oord and GeoSea, with 539 and 402 foundations installed respectively, and three other players with lower relevance in the market: Seaway Heavy Lifting, MPI Offshore and OWF JV, with 381, 310 and 245 foundations installed respectively.

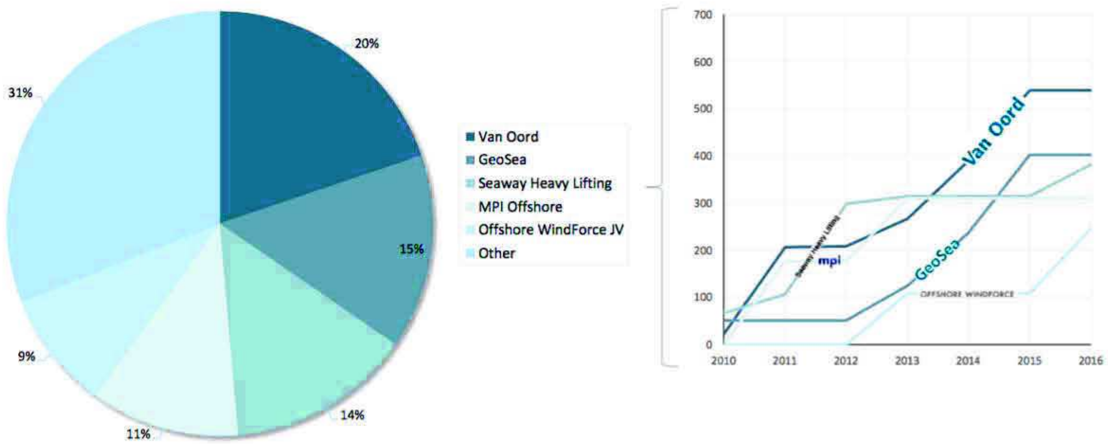


Figure 2.9 Accumulated market share of foundations installation since 2010. Source: 4C Offshore.

Cable manufacturers

In this case, the market is very different depending on the voltage of the cables, as each type of cable has different characteristics.

In the 30-36kV cable market, the three main players are JDR Cable Systems, with 826km of cable installed, Nexans (631 km) and NSW (545km). In the 132-220 kV market, NKT Cables and Prysmian lead the competition with 558 and 528 km of cable installed respectively, followed by Nexans and ABB Cables, with 356 an 308km installed.

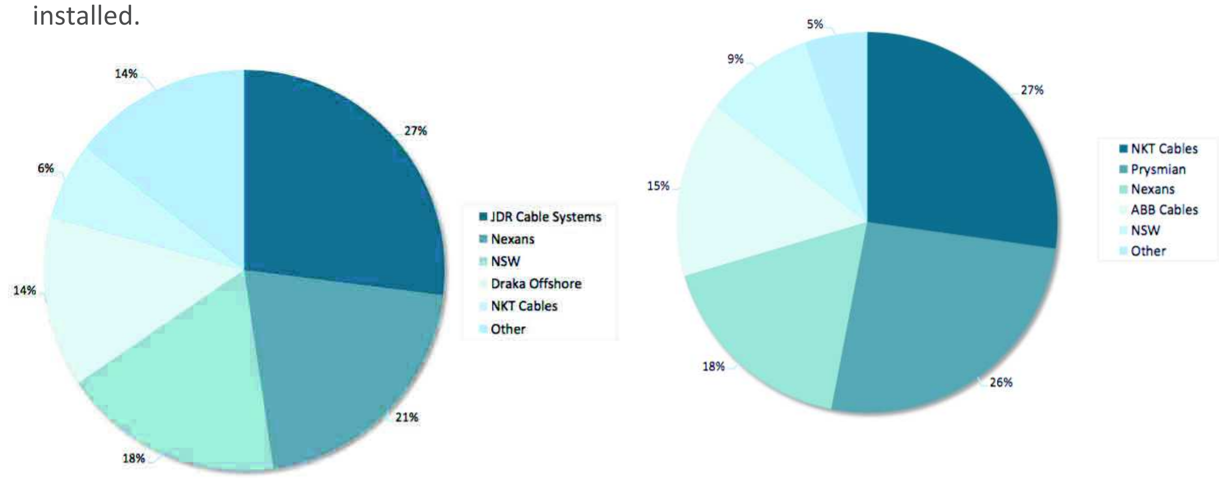
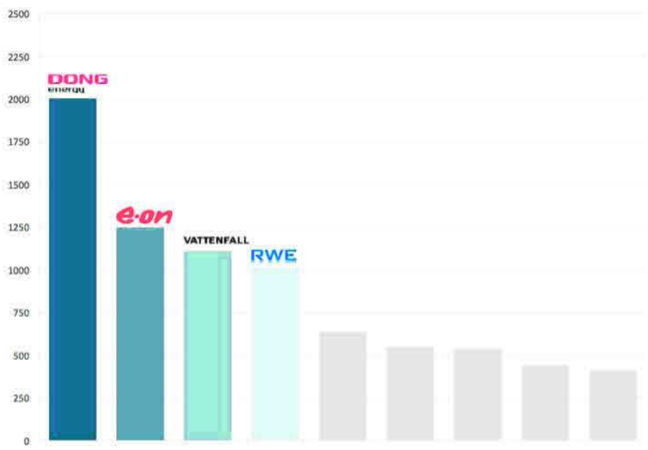


Figure 2.10 Accumulated market share of cable manufactures (30-36kV left and 132-220kV right) since 2010. Source: 4C Offshore.

Windfarm developers (ownership companies)

Finally, regarding the companies which own the offshore windfarms, DONG Energy maintains its position as the biggest owner of offshore wind power in Europe with 15.6% of cumulative installations at the end of 2015. EON (9.6%), Vattenfall (8.9%), RWE (6.4%) and Northland Power (3.8%) complete the top five developers and owners.



	Owned Capacity (MW)
DONG Energy	2010
E.ON	1254
Vattenfall	1115
RWE	1017
Northland Power	642
Stadtwerke München	555
ScottishPower Renewables	545
Siemens	444
UK Green Investment Bank	415

Figure 2.11 Accumulated market share of offshore capacity ownership. Includes windfarms fully commissioned and under construction. Source: 4C Offshore.

2.3 MARKET OUTLOOK

Coming years 2016 – 2017

The volume of new grid-connected installations will be lower in 2016 than it was in 2015. This is due in part to the high volume of turbines installed in 2014 that were only grid-connected in 2015 in Germany; and in part to the reduced number of project starts in 2015 compared to 2014.

However, turbine orders in 2015 were stronger than in 2014, presenting an early indication of good momentum for offshore wind after 2016. Year-on-year orders grew by 74.5% to 5.1 GW of firm and conditional orders placed.

Offshore construction work is expected to start at sites larger than those worked on in 2015, such as Iberdrola's Wikinger wind farm in Germany and EON's Rampion in the UK, meaning that overall average wind farm sizes will increase in 2016. Average turbine size will also increase as the industry develops larger models. Once completed, the six offshore projects currently under construction will increase installed capacity by a further 1.9 GW, bringing the cumulative capacity in Europe to 12.9 GW.

Figure 2.12 shows the capacity planned to be installed, divided by country and status: consent authorised, consent submitted and early planning. The image remains clear that the planning activity is mainly centred on the two giants of offshore wind, Germany and the UK. This takes into account factors such as government outlook and respective policies on renewable energy and offshore wind, competition for subsidies with other renewable energy sources and available financing options to name a few constraints.

	United Kingdom	Germany	France	Netherlands	Denmark	Belgium
Consent authorised	9,753MW	6,260MW	12MW	1,540MW	400MW	1,191MW
Consent submitted	3,062MW	20,169MW	1,924MW	320MW	1,210MW	224MW
Concept/early planning	12,239MW	8,784MW	2,044MW	2,100MW	1,474MW	2.3MW

Figure 2.12 Situation of planned projects in Europe by country and status. Source: 4C Offshore.

Year 2020

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

The 2009 directive also required all Member States to produce National Renewable Energy Action Plans (NREAPs) determining the share of each renewable technology in the energy mix from 2010 to 2020 and, therefore, setting sectorial objectives. The 27 NREAPs' combined objective for offshore wind capacity by 2020 is 43.3 GW, which will allow meeting between 4 and 4.2% of the EU's electricity demand.

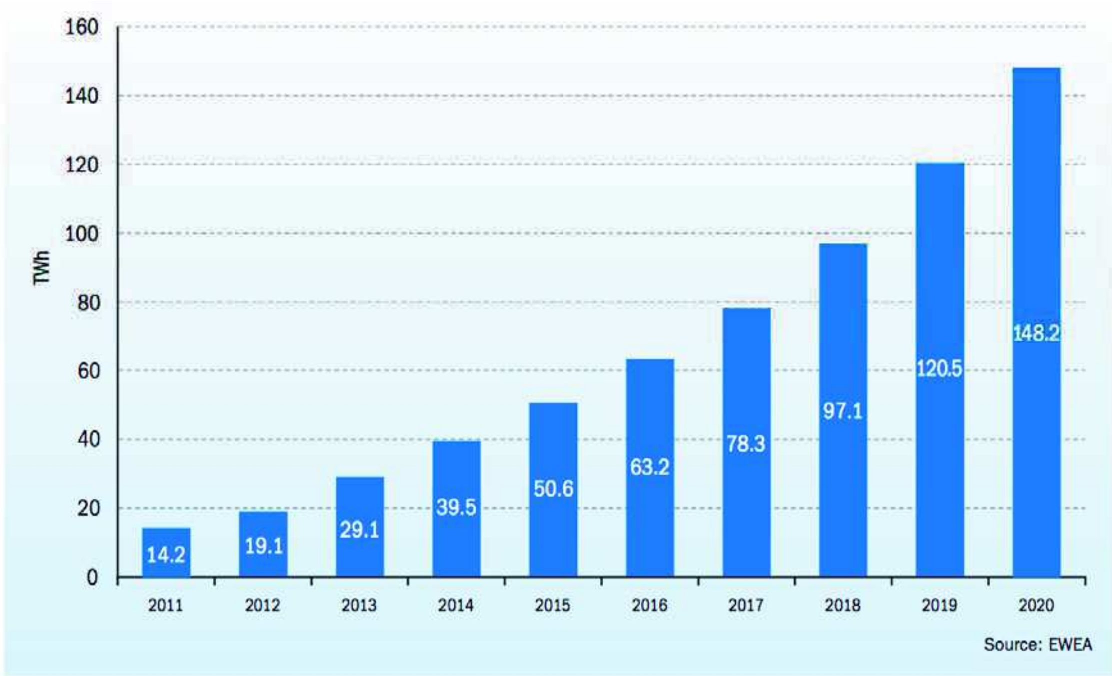


Figure 2.13 Offshore wind electricity production in period 2010 - 2020. Source: EWEA.

Figure 2.13 represents the predictions of offshore wind power generation made by the European Wind Energy Association (EWEA) in 2010. It assumes 40GW of installed capacity in 2020, that would produce 148 TWh of electricity. Approximately a quarter of Europe's wind energy would be produced offshore in 2020, according to EWEA's scenarios. Including onshore, wind energy would produce 581 TWh, enough to meet between 15.7% and 16.5% of total EU electricity demand by 2020.

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

- Total installed capacity of 40.000 MW.
- Meeting between 4% and 4.2% of total EU electricity demand.
- Annual installations of 6,900 MW.
- Avoiding 102Mt of CO_2 annually.
- Total electricity production of 148 TWh.
- Annual investments in offshore wind turbines of 10.400 M€.
- Cumulative investments in wind turbines of 65.900 M€ in the period 2011- 2020.

Year 2030

The EU must decide as soon as possible on an energy and climate policy framework for 2030, to allow the continuity of investments, growth of wind energy, and the meeting of European greenhouse gas reduction commitments by 2050.

This 2030 framework must be centred on mutually reinforcing binding targets for renewable energy, greenhouse gas emission reduction and energy efficiency, and will reinforce investments in Offshore Business. Between 2021 and 2030, the annual offshore market for wind turbines is estimated to grow steadily from 7,8 GW in 2021 to reach 13,7 GW in 2030. 2027 would be the first year in which the market for offshore wind turbines (in MW) exceeds the onshore market in the EU.

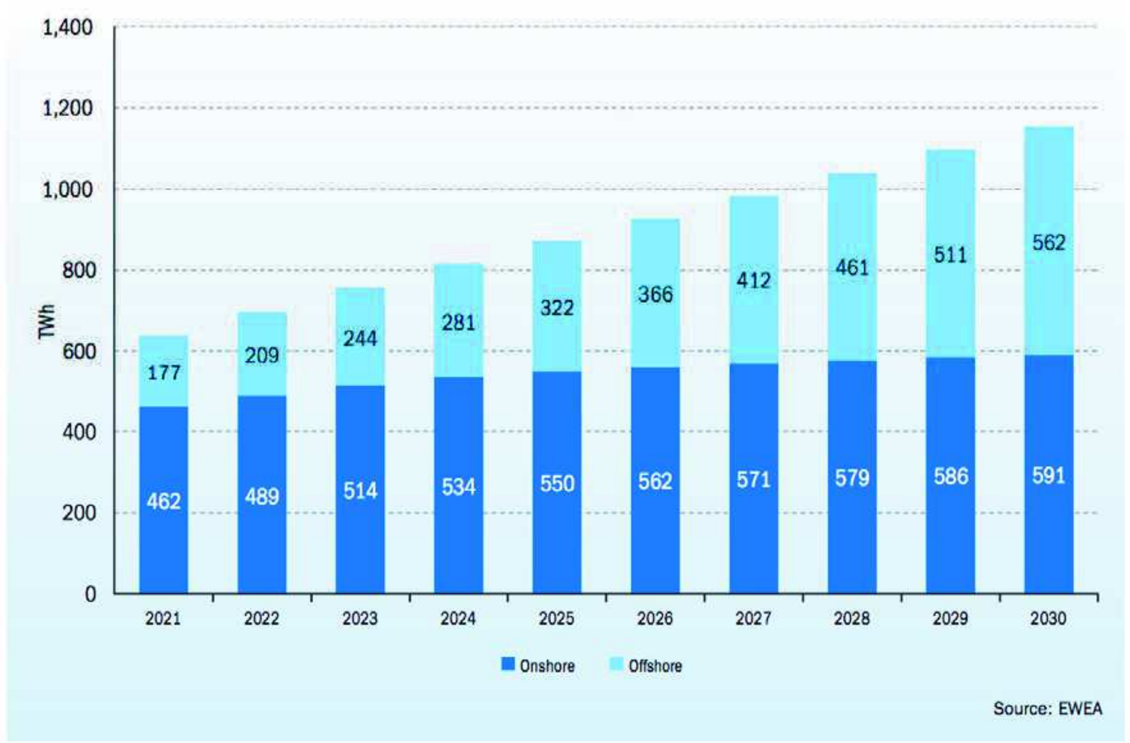


Figure 2.14 Offshore and onshore wind electricity production in the period 2021- 2030. Source: EWEA.

The 150 GW of installed capacity in 2030 would produce 562 TWh of electricity, equal to 13,9% of EU electricity consumption. Approximately half of Europe's wind electricity would be produced offshore in 2030. An additional 591 TWh would be produced onshore, bringing wind energy's total share to 28,5% of EU electricity demand.

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

- Total installed capacity of 150.000 MW.
- Annual installations of 13.700 MW.
- Total electricity production of 562 TWh.
- Meeting 13,9% of total EU electricity demand.
- Avoiding 315 Mt of CO_2 in 2030.
- Annual investments in offshore wind turbines of 17.000 M€ in 2030.
- Cumulative investments of 145.200 M€ from 2021 to 2030.

2.4 DEVELOPMENT TRENDS

Wind turbine capacity

Wind turbine capacity has grown 41.1% from 2010 to 2015. In 2015, the average capacity of new wind turbines installed was 4.2 MW, a significant increase from 3.0 MW in 2010, reflecting a period of continuous development in turbine technology to increase energy yields at sea.

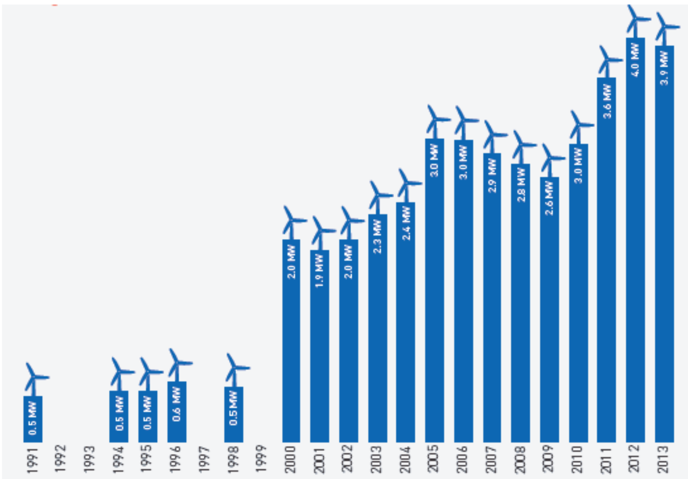


Figure 2.15 Average turbine size installed by year. Source: EWEA.

The deployment of 4-6 MW turbines seen in 2015 will be followed by the gradual introduction of 6-8 MW turbines closer towards 2018, as the ones to be installed in East Anglia One Project developed by Scottish Power in UK, whose turbines are rated with 7 MW of capacity.

Increase in the size of the turbines allows a reduction in cost, specially operation and maintenance costs, because it reduces the number of turbines on a windfarm. It is also interesting to remark the efforts being done by turbine manufactures to increase the efficiency (in terms of energy generated per year) if the new types of turbines.

Average windfarm size

In the last five years, the average wind farm size has more than doubled, from 155.3 MW in 2010 to 337.9 MW in 2015. Multiple consents granted last year in the UK for 1.2 GW sites in the Dogger Bank provide indications for the scale of offshore wind farms in the longer term, such as East Anglia One with a capacity of 714 MW.

Larger wind farms allow improved fixed cost allocation, so they contribute to reduce the energy cost of the technology. The increase in the size of the windfarms is motivated by the increase of the number of turbines and the increase in the capacity of the turbines, as seen in the previous point.

Figure 2.16 Average turbine windfarm size by planning stage. Source: Roland Berger.

Location of the windfarms: deeper and further

Offshore wind farms have moved further from shore and into deeper waters. At the end of 2015, the average water depth of grid-connected wind farms was 27,1 m and the average distance to shore was 43,3 km. This is primarily the result of increased deployment in Germany during 2015, where sites are an average of 52,6 km from shore. By comparison, UK projects were on average 9,4 km from the shoreline. Dutch projects were sited at an average of 31,4 km away from shore.

The trend toward building windfarms further from shore is motivated by the approval of new environmental laws (for example in Germany) and the limited space close to shore (as in UK). In consequence, greater distance to shore usually leads to deeper water at site, which requires new foundation solutions

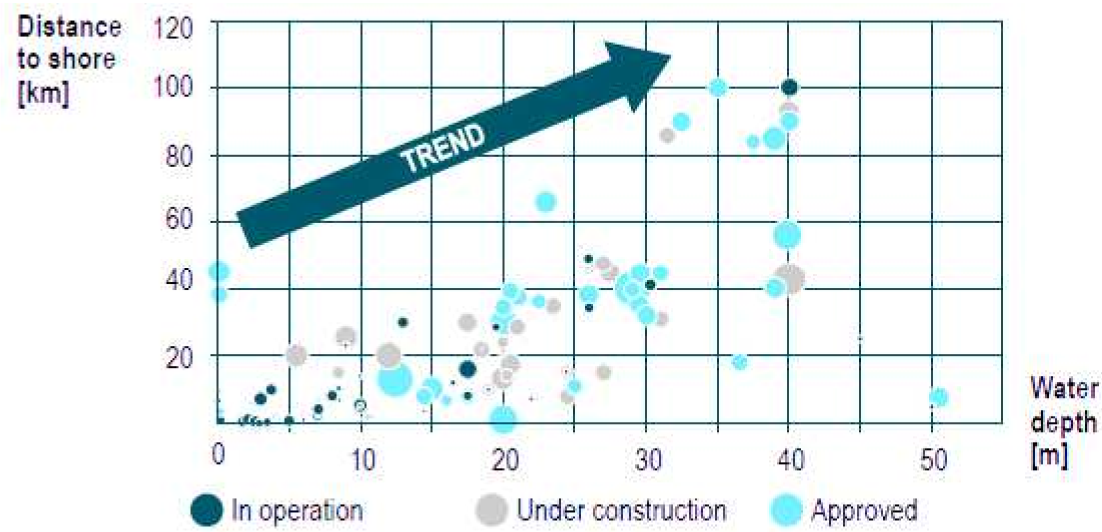


Figure 2.17 Trends in the location of planned windfarms. Source: Roland Berger.

Employment and skill requirements in the future

Historically, the main drivers for the deployment of renewable energy in many countries were the twin pillars of climate change objectives and energy security. However, the financial crisis and the resultant recession are adding industrial development, export potentials and employment opportunities associated with renewable energy as a primary motivation for promoting renewable energy development.

The potential rewards are enormous. EWEA has estimated that the wind energy sector in Europe will create around 273.000 direct and indirect new jobs over the next decade, taking the industry to a total of approximately 462.000 direct and indirect jobs by 2020. The corresponding figures for the offshore sector alone are 134.000 and 169.500 respectively, highlighting the fast increasing importance of offshore development within the broader wind industry in Europe. By 2030, around 480.000 people are expected to be employed in the sector, around 300.000 of whom in the offshore sector (almost 62% of the total).

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

3

CURRENT LCOE OF OFFSHORE WIND

3.1 Justification of the use of LCoE

Definition of LCoE

The levelized cost of electricity (LCOE) is a measure that allows the comparison between different methods of electricity generation. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the minimum cost at which electricity must be sold in order to make a project profitable.

LCOE can be calculated as the net present value of the unit-cost of electricity over the lifetime of a generating asset. The discount rate used in the calculation is the Weighted Average Cost of Capital (WACC) over the lifetime of the project, as determined by the capital structure and financing costs.

$$LCOE = \frac{Sum\ of\ cost\ over\ lifetime}{Sum\ of\ energy\ produced\ over\ lifetime} = \frac{\frac{\sum_{1=1}^{n} Ci}{(1+r)^i}}{\frac{\sum_{1=1}^{n} Ei}{(1+r)^i}}$$

being

- $Ci = Sum\ of\ cost\ per\ year\ (€)$
- $Eiq12q = Energy\ delivered\ (MWh)$
- $R = Discount\ rate = WACC\ of\ the\ project$
- $n = Lifetime\ of\ the\ project$

The LCOE is calculated over the design lifetime of a plant, which is usually between 20 to 40 years (in our case, we will use 25 years, as we will see in the following points), and given in the units of currency per megawatt-hour, for example GBP/MWh or EUR/kWh.

Why the LCoE?

LCOE is a first-order economic assessment of the cost competitiveness of an electricity-generating system that incorporates all costs over its lifetime:

- Initial investment Capex.
- Operations and maintenance costs.
- Fuel costs.
- Cost of capital.
- Decommissioning costs.

The importance of the factors varies among the technologies. For technologies such as solar and wind generation that have no fuel costs and relatively small variable O&M costs, LCOE changes in proportion to the estimated capital cost of generation capacity. For technologies with significant fuel cost, both fuel cost and overnight cost estimates significantly affect LCOE.

The consideration of all these costs in the calculation, and the fact that all cost estimates are adjusted for inflation and discounted to account for the time-value of money, makes the LCOE the best economic figure to compare different technologies of generation.

3.2 PROJECTS AND ASSUMPTIONS CONSIDERED

Projects selected for valuation

To calculate the current LCOE of the offshore wind energy is necessary to choose a windfarm project, consider all the cost incurred and the expected generation, and calculate the value using the formula explained above. Selecting the appropriate project is a very relevant issue, as it has to be representative of the total offshore energy installed at this moment. The following criteria have been considered:

- **Status of the project**. Projects having reached FID recently, with an advanced stage of development. Still not in operation, to guarantee that estimations of costs are updated and not obsolete.

- **Location of the project**. As explained in the previous chapter, UK and Germany are the two countries which more offshore wind capacity installed in Europe at this moment, with 5.060,5 MW (45,9%) and 3.294,6 MW (29,9%) respectively. Both countries have different regulatory schemes, which impact on revenues and taxes. Regarding this point, it is also important the location of the windfarm in the sea: distance to shore and water depth.

- **Availability of data.** Projects selected need to have available information published: capex and O&M estimations, approved remuneration… to be able to effectively calculate the LCOE.

After considering these criteria, two projects have been selected for the calculation of the LCOE in this work. The projects selected are **East Anglia ONE (EAONE)** in UK, and **Wikinger (WIK)** in Germany. The final LCOE considered will be the LCOE obtained in each project pondered by the relative weigh of the country in the total installed offshore capacity.

These two projects fulfil the characteristics required, providing a representative view of the current costs of offshore wind energy.

- EAONE project reached FID in February 2016, and it is forecasted to start its construction in 2017. WIK reached FID in April 2014, is currently under construction and it is forecasted to be operative in 2017.

- EAONE in UK and WIK in Germany cover together the countries where 75% of the current offshore capacity is installed. The consideration of the two different regulatory schemes of these countries constitute a complete representation of the legislation affecting this energy.

- Finally, both projects accounts with enough published information to develop the calculation of the LCOE.

Following it is presented the most relevant characteristics of each project.

East Anglia ONE (UK)

In 2009, Scottish Power Renewables, working in a 50:50 joint venture partnership with Vattenfall Wind Power, was awarded rights to develop offshore capacity off the coast of East Anglia as part of the Crown Estate's Round Three programme.

East Anglia ONE was the first project to be identified for development in the East Anglia Zone. Public consultation on the project began in 2010 and continued to the submission of the application for consent in November 2012. In June 2014, following the approval of the Secretary of State for Energy, East Anglia ONE became the largest energy project in England and Wales to be consented. In February 2015, East Anglia ONE also became the first Round Three project in England and Wales to be awarded a Contract for Differences.

Highlights of the project

- Site capacity: 712MW.
- Turbine type: Siemens SWT-7.0-154 (7 MW).
- Number of turbines: 102.
- Depth range: 30 – 42m.
- Distance from shore: 45,4km.

- FID date: February 2016.
- Estimated COD date: June 2020.
- Estimated Capex: 2.000M£[1].

1. It does not include 500M£ investment in OFTO that will be reimbursed.

Wikinger (Germany)

Wikinger windfarm is a technically challenging project with difficult sea-bed conditions and deep waters. Located in the Baltic Sea, approximately 75 km from the mainland close to the Island of Rügen, Wikinger is in the northern part of an area known as Westlich Adlergrund that the German authorities have designated as a Priority Offshore Development Area.

The site covers 34 km^2 and will host 70 Adwen AD5-135 wind turbines, generating up to 350 megawatts. The design and construction of the Offshore Sub Station is being led as an in-house project jointly with Iberdrola Engineering and Construction.

Highlights of the project

- Site capacity: 350MW.
- Turbine type: Adwen AD5-135 (5 MW).
- Number of turbines: 70.
- Depth range: 37 – 43m.
- Distance from shore: 75km.

- FID date: April 2014.
- Estimated COD date: December 2017.
- Estimated Capex: 1.400M€.

Assumptions considered in the calculation of LCOE

Calculation method

The method used in this report to calculate the LCOE is based on the Free Cash Flow methodology. Free cash flow (FCF) is a measure of financial performance calculated as operating cash flow minus capital expenditures. It represents the cash that a company is able to generate after laying out the money required to maintain or expand its asset base.

$$FCF = EBITDA \cdot (1 - t) - Change\ in\ WC - Capex$$

Note that debt interests are not considered in this methodology, as the discount rate used (WACC) internalize the cost of the debt in the calculation. Another consideration to make is that for this report, and with the aim of simplifying the procedure, change in working capital (WC) has not been considered.

Following these criteria, the LCOE can be calculated using this composed formula:

$$LCOE = \frac{NPV\ Capex}{NPV\ MWh} + \frac{NPV\ Opex}{NPV\ MWh} + \frac{NPV\ Taxes}{NPV\ MWh} - \frac{NPV\ TV}{NPV\ MWh}$$

The following figure shows the schematic representation used to calculate the Free Cash Flow:

Annual period	unit	NPV	total	31 dic 09	31 dic 10	...	31 dic 50
Net output	MWh						
Price	€/MWh						
Revenue (+)	€m						
OPEX (-)	€m						
EBITDA (+)	€m						
Taxes (-)	€m						
Net Income (+)	€m						
Terminal Value (+)	€m						
Capex (-)	€m						
FCF	€m						

Figure 3.1 Template used for the calculation of LCOE.

The following criteria has been considered:

- **Annual periods.** The distribution of all costs and revenues will follow a yearly basis.
- **NPV Base date.** To homogenise the criterion, in the two projects the base date considered correspond with the FID date.
- **Discount rate**. The discount rate used to calculate NPV is the WACC of the project, that internalises the cost of debt in the calculation.

Lifetime of the projects and terminal value

Based in EWEA, lifetime we have considered for for both projects, EAONE and WIK, is equal to 25 years. This refers to the operating life of the windfarm, from COD date to Decommissioning Date, and it not implies than other FCF could appear before, for example investment costs.

At the end of the useful life, the windfarm still has a value, considering that it can be sold to another company, repowered, or decommissioned. This value is reflected in the Terminal Value. In our case, we have considered that Terminal Value is equal to 20% of the total Capex invested in the project, based in NREL Offshore Wind Technology Market Report. This 20% is considered in FID date, and it has been indexed using 2% inflation up to decommissioning date.

Net Output

Net output is the total energy provided by the windfarm at the connection point to the transmission network. This implies taking into account the network losses incurred in the internal grid of the windfarm.

The net output is measured in MWh/year. The formula applied to calculate the net output is:

$$Net\ output\ (MWh/year) = Capacity(MW) \cdot Net\ Cap.factor\ (\%)\ \cdot 8.760h$$

And the assumptions considered are:

- **Turbine capacity.**
    - **EA1.** 102 x Siemens 7 MW = 714 MW.
    - **WIK**. 70 x Areva 5MW = 350 MW.

- **Capacity factor.**

  Net capacity factor is a ratio of the actual energy delivered to the point of interconnection in a given period (typically a year) over the theoretical potential energy that could be delivered if the plant were to operate continuously at nameplate capacity over the same period of time. It accounts for electrical losses, availability losses, and losses caused by environmental factors.

  The factor used in our valuation is based in the estimations provided by the National Renewable Energy Laboratory (NREL) of the US, in its 2014–2015 Offshore Wind Technologies Market Report. The image below represents the estimations of the capacity factor for selected European offshore wind projects classified by country.

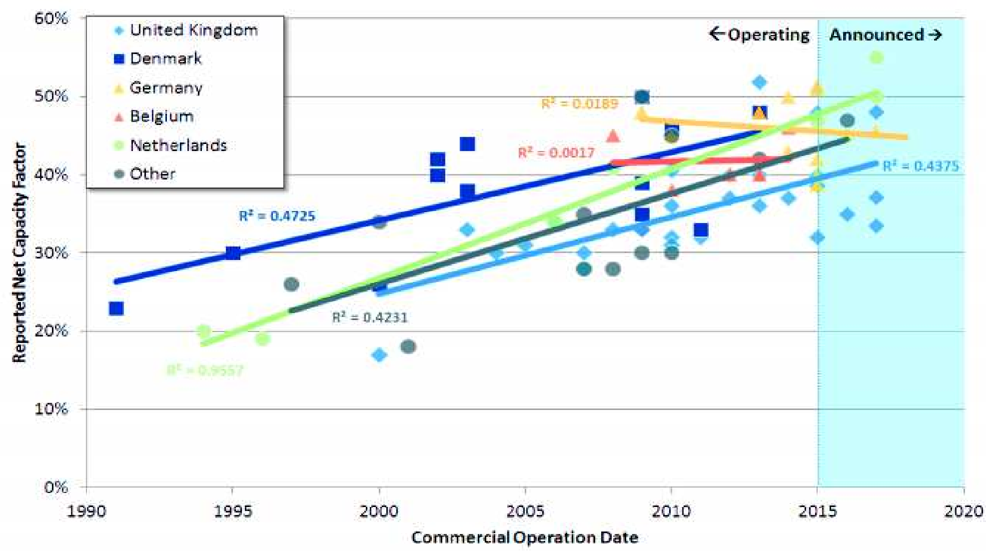


Figure 3.2 Net capacity factor for selected European offshore wind projects (by country).

  Considering the location of our projects, UK and Germany, and the year 2015 (latest estimation available), we have selected a capacity factor of 40% for EA1 and 45% for WIK.

With these assumptions, total energy produced by each project is 2.460 MWh/year for EAONE, and 1.380 MWh/year in the case of WIK.

Revenues

The revenues of the project are equal to the energy produced multiplied by the price earned for each MWh. As the energy produced has already been calculated, the problem here is reduced to the estimation of the remuneration, which follows a different scheme in each project.

East Anglia Project

As mentioned before, in February 2015, East Anglia ONE became the first Round Three project in England and Wales to be awarded a Contract for Differences by the UK Government. This contract for differences set a remuneration of £120/MWh (real values 2012) for the first 15 years of operation of the windfarm.

Taking this data into account, and considering the inflation rate (CPI) equals to 2%, which is the objective of the Bank of England, is easy to calculate the remuneration for the energy produced during the first 15 years. Note that we have to consider that the CfD period starts on COD Date (Jun 2020), therefore the price has to be updated up to that year.

		Base year		Year 1	Year 2	Year 3		Year 14	Year 15
Annual period	**unit**	**31 dic 12**	**...**	**31 dic 20**	**31 dic 21**	**31 dic 22**	**...**	**31 dic 33**	**31 dic 34**
Inflation Rate	%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%
Inflation Factor		1,00		1,17	1,20	1,22		1,52	1,55
Annual CfD Price	£/MWh	120,00		140,60	143,41	146,28		181,88	185,52

Figure 3.3 CfD prices during the first 15 years of the project.

For the remaining 10 years of the project lifetime, the revenues have to be obtained by the market prices of the electricity. To estimate these market prices, it has been considered the price for 2015, including average capacity payments, which according to the data provided by the market operator in UK, APX Power UK Spot, is £52/MWh. It has been applied to this price the same inflation than the used for the CfD, 2% annual increase.

		Base year		Year 1	Year 2	Year 3		Year 9	Year 10
Annual period	**unit**	**31 dic 15**	**...**	**31 dic 35**	**31 dic 36**	**31 dic 37**	**...**	**31 dic 43**	**31 dic 44**
Inflation Rate	%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%
Inflation Factor		1,00		1,49	1,52	1,55		1,74	1,78
Ann. Market Price	£/MWh	52,00		77,27	78,81	80,39		90,53	92,34

Figure 3.4 Wholesale market prices during 10 years after finishing CfD period.

Wikinger project

In Germany the public support to the offshore renewable windfarms is based on a Feed in Tariff (FiT) mechanism. The operators of new wind farms at sea have the possibility to choose between two funding models: base model or compressed model.

In the base model, the operators receive an increased subsidy of 15 cents/kWh during the first 12 years of operation. This period may be extended if the wind turbines are installed at water depths of more than 20 metres and at a distance from the coast of more than 12 nautical miles. After the initial funding period, the subsidy sinks to the basic value of 3.5 cents/kWh.

Alternatively, the operators of offshore wind farms can choose the so-called compressed tariff model. With this, operators receive a higher initial subsidy than in the base model (19.0 instead 15.0 cents/kWh) albeit for a shorter period of eight years. This model is supposed to create more attractive conditions for investors by offering an accelerated reflux of capital and to facilitate the financing of offshore wind farms as a whole.

Like in the base model, the period in the compressed tariff model, in which the increased initial funding is granted, is extended if certain water depths and distances from the coast are achieved. Period is prolonged with 15.0 cents/kWh by 0.5 months for each nautical mile beyond 12 miles distance from coast and by 1.7 months for each meter of extra water depth over 20m. Afterwards the subsidy also sinks to the basic value of 3.9 cents/kWh.

This regulation affects wind parks which will be commissioned before 2018, then the FiT tariff will be lowered by 5% each year.

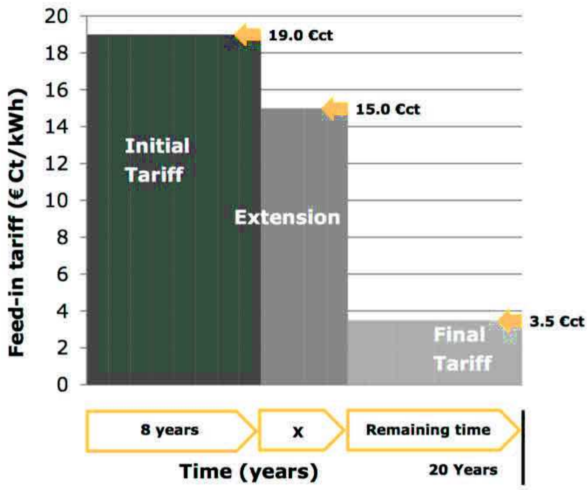


Figure 3.5 FiT scheme in Germany. Source: Ministry of Energy.

Wikinger project, as stated in Iberdrola website, is going to receive the compressed model Fit. Taking into account that the project is located 40 nautical miles from coast, and the average water deep is 40m, the extension period of the FiT for this project is approximately 48 months.

		COD year		1st Period	2nd Period		3rd Period		Final year
Annual period	**unit**	**31 dic 17**	**…**	**31 dic 24**	**31 dic 25**	**…**	**31 dic 28**	**…**	**31 dic 36**
Annual FiT	€/MWh	190,00		190,00	150,00		35,00		35,00

Figure 3.6 FiT during first 20 years of the project.

Apart from the FiT, the project can also choose to be remunerated though market prices. In practice, when market prices are higher than the FiT, project would prefer to not take the FiT. As in EAONE, the 2015 price of electricity in Germany, including average capacity payments, has been considered. According to the data provided by the market operator this price is approximately 50€/MWh. We have also applied to this price the same inflation used before, 2% annual increase. Distribution of prices obtained is the following one:

		Base year		COD Year					End Project
Annual period	**unit**	**31 dic 15**	**…**	**31 dic 17**	**…**	**31 dic 37**	**…**	**31 dic 41**	**31 dic 42**
Inflation Rate	%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%	2,00%
Inflation Factor		1,00		1,04		1,55		1,67	1,71
Ann. Market Price	€/MWh	50,00		52,02		77,30		83,67	85,34

Figure 3.7 Wholesale market prices during the whole life of the project.

As mentioned before, revenues for Wikinger project should be calculated applying the higher price (FiT or market price).

Opex

Opex covers all costs incurred after the COD, and before the decommissioning, that are required to operate the project and maintain turbine availability to generate power. These expenditures are generally thought to contribute between 20% and 30% to life cycle costs for offshore wind projects, depending on site characteristics. The strongest drivers are distance from shore, accessibility limits related to meteorological conditions (wave height), and turbine rating (i.e., fewer, larger turbines suggest fewer transfers per megawatt).

Operational expenditures for offshore wind projects are subject to considerable uncertainty because of a lack of empirical data. Although wind project owners almost always report Capex, they rarely report Opex. Uncertainty is further amplified because it is standard practice in the offshore wind industry for turbine OEMs to offer 5-year warranty periods, meaning that only projects installed before 2010 are now subject to the full range of operating costs. Industry and government stakeholders in the United Kingdom recognize that this lack of transparency could be a barrier to the industry in the future, obscuring potential cost reduction opportunities and failing to address investor risk perceptions.

In our case, Opex cost are based in the estimations provided by the International Renewable Energy Agency (IRENA) in its Wind Power Review of March 2016. According to IRENA report, O&M costs in offshore wind industry in Europe were in the range of 27-54 $/MWh. As EAONE and WIK are projects still in construction, considering O&M costs near to the upper limit is a more conservative approach.

According to this estimation, O&M costs considered for both projects are

- **EA1.** 40 £/MWh, with an annual increase of 2%.
- **WIK**. 25 €/MWh, with an annual increase of 2%.

Taxes

EBITDA is obtained after discounting Opex to the Revenues. In this report it is considered that the 100% of Capex is eligible for capital allowances. Therefore, corporate tax is applied to the EBITDA minus the capital investment of each project.

Germany

The corporate tax rate considered in our valuation is 22,85%. The overall income tax rate for corporations includes corporate income tax at a rate of 15%, solidarity surcharge at a rate of 0,825% (5,5% of the corporate income tax), and local trade tax. The local trade tax generally varies between 7% and 17.15%. In our model the lower limit has been considered.

United Kingdom

From 1 April 2015 to 31 March 2017, the corporate tax rate is 20%. The UK government has announced a staged reduction in the main rate of corporation tax including, from 1 April 2014, a reduction from 23% to 21% and, from 1 April 2015, a reduction to 20%. There will be a further reduction to 19% from 1 April 2017 and to 18% from 1 April 2020, although in the report is not considered as is still not approved.

Capex

Capex is the single largest contributor to the life cycle costs of offshore wind plants and includes all expenditures incurred prior to the COD. Unlike Opex, Capex figures are normally self-reported by developers, but difficult to verify independently. In addition to this, it is often unclear whether the reported Capex is comprehensive and fully captures the cost to install the project and connect it to the grid or not.

In its 2015 Offshore Wind Market Report, NREL published the estimations and trends of project´s Capex in coming years. The following graph shows Capex data segmented by country and indicates that these expenditures are expected to trend downward in most markets from 2015 to 2020.

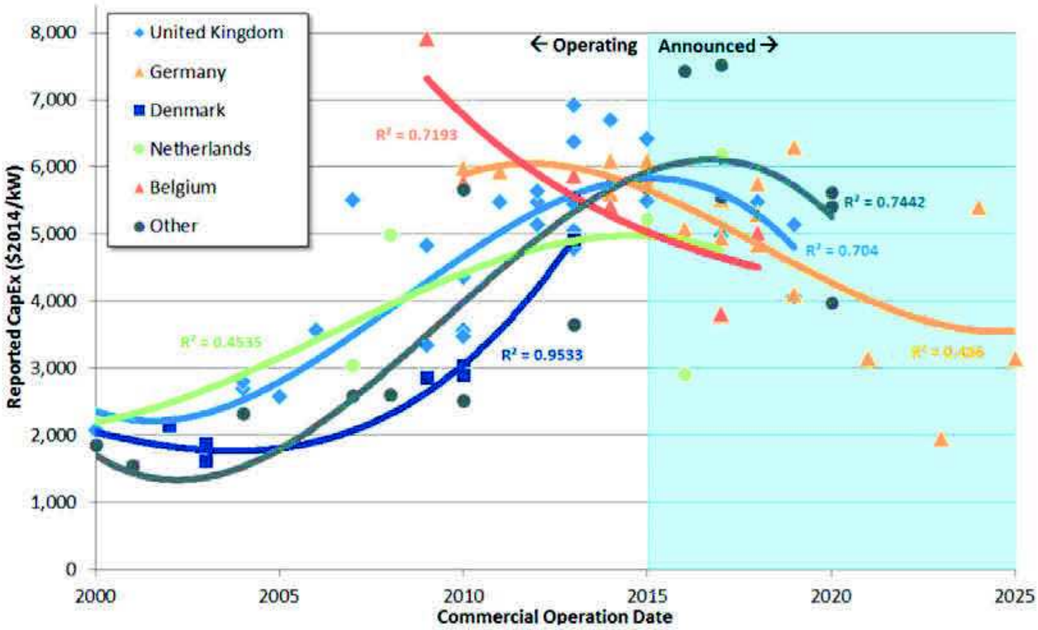


Figure 3.8 Capex trends for offshore wind projects by country.

It is important to pay special attention to the regulatory scheme for the construction of the network. In many countries responsibility for constructing and operating offshore electricity transmission assets falls to either the windfarm developer or to the onshore transmission operator (TO). In the UK, separate Offshore Transmission Owners (OFTOs), which are neither the windfarm developers nor the onshore TOs, take responsibility for the assets under long term licences. The licence guarantees revenues over the lifetime of the assets subject to certain conditions such as satisfying performance obligations. Under the OFTO regime, established in 2009 the windfarm developer builds the transmission network, and then the OFTO reimburse the cost of the construction plus an established revenue. In the case of Germany, transmission network is directly constructed and operated by the TO, and not included in the project costs.

East Anglia Project – Capex

Official Capex reported (2.500M£) includes the construction of the transmission network that will be reimbursed by the OFTO. According to IRENA report, the network costs usually accounts for 20% of the total Capex. Therefore, the Capex considered is 2.000 M£, that excludes OFTO.

Wikinger Project – Capex

Official Capex reported (1.400M€) does not include construction of the transmission network. Therefore, no adjust is required to our valuation.

Capex calendar

Another relevant element is the Capex calendar, i.e., the distribution of investments among the time. It has a significant impact on the LCOE because it is not the same to invest the total amount at the beginning of the project than to do it at the end.

According to the information provided by Accenture in [CSAC13], the average duration of the development and installation phase takes between 8-10 years.

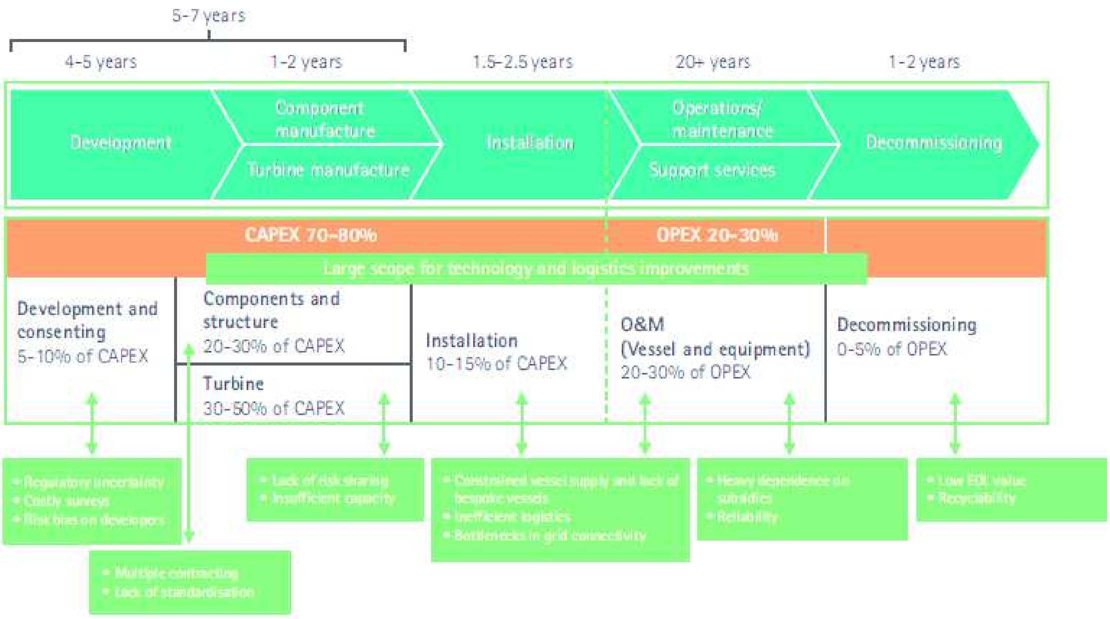


Figure 3.9 Detail of the development and installation phase in offshore projects. Source: Accenture.

The Capex calendar in the LCOE calculation of this report has been calculated based in this information. Distribution of Capex in each project is the following one:

East Anglia Project – Capex Calendar

		Year -7	Year -6	Year -5	Year -4	Year -3	Year -2	Year -1	COD Date
Phase		DEVELOPMENT				MANUFACTURE		INSTALLATION	
Annual period	**unit**	**31 dic 13**	**31 dic 14**	**31 dic 15**	**31 dic 16**	**31 dic 17**	**31 dic 18**	**31 dic 19**	**31 dic 20**
Capex % Expenditure	%	0,50%	1,00%	2,50%	6,00%	15,00%	20,00%	20,00%	35,00%

Wikinger Project – Capex Calendar

		Year -7	Year -6	Year -5	Year -4	Year -3	Year -2	Year -1	COD Date
Phase		DEVELOPMENT				MANUFACTURE		INSTALLATION	
Annual period	**unit**	**31 dic 10**	**31 dic 11**	**31 dic 12**	**31 dic 13**	**31 dic 14**	**31 dic 15**	**31 dic 16**	**31 dic 17**
Capex % Expenditure	%	0,50%	1,00%	2,50%	6,00%	15,00%	20,00%	20,00%	35,00%

WACC

Weighted average cost of capital (WACC) is a calculation of a firm's cost of capital in which each category of capital is proportionately weighted. Debt and equity are the two components that constitute a company's capital funding.

Lenders and equity holders expect to receive certain returns on the funds or capital they have provided. WACC indicates the return that both kinds of stakeholders (equity owners and lenders) can expect to receive. It is the investor's opportunity cost of taking on the risk of investing money in a company.

WACC is calculated as follows:

$$WACC = \frac{E}{E+D} \cdot Ke + \frac{D}{E+D} \cdot Kd \cdot (1-t)$$

being

- $E = \%$ *on Equity in the company´s capital*
- $D = \%$ *on Debt in the company´s capital*
- $Ke =$ *Cost of equity*
- $Kd =$ *Cost of debt*
- $t =$ *Corporate Tax*

Cost of debt (Kd)

For companies that use capital markets, Kd can be calculated by the quotation of their bond issues. If the company does not use capital markets, Kd can be estimated analysing accounting statements and business/industry risk._In the case of Iberdrola, last information available about its corporate bonds emissions (20 years) reflect that average current interest is located between 5,8% and 6,0%.

The corporate tax differs depending on the country. As explained before, corporate tax in Germany is 22,85% and in UK is 20%.

Cost of equity (Ke)

Cost of equity is always higher than the cost of debt, because shareholders assume more risk when compared with debtholders. Cost of equity can be calculated using the Capital Asset Pricing Model (CAPM).

$$Ke = Krf + (beta \cdot MP) + \text{ Country Risk}$$

- **Krf = Risk free interest rate**. For a investment in EUR it is normal to use the yield of Germany 30 year bond.

- **beta = Beta coefficient**. It measures the tendency of a stock to move (change price) with the market. In the case of Iberdrola, beta is 0,65.

- **MP = Market Premium.** Represents the excess required return for investing in the stock market compared with an investment in a long term bond. In European Stocks Markets is 7%.

- **Country risk.** Measured as the difference (spread) between the yield of a local government bond and the German bond with similar maturity.

WACC East Anglia Project

Applying the assumptions considered above, the WACC obtained for EAONE is:

$Ke = 2\% + (0{,}65 \cdot 7\%) + 1{,}2\% = 7{,}75\%$

$Kd = 6\%$

$WACC = 0{,}54 \cdot 7{,}75\% + 0{,}46 \cdot 6\% \cdot (1 - 20\%) = 6{,}40\%$

WACC Wikinger Project

Applying the assumptions considered above, the WACC obtained for EAONE is:

$Ke = 2\% + (0{,}65 \cdot 7\%) + 0\% = 6{,}50\%$

$Kd = 6\%$

$WACC = 0{,}54 \cdot 5{,}50\% + 0{,}46 \cdot 6\% \cdot (1 - 22{,}85\%) = 5{,}60\%$

3.3 Results obtained

East Anglia Project

Applying all the assumptions previously considered with the FCF methodology, the results obtained are the following ones:

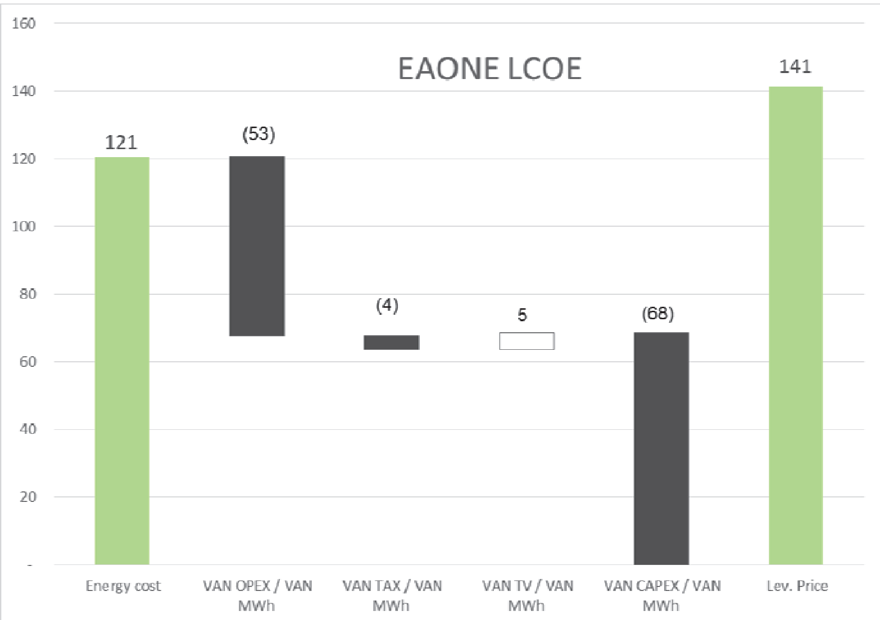
Discount rate - WACC	6,40%		
Annual period	**unit**	**NPV**	**total**
Net output	GWh	16.272	61.495
Price	£/MWh	934	3.278
Revenue	£m	2.297	8.062
OPEX	£m	(865)	(3.480)
EBITDA	**£m**	1.432	4.583
Taxes	£m	(64)	(517)
Net Income	**£m**	1.369	4.066
TV	£m	81	710
Capex	£m	(1.115)	(2.000)
FCF	**£m**	335	2.776

With these data, and applying the LCOE, formula:

$$LCOE = \frac{NPV\ Capex}{NPV\ MWh} + \frac{NPV\ Opex}{NPV\ MWh} + \frac{NPV\ Taxes}{NPV\ MWh} - \frac{NPV\ TV}{NPV\ MWh}$$

Lev. Price	**141,2**	**£/MWh**
VAN OPEX / VAN MWh	53,2	£/MWh
VAN TAX / VAN MWh	3,9	£/MWh
VAN TV / VAN MWh	-4,97	£/MWh
VAN CAPEX / VAN MWh	68,5	£/MWh
Energy cost	**120,6**	**£/MWh**

LCOE obtained is 120.6 £/MWh



Wikinger Project

Applying all the assumptions previously considered with the FCF methodology, the results obtained are the following ones:

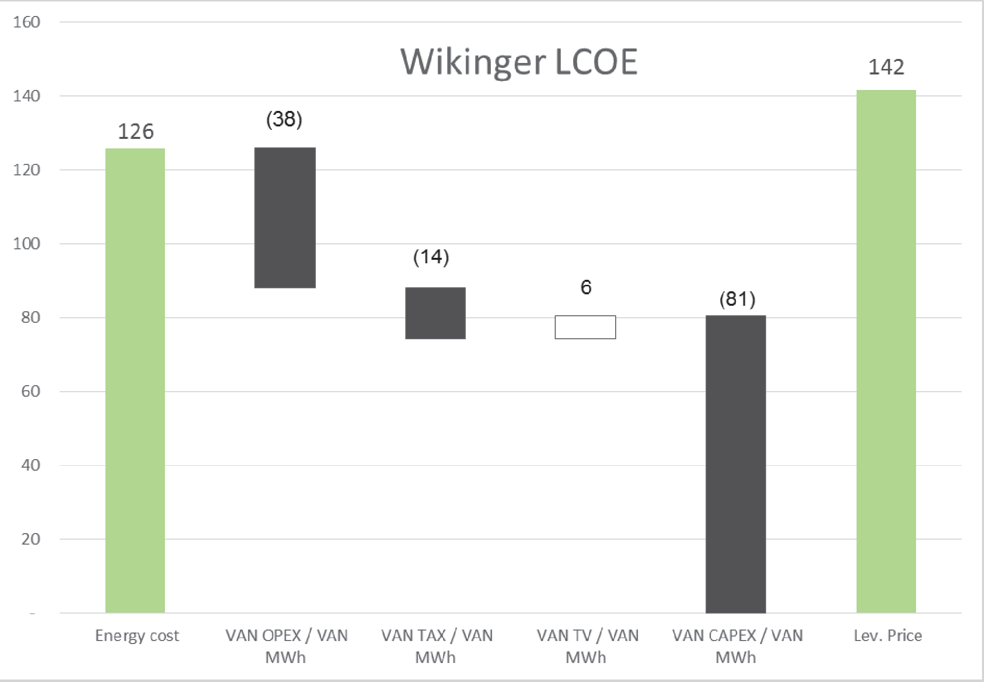
Discount rate - WACC	5,60%		
Annual period	**unit**	**NPV**	**total**
Net output	MWh	12.230	33.726
Price	€/MWh	1.286	3.089
Revenue	€m	1.735	4.167
OPEX	€m	(463)	(1.349)
EBITDA	€m	1.272	2.818
Taxes	€m	(171)	(632)
Net Income	€m	1.101	2.186
TV	€m	79	478
Capex	€m	(986)	(1.400)
FCF	€m	194	1.264

With these data, and applying the LCOE, formula:

$$LCOE = \frac{NPV\ Capex}{NPV\ MWh} + \frac{NPV\ Opex}{NPV\ MWh} + \frac{NPV\ Taxes}{NPV\ MWh} - \frac{NPV\ TV}{NPV\ MWh}$$

Lev. Price	**141,8**	**€/MWh**
VAN OPEX / VAN MWh	37,8	€/MWh
VAN TAX / VAN MWh	14,0	€/MWh
VAN TV / VAN MWh	-6,46	€/MWh
VAN CAPEX / VAN MWh	80,6	€/MWh
Energy cost	**126,0**	**€/MWh**

LCOE obtained is 126.0 €/MWh



Final LCOE and conclusions

The final LCOE considered in this report will be the LCOE obtained in each project pondered by the relative weigh of the country in the total installed offshore capacity. As stated at the beginning, UK and Germany are the two countries which more offshore wind capacity installed in Europe at this moment, with 5.060,5 MW (45,9%) and 3.294,6 MW (29,9%) respectively.

Another consideration is that the currency used in the report is the Euro. To convert the LCOE of East Anglia One from British Pounds to Euros the exchange rate used is the official rate at FID date. Taking into account that FID was in February 2016, the rate used is the average during this month, 1.288.

- **LCOE EAONE** = 120.6 £/MWh · 1.288 = 155.30 €/MWh
- **LCOE WIK** = 126.0 €/MWh

$$LCOE\ considered = EAONE\ LCOE \cdot \frac{45.9}{75.8} + WIK\ LCOE \cdot \frac{29.9}{75.8}$$

Applying this formula, the LCOE considered is equal to **143.80 €/MWh.**

After reviewing the value obtained, it remains clear that there is still a long way until offshore wind achieves competitiveness. Chapter 8 will analyses the position of offshore wind in the current energy mix, and it will reflect that it currently costs significantly more than onshore wind or Combined Cycle Gas Turbines (CCGT).

4

OPPORTUNITIES BASED ON TECHNOLOGY ACCELERATION

4.1 WIND TURBINES

State of the art

During the last decade, the fast development of onshore wind energy has created significant pressure on turbine manufacture supply chain as demand has come to exceed supply. Turbine production capacity has, to a large degree, been limited by second and third level supplier constraints. In particular, shortages of key components such as gears, large bearings, transformers, castings, forgings and carbon-fibre have contributed to this trend.

Given the additional risks associated to the offshore market and the high demand for turbines in lower-risk onshore markets, until the end of last decade manufacturers had limited incentive to participate in offshore wind market.

Despite this, growth rates for offshore wind during last decade were relatively high, with a yearly average growth of 40%, leading to a total installed capacity of around 3 GW by 2010. However, this growth was based in the utilisation of onshore technology in turbines installed offshore, what creates inefficiencies in the energy production. At the beginning of this decade, specific offshore technology started to be developed, and since then market has even potentiated and total demand of offshore capacity has increased.

To study the balance between supply and demand in the offshore wind turbine market, EWEA has elaborated a research, considering both capacity of supply in four different scenarios and its own forecast of the demand, that it is represented in figure 4.1 below.

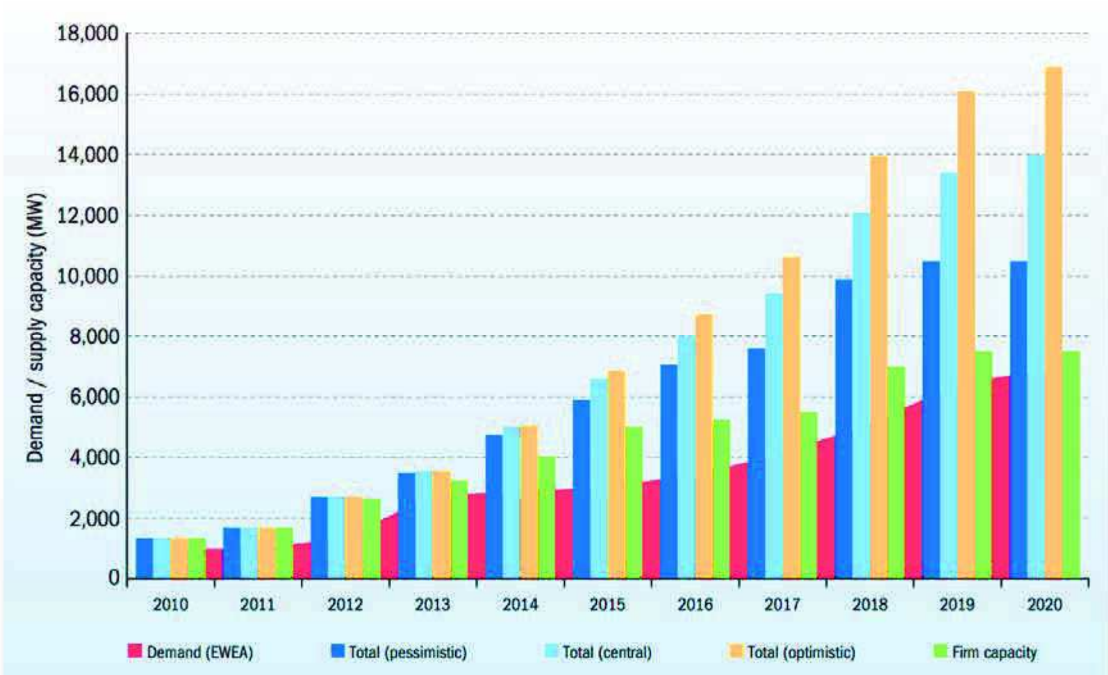


Figure 4.1 Analysis of supply and demand for offshore wind turbine technology in Europe. Source: EWEA.

The study shows that supply has been enough to meet demand for offshore wind turbine products. During this decade, even in the most pessimistic scenario for new entrant products, oversupply is estimated to range between 2 and 8 GW per annum, which implies that a high and increasing degree of competition within this sector can be expected through to 2020.

Future trends

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

As explained before, initially onshore wind technology was used to supply this niche market, and therefore wind turbine designs were restricted by the numerous planning constraints on onshore models, such as size, noise emissions, tower height, transport and construction limits. But in the recent years the offshore wind market has grown to a size at which the development cost of final products can be recovered over hundreds of units, favouring the manufacturing of turbines specifically designed for offshore wind.

Growth in turbine size

Onshore wind turbines have grown considerably in size over the last two decades, both in terms of rated power and in rotor swept area. In parallel, technological developments in areas such as aerodynamics, variable speed regulation and independent blade pitch control have been numerous and fast paced.

Trying to follow the same steps, the size of offshore wind turbines is scaling rapidly. The first deployment of an 8 MW prototype enter in the market in 2014 and a number of commercial orders for 6 to 8 MW turbines were executed in 2015. Larger offshore turbine sizes are enabled because there are fewer logistical limits due to transportation and installation than in land-based projects. For example, land-based wind turbine components need to be shipped by road or rail, but offshore turbine components can be transported by vessels.

The following figure 4.2, elaborated by NREL, shows global offshore wind turbine trends in capacity (blue), rotor diameter (green) and hub height (orange) since the beginning of the industry in 1991. The forecast through 2020 is based on projects that have announced or singed a supply contract or agreement with a turbine manufacturer.

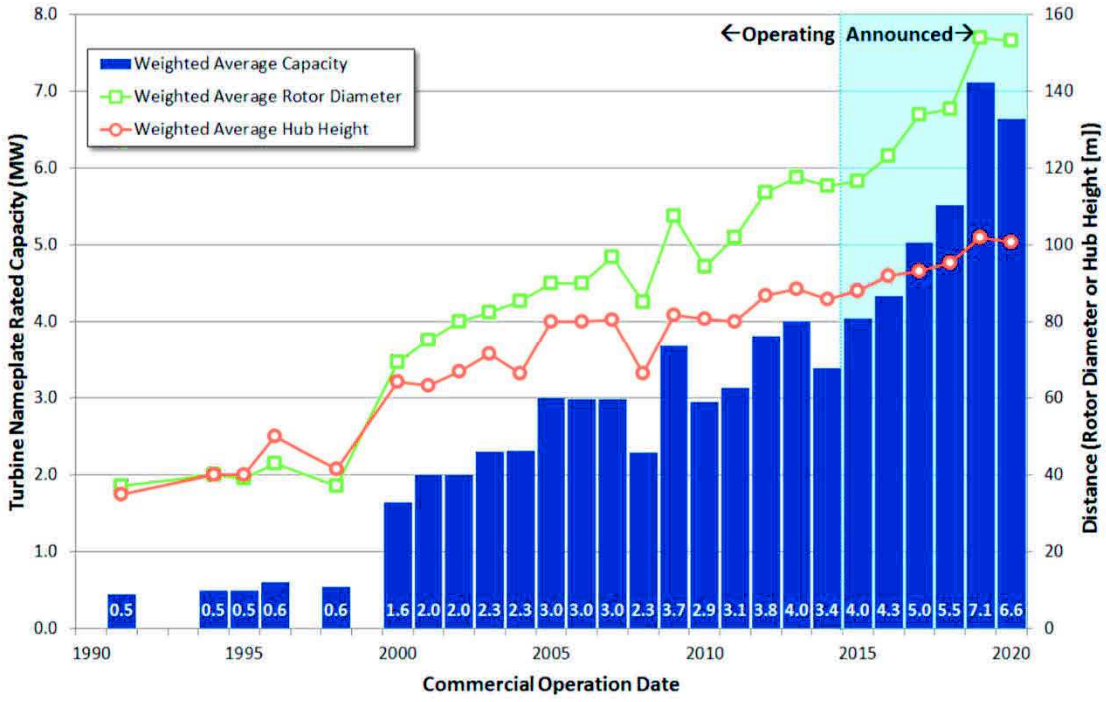


Figure 4.2 Global turbine capacities, rotor diameters, and hub heights over time. Source: NREL.

The figure shows that between years 2010 and 2015 the turbine size stabilised around 3–4 MW, although announced turbine supply agreements (TSAs) suggest that the average turbine rating will begin to increase again in 2016, reaching an average of between 6 and 8 MW in the 2019 – 2020 years.

Turbine ratings may stabilise again in the year 2020 while the industry adapts to 6-8 MW turbine sizes, but further long-term growth in turbine size is still likely. Both leading offshore wind turbine manufacturers, Siemens and Vestas, have indicated that they will have a 10 MW design in the prototype stage by 2020. The Danish Energy Agency recently released a tender that could support the deployment of prototype turbines with up to 50 MW of capacity to help accelerate the commercialization of turbines and other technologies that have the potential to drive cost reduction. There are a number of technical, infrastructure, and vessel-related challenges associated with upscaling turbines to reach more than 10 MW ratings. However, the industry has historically taken action in unison to address these concerns as turbines sizes have grown.

Increase in rotor size

Choosing the ratio of rotor swept area to rated power is a key decision in wind turbine design. Both dimensions have grown considerably but there is some evidence to suggest that turbine manufacturers developed offshore turbines with somewhat larger rotors relative to rated power capacity in the second part of the last decade, as illustrated in figure 4.3.

Two manufacturers have enlarged the rotor size of an existing platform at a fixed rated power as highlighted by the red arrows. However, in contrast, one manufacturer (green arrow) decided to increase rated power as opposed to rotor size. Recent product announcements have confirmed the trend towards larger swept areas in relation to rated capacity, reducing the cost of energy produced.

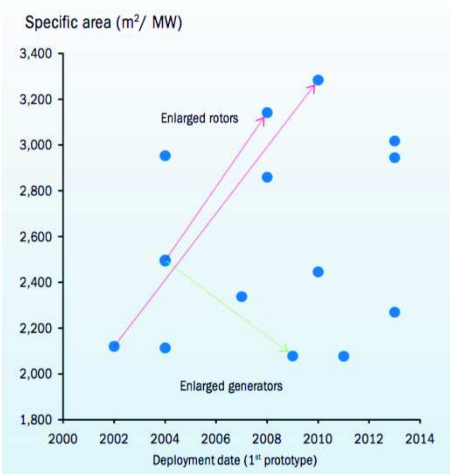


Figure 4.3 Trends in swept area. Source: EWEA

Reduction on specific mass

In the last decade material efficiency has also improved significantly and new products that will be launched in few years indicate that this trend can continue. This is illustrated in figure 4.4, which reflects the specific mass of turbines since 2000.

The optimisation of loads via advance control systems with associated structural design efficiencies and the use of more efficient materials like carbon-fibre are examples of factors that contributed to these improvements.

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

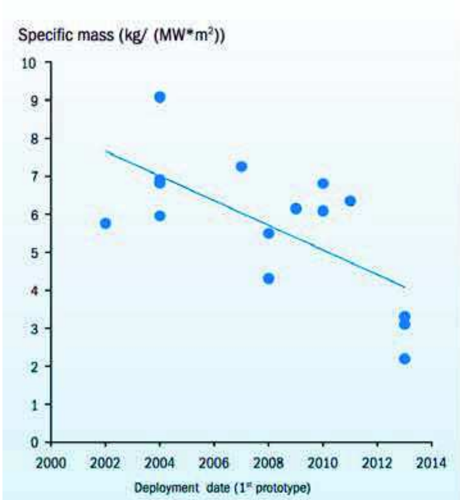


Figure 4.4 Trends in specific mass. Source: EWEA

Transmission and conversion architectures

Traditionally, offshore machines have used high-speed drivetrain architectures with three-stage gearboxes. However, turbine manufacturers are now adopting medium-speed (two-stage gearboxes) and direct-drive designs for the next generation of turbines. These designs are expected to deliver benefits in terms of weight, reliability, and energy production at larger turbine ratings. Figure 4.5, elaborated by EWEA, shows the trends for both turbine-rated capacity and drivetrain architecture by year of prototype installation (actual or announced).

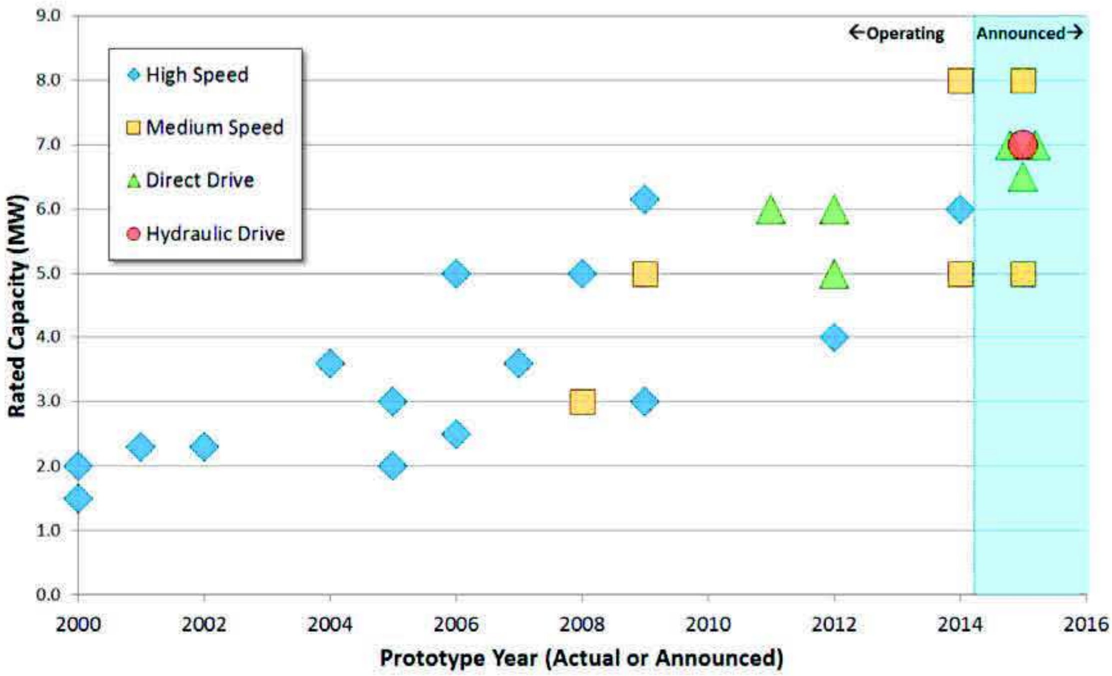


Figure 4.5 Wind turbine rated capacity and drivetrain architectures.

The trend shows a large and sustained increase in rated turbine capacity from 2000 through 2016, but only since 2008 there is a shift away from high-speed architectures to alternative designs beginning in 2008. This shift was due in part because of an increasing concern over the reliability of gear-driven designs and the additional maintenance costs for offshore service.

The new drive train concepts that are being developed are:

- Direct-drive concepts that do away with gearboxes, as prototyped by, among others, Alstom, GE, and Siemens.
- Hydraulic drive concepts that do away with the power converter and also introduce modular components, as proposed by Mitsubishi.
- Geared, mid speed concepts that do away with the high-speed gearbox stage – as proposed by Gamesa, Samsung and Vestas.

Latest turbine models launched to the market

Reducing the Levelised Cost of Energy (LCOE) has become the primary concern for all developers as government subsidies narrow in established markets, calling for cost reductions from a maturing industry: larger turbines play a key component in accessing cost savings. Increased competition is helping to fuel technological advancements, as opposed to a single player dominating the market such as traditionally has been Siemens.

At the 2015 EWEA Offshore conference in Copenhagen, Siemens presented its new SWT-7.0-154 direct-drive turbine capable of delivering almost 10% more energy than its predecessor. Senvion has also completed commissioning and the initial test phase of its prototype 6.2M 152 upgrade; with 20% larger blades, the 6.2M 152 is capable of producing 20% more energy at wind speeds of 9.5m/s compared to its predecessor. AREVA and Gamesa have formally joined forces under the Adwen banner to compete in the 8MW-class market, expecting to offer serial production in 2018.

The figure below illustrates where four turbine models from Siemens, MHI-Vestas, Senvion and Adwen in the 6-8MW class have been selected for high certainty projects, detailing some of the characteristics.

	SIEMENS D7 PLATFORM	MHI-VESTAS V164-8.0MW	SENVION 6.2M	ADWEN AD 8-180
				
Nominal power (MW)	6.0 - 7.0	8.0	6.15	8.0
Rotor diameter (m)	120-154	164	126-152	180
Blade length (m)	75	80	74	*TBA*
Swept area (m²)	18,600	21,124	18,146	*TBA*
Status	Operational	Prototype	Operational	Planning
Projects	*SWT-6.0-120* 2x Gunfleet Sands *SWT-6.0-154* 35x Westermost Rough 67x Dudgeon 91x Race Bank 56x Galloper 5x Hywind Pilot Park 60x Arkona 97x Gode Wind 1 and 2 67x Veja Mate *SWT-7.0-154* 84x Beatrice 64x Neart na Gaoithe 102x East Anglia ONE 47x Walney Extension 174x Hornsea One 71x EnBW Hohe See 42x Rentel 4x Nissum Bredning	*V164-8.0MW* 56x Borkum Riffgrund II 50x Horns Rev 3 45x Norther 32x Burbo Bank Ext 40x Walney Extension	*6.2M126* 18x Nordergründe 54x Nordsee One 48x Nordsee Ost 24x Thornton Bank II 24x Thornton Bank III 8x Kincardine	*AD 8-180* 62x Le Tréport 62x Noirmoutier 62x Saint-Brieuc
Total units	968	223	176	186

Figure 4.6. New turbine models presented in EWEA 2015 Offshore Conference. Source: 4C Offshore.

Impact on LCOE

Increase in turbine capacity

Increases in the rated power of turbines decreases total unit capital costs and operating costs and increases energy production, producing a powerful improvement in LCOE.

Increases in rated power from 4 MW to 6 or 8 MW turbines will increase the unit capital cost of the turbine, but will reduce the costs of support structures and installation even more. This is illustrated in figure 4.7, elaborated by The Crown State, where the sum of capital costs of two 4 MW turbines is compared with the capital costs of one 8 MW turbine. This shows that the decrease in installation and support structure costs leads to an overall reduction in capital costs of about 4%.

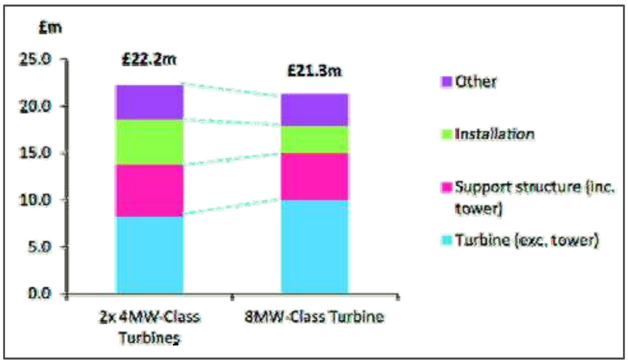


Figure 4.7 Cost comparison between 4MW and 8MW turbines. Source: The Crown State.

This increase in rated power of turbines, according to The Crown State estimations, can reduce operating costs by of the order of 12%. This is due to the fact that a proportion of operations and maintenance costs (around 3%) are fixed (environmental monitoring…) and do not increase with turbine size. These cost reductions are combined with an increase in energy production of up to 5% caused by an increase in hub height wind speed due to the larger rotor size and a decrease in aerodynamic losses

Considering all the values (reduction on capital costs by 4%, operating cost by 12% and increase of production of 5%), the total expected impact in the LCOE of an increase in turbine size is approximately 9%.

Increase in turbine rotor

At the same time, the increase in turbine rotor will increase capacity factor and energy production, although at the same time the capital costs. Current turbine rotor sizes have, in general, been optimised for onshore use. The optimum rotor size for a turbine offshore is larger because turbine costs are a smaller proportion of total capital costs. The key innovation therefore is to produce longer blades at low cost. Input from industry indicates that increasing a 6 MW turbine blades from 72m to 78m will increase energy production by 8%, increase capital costs by 9% and operating costs by 0.4%, leading to an overall improvement in LCOE of a little over 1%.

Improved blade design and manufacture

As well as increases in the length of blades, significant improvements are expected in their design and manufacture, that as explained before are mainly related with the reduction of specific mass, improved aerodynamics and manufacturing and use of new materials.

Overall, following the indications of the Technology Work Stream Report elaborated by BVG Associates, these innovations are expected to reduce LCOE by around 3% for the year 2020.

Changes in transmission architectures

As explained before, up to date offshore wind turbines have used mechanically geared drive trains with high-speed generators to convert the rotational energy from the rotor into electricity. In some cases, the reliability of these drive trains has been poor.

The new concepts will compete with improvements in the current drive trains including better lubrication and improved materials. The actual performance of these various innovations will determine the winning technologies. The analysis carried out by The Crown States underlines that a reduction up to 2% in the LCOE is possible due to improvements in drive train.

Other turbine innovations

According to BVG, a variety of other innovations related to the turbine have the potential to reduce LCOE by a further 3% by FID 2020 including:

- Improved AC power take-off systems or the introduction of DC power systems.
- Improved blade pitch control.
- Advances in blade bearing and pitch systems and hub design, materials and manufacture.

Overall impact on LCOE of new generation turbines

Taking into account all these improvements in the new generation of turbines, a 17% of reduction on the current LCOE is expected by the year 2030, according of The Crown State estimations. This shows that the higher capital costs of new generation turbines will be more that counterbalanced by increased capacity factor and lower operating costs.

Figure below, elaborated by EWEA, represents the distribution of the total potential reduction of the LCOE that can be due to improvements in wind turbines.

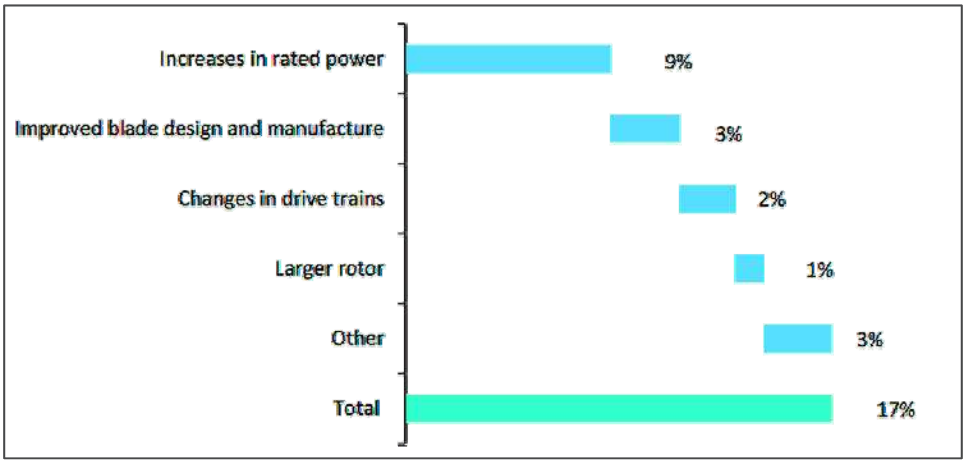


Figure 4.8 Potential reduction in LCOE consequence of improvements in wind turbines. Source: The Crown State.

In this report we have considered all the reduction forecasted by EWEA, 17%. Applying this reduction to the LCOE obtained in the calculation of this report, we obtain:

$$LCOE\ Impact\ (Wind\ Turbines) = 24{,}5\ €/MWh$$

4.2 SUBSTRUCTURES

State of the art

A major difference between onshore and offshore wind farms is the relative complexity and cost of civil works, especially the substructures required for offshore turbines. For offshore wind farms, substructure supply and installation represents around 20% of the capital costs. The size and water depth constraints of manufacturing, transporting and installing wind turbines are vital factors in determining the current techno-economic limitations of offshore wind farms.

Supporting the massive increase in demand forecast for the next decade for offshore wind substructures will require significant expansion in manufacturing capacity. The technical barriers to manufacturing substructure components are relatively low and establishment of fabrication facilities is an obvious move for large marine engineering firms who have reduced demand from the oil and gas and maritime sectors in recent years. The relatively low barriers to entry, high supply elasticity (due to the short lead times for bringing new production facilities online) and logistical incentive to source locally will create significant industrial development opportunities in European countries with access to the offshore wind areas.

Different types of substructure have been utilised and proposed to date. Important considerations when selecting a structure type include cost, water depth, seabed conditions, turbine characteristics and technical/commercial risk factors. The majority of the wind farms currently in operation in water depths of under 20-25 metres have monopile foundations, as they are relatively simple to produce, easier to install and less costly, although they are losing market share in favour of the new space-frame structures (e.g. jackets, tripods and tripiles) that are being installed since 2007. Gravity-based structures (GBS), which are also relatively easy to produce, have maintain a small proportion of market share since the beginning.

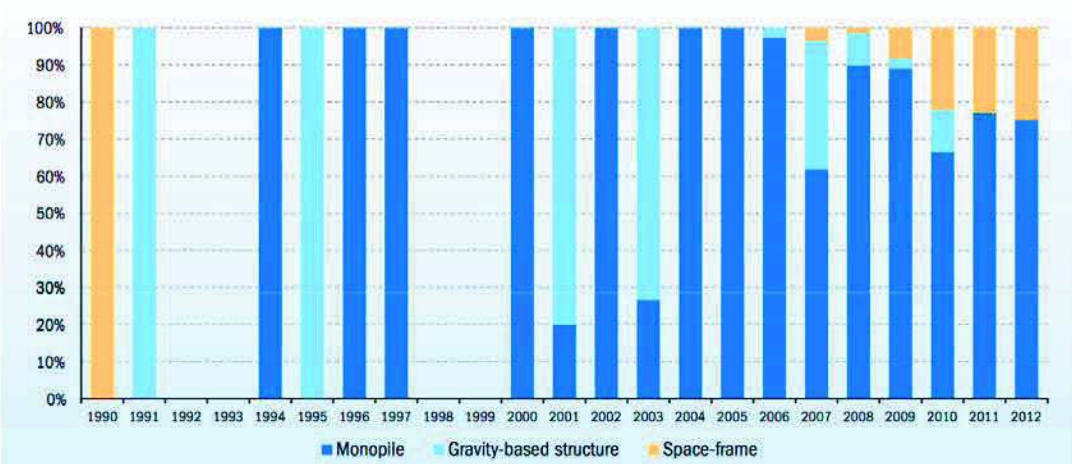
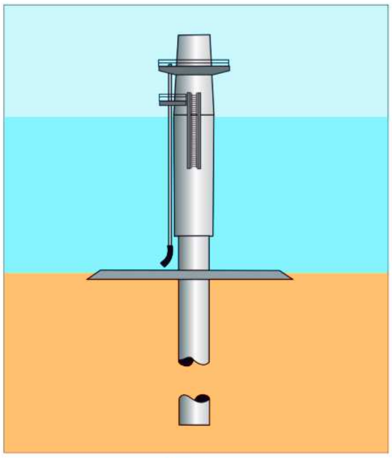


Figure 4.9 Historic offshore wind turbine foundation market share. Source: EWEA.

Substructure types

Monopiles

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

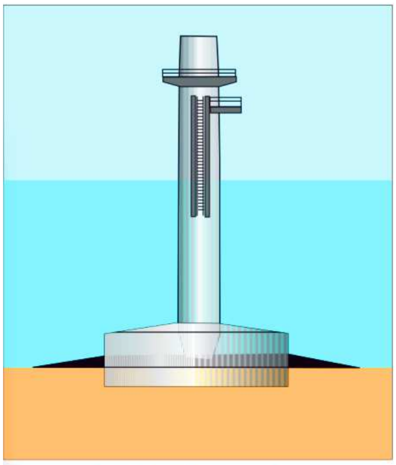


Monopile

A disadvantage of the monopile is that is becomes less stable in deeper waters, and is best suited to water depths of up to 25 metres. It is possible however, that future developments in manufacturing capabilities and size of installation equipment will mean that monopile structures with very large diameters will be possible, reducing the monopile's inflexibility and making it suitable for deeper water sites.

Gravity-based structures

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



Gravity-based Structure (GBS)

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

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

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

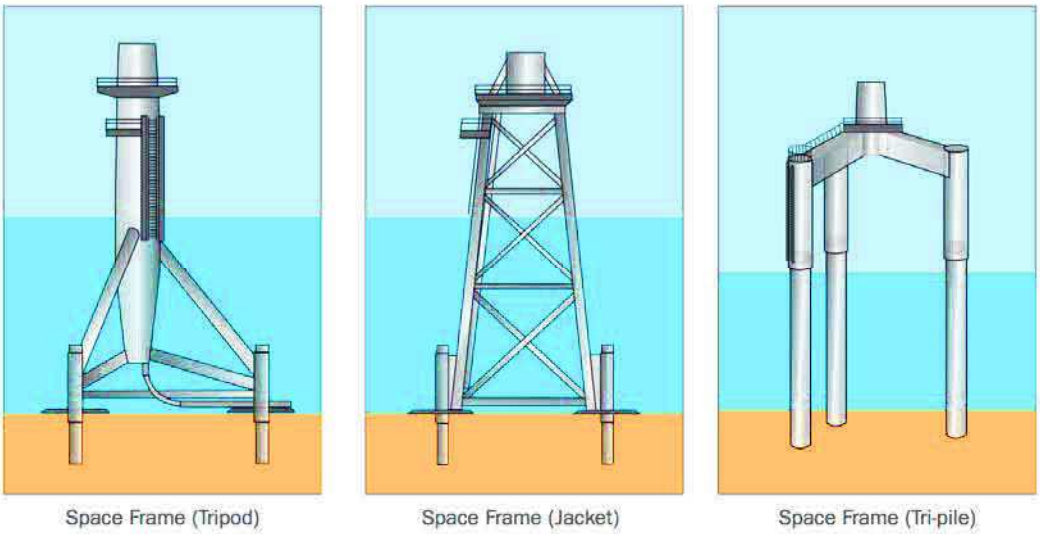
Space frame structures

For deeper locations, space frame structures are likely to be considered. Broadly speaking, these concepts fall into two categories: multipods (including tripods and tri-piles) and jackets. These designs transmit forces to the foundations in the seabed via a structure made up of several piles, with the aim of minimising the ratio of mass to stiffness.

- **Tripods**. The tripod is a standard three-legged structure made of cylindrical steel tubes. The central steel shaft of the tripod is attached to the turbine tower. The tripod can have either vertical or inclined pile sleeves.

- **Tri-piles.** Tri-piles consist of three foundation piles connected via a transition piece to the turbine tower with the transition piece located above the water level.

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



Future trends

Innovations in fixed substructures

According to the Technology Workstream report elaborated by BVG, main oncoming innovations in fixed substructures can be categorised as either predominantly affecting the tower between the nacelle and the foundation, the foundation itself or the sea bed connection. Innovations related to the tower are not mutually exclusive and could be used in combination with each other. The innovations may also be combined with other foundation and sea bed connection innovations. For foundations, there are a range of designs and each has specific innovations associated with them. For this reason, innovations have also been separated by whether they primarily affect Monopiles or jackets.

Groupings	Innovation types
Tower	Introduction of holistic design of the tower with the foundation Introduction of single-section towers
Foundation	Improvements in monopile design Improvements in monopile design standards Improvements in jacket manufacturing Improvements in jacket design Improvements in jacket design standards
Sea bed connection	Introduction of suction bucket technology

Figure 4.10 Oncoming innovations in fixed substructures. Source: BVG.

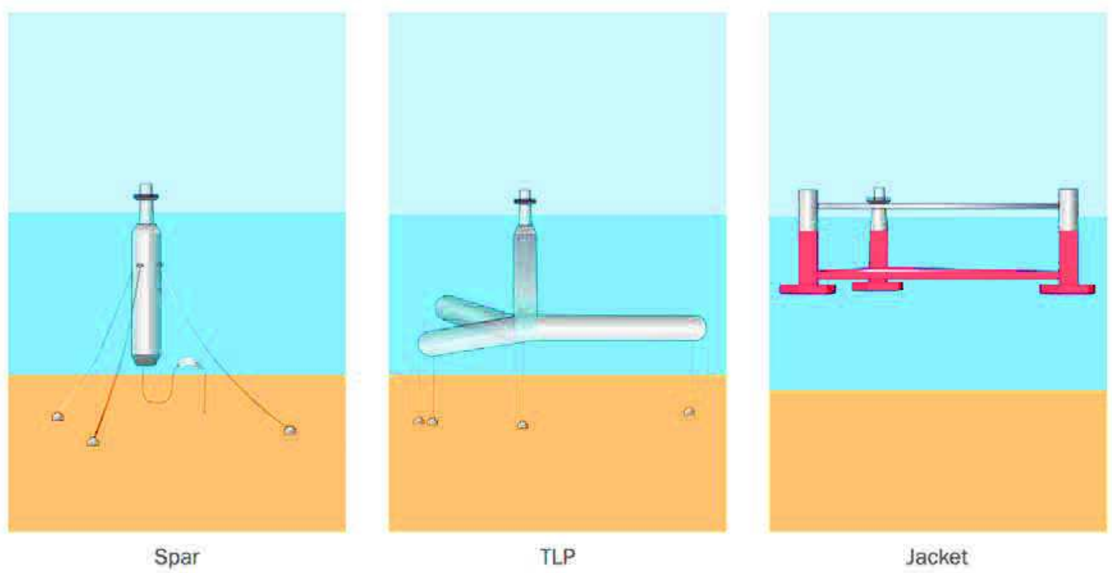
Floating substructures

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

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

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

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



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

Impact on LCOE

The production and installation of substructures rep- resents up to 20% of the capital expenditure (CAPEX) of offshore wind farms. Offshore wind costs can, therefore, be considerably reduced if substructure costs are reduced. This can be achieved through demonstrating new designs with low installation and production costs.

Innovations in fixed substructure types

Looking at the information published in the Technology Workstream report elaborated in 2013 by BVG, innovations relating to the turbine support structure are anticipated to reduce the LCOE by approximately 3,5%, although the potential is higher and can achieve 5%.

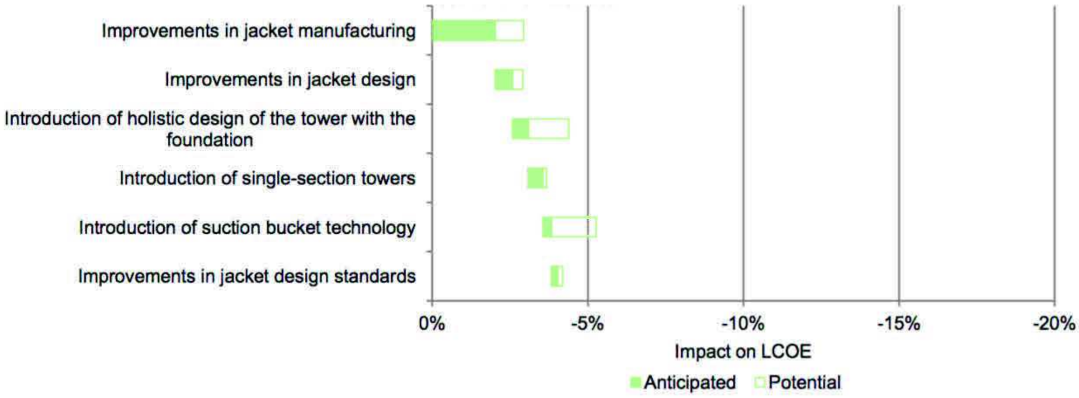


Figure 4.11 LCOE impact of innovations in fixed substructure types.

Considering the most conservative prediction, which is an impact of 3.5% in the LCOE, the approximate impact in our estimated value is:

$$LCOE\ Impact\ (Innovation\ in\ fixed\ substructures) = 5{,}0\ €/MWh$$

Use of floating substructures

Floating offshore substructure costs mainly consist of the platform and the anchoring system, which are similar to those for fixed substructures. The major difference between the two solutions is in the design and installation costs where floating offshore designs are expected to be cheaper. Overall, floating offshore designs are also expected to produce more energy, as they can accommodate bigger turbines that lower the final cost per MWh.

To evaluate the economics of floating designs, EWEA performed a comparison with jacket foundations, whose technical characteristics allow for installation in water depths of up to 45-50m. The findings show that floating offshore wind designs are competitive in terms of LCOE with existing jacket foundations from around 50m water depths, allowing a reduction on the LCOE on approximately 3% with respect to fixed substructures.

As there is still no evidence of the reduction on costs that floating substructures can achieve, and taking into account that reduction in LCOE are possible for projects with more than 50m of depth (less than 50% of current projects), we will consider only half of the reduction predicted by EWEA as the guideline for the thesis. This is, 1.5% of reduction in LCOE, equivalent to:

$$LCOE\ Impact\ (New\ floating\ substructures) = 2{,}2\ €/MWh$$

4.3 Electrical infrastructure

State of the art

Offshore substations

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

The electrical equipment installed on the offshore substation is very similar to the one used in onshore substations, although with additional environmental protection. A failure at the substation may have a very significant effect on energy production, and that is why the offshore substation is recognised as a major risk. Designs have been developed to provide substantial redundancy, and recent projects often have two transformers, and two export cables to shore. It is normal for each transformer and export cable to be rated around 50% of the wind farm rated capacity, but since the wind farm operates for most of the time well below its rated output, this method still allows around 70 to 80% of the annual energy production to be exported in the event of a single failure.

Oil and gas practice is taken into account when installing offshore substations. Firstly, a foundation structure is installed, usually a jacket structure, though monopiles have also been used. A 'topsides' structure is built onshore, complete with all electrical equipment, and commissioned as far as possible, before being transported to the site and installed on the foundation structure. Cables are then pulled in and terminated, and final commissioning is completed.

Export cables

As noted above, the MV cables that connect turbines ('array cables') use existing subsea cable technology. The higher-voltage export cables to connect with land, necessary when using offshore substations, also use standard subsea cable technology.

The existing manufacturing capacity of exporting cables has been strained by the demand, and if offshore wind continues to expand as anticipated, in the future substantial additional manufacturing capacity will be needed.

Regarding installation of the cables, current projects are finding difficulties when obtaining suitable cable installation vessels, and there has been substantial development of vessels, installation techniques, and installation tools. Many of the problems encountered with offshore wind farm construction have been related to cable installation and protection.

High Voltage Direct Current

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

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

The DC/AC conversion process onshore offers significant advantages to the system operator in terms of reactive power and voltage, both steady-state and dynamically, and of the fault current. With an HVDC connection, there is substantially more design freedom for the wind farm electrical system and for the wind turbines. For example, it would be possible to run the wind farm electrical system at variable frequency. Higher frequencies could substantially reduce transformer size and cost. It may also be possible to directly achieve DC output from each turbine. These issues are closely tied in with wind turbine design, and are unlikely to be tackled on a project basis.

Future trends

Lightweight Offshore Substations

According to the UK's Offshore Wind Programme Board, a lightweight offshore substation is an offshore substation that can be installed by a vessel with a lift capability of 1000t, with the topsides being installed in a single lift. Using the same jack-up to install both the turbines and the substations removes significant cost normally associated with deploying a heavy lift vessel specifically for substation installation. ABB, DONG and Siemens have announced works on lightweight designs, being the most advanced the Siemens' Offshore Transformer Module (OTM). The OTM, which was originally developed for a particular offshore wind farm comes in two base designs which can be modified to site specific requirements: a 'standalone' version where the topside has its own substructure and an 'integrated' design where the topside shares a substructure with a wind turbine.

The standalone design (without shunt reactors) is characterised by a low topside weight of 660t. This low weight, according to the OWPB, is not driven by the electrical and mechanical payload but rather by the low structural weight of the topside relative to this payload. The weight of the OTM's topside structure is about 75% of the weight of the payload compared to 150-200% for a conventional multi-deck substation. The OTM is a single deck structure with external transformers and no diesel generator room, store rooms, toilet or utility rooms. The deck has also been designed to allow flexibility whilst accommodating deflections rather than reducing them.

The impact of the design improvements in the Siemens' OTM are shown below in figure 4.12, published by 4C Offshore. It is much lighter than the average for their power rating. It is notable also that German substations which are far from shore and typically have more extensive facilities on board have a higher relative structural weight than those in the UK whose designs are more minimalised, particularly for new substations in construction.

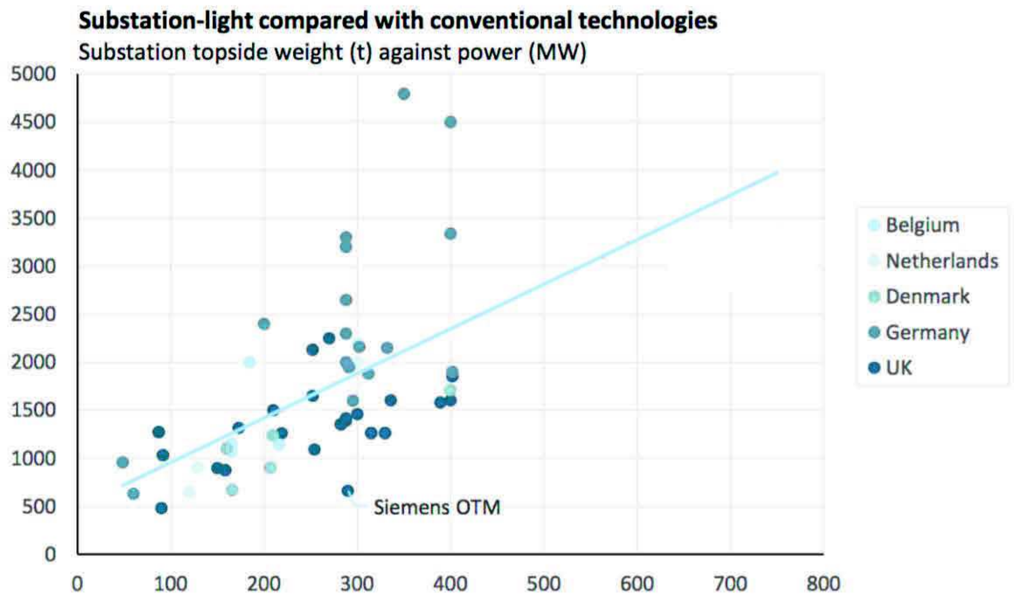


Figure 4.12 Data plot of substation topside weight (t) against power (MW). Source: 4C Offshore.

Higher cost efficiency for HVDC

At the National Maritime Conference in Bremerhaven during October 2016, Siemens unveiled a new grid solution to help further HVDC's impact on wind parks situated at much greater distances to shore. The platforms housing the transmission technology has been dramatically reduced in both size and weight by splitting the transmission over three smaller platforms to be connected sequentially and then routed to shore, and replacing any HVAC collector stations in the previous design layout. The compact design permits utilises Diode Rectifier Units (DRUs), which are installed instead of the usual air-insulated transistor modules. Following the expense of the HVDC offshore converter stations constructed in German waters thus far, Siemens has stated a 'paradigm shift' was required in order to achieve significant cost savings and keep the technology viable for future developments.

The system is modular and flexible in terms of its positioning within a wind farm and easier to install: the maximum volume of a platform is reduced by 80%, whilst the weight is cut by two-thirds. Siemens has estimated that cost savings in the region of 30% will be achieved as the improved technology boasts increased enabled transmission capacity (up to 1200MW, rather than 900MW) whilst reducing transmission losses in the region of 20%.

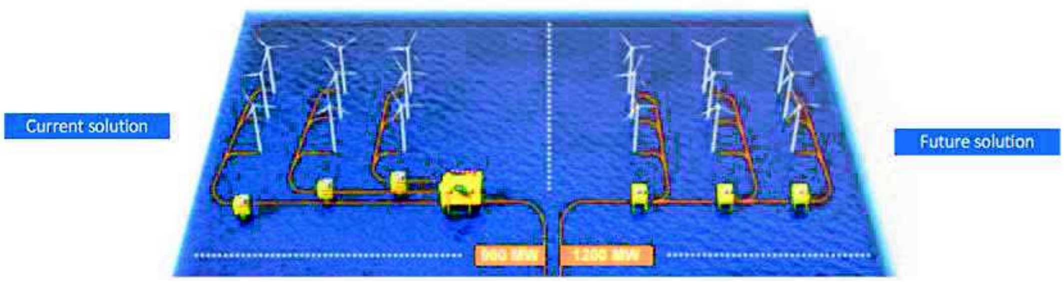


Figure 4.13 Siemens Grid Access using Diode Rectifier Units (SGA-DRU) HVDC solution. Source: 4C Offshore.

Array cables system trends

As stated before, array cable systems for commercial projects are typically rated at 33 kV and connected radially to the substation. The rated capacity of cables at this voltage is approximately 36 MW for a single cable connected to the substation, which has worked well with turbines rated below 6 MW. Moving to larger turbine sizes limits the number of turbines that can be connected to the substation with a single cable, which, all else equal, will increase the length of array cables required for a given project.

Increasing the array system voltage to ~66 kV would enable more efficient array cable layouts for projects using larger turbine ratings and reduce Capex. Other benefits of higher array voltage would be fewer electrical losses (up to 75%) within the array cable system, decreased substation transformer weight and number of substations, as well as the ability to adopt more redundant array cable layouts (e.g., ring configurations) to increase reliability. Progress towards higher voltage array systems has been slower than anticipated. Two projects in the United Kingdom, East Anglia ONE Project, studied in this report, and Near Na Gaoithe, recently released a supply chain report that highlighted plans to adopt higher voltage array cables.

Impact on LCOE

According to the information published in the Technology Workstream report elaborated in 2013 by BVG, innovations in array cables have the potential to reduce the LCOE by approximately 0.5%. Industry believes that there is relatively little potential to reduce the cost of energy through array cable innovations, as the underlying technology is long established and proven in many industries.

Savings are generated mainly through reduced CAPEX, but also through modest reductions in OPEX and increases in the energy delivered. Figure 4.14 shows that the largest savings from innovations in array cables are available from introducing cables with higher operating voltages. This innovation enables a reduction in both cable length and the total number of connections by reducing the number of cable strings required. It also offers a reduction in electrical losses.

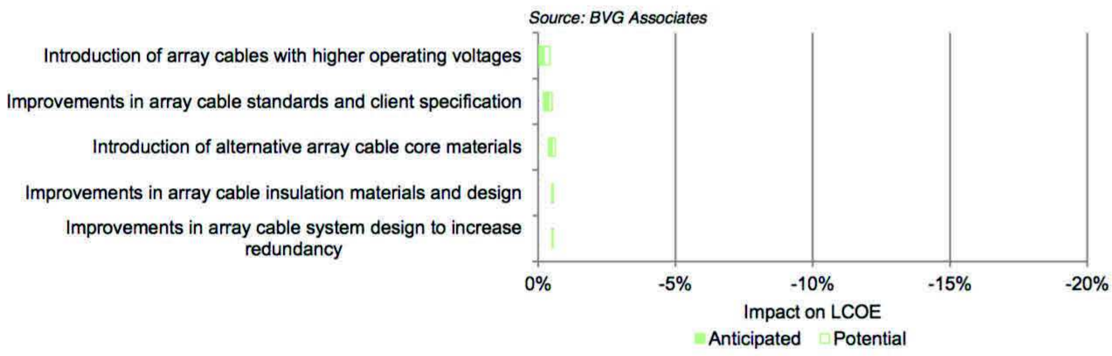


Figure 4.14 LCOE impact of innovations in array cables.

Applying the estimated reduction forecasted by BVG to the reference LCOE value calculated in this report, we obtain that the impact is:

$$LCOE\ Impact\ (Innovations\ in\ array\ cables) = 0{,}7\ €/MWh$$

4.4 VESSELS

State of the art

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

Depending on the operation in question, these needs range from the simple use of basic, generic vessels currently used in other industries without the need for further modification, to bespoke, highly expensive vessels designed for specific installation tasks. Given the expected steep growth in the European offshore wind energy market over the next ten to twenty years, and given that sites will move into ever more challenging conditions, meeting the demand for the highly specialised installation vessels will be a key dynamic in the offshore wind industry supply chain.

The activities that a vessel develop in an offshore windfarm are the following ones:

- **Site development.** The main functions of the vessels during the development stage include carrying out of the surveys required for an Environmental Impact Assessment, geophysical surveys and geotechnical surveys (including cable route survey).

- **Site construction.** It is during the construction phase that the greatest demands are made on vessel types, specifically during the installation of substructures and turbines. The main points of consideration when selecting vessels for these tasks include: ship performance, cost, lift capacity, precision when lifting, vessel dimensions, meteorological and oceanographic limitations, technical risk and commercial availability. Other lower specification vessels are used to trans- port equipment and personnel to the site.

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

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

Vessels types

Jack-up vessel

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

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

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

Jack-up vessel

Leg-stabilised crane vessel

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

Leg-stabilised crane vessel

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

DP2 Heavy lift cargo vessel

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

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

DP2 Heavy lift cargo vessel

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

Semi-submersible heavy lift vessel

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

Semi-submersible heavy lift vessel

Shearleg cranebarge vessel

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

Vessels of this type are available in northern European waters and have a capacity of up to 3,300t. They can transit in seas with significant wave heights of over 1 m, and carry out lifting operations in seas with waves of between 0.5 and 1 m high depending on the size of the craft.

Shearleg cranebarge

Floating dumb barge with crane

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

Dumb barges are the most basic of craft, and any additional equipment to enhance their capability must be added to the deck of the barge. The stability of this configuration of craft means that it is unsuitable for the role of the principal installation vessel. However, craft of this type will often be used for a multitude of small roles on any offshore construction site, and may fulfil the role of a feeder vessel.

Floating dumb barge with crane

Future trends

New type of vessels

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

There is some evidence of strategic investment by developers to secure vessels. However, the near-term relaxing of supply constraints may stem this movement. The supply chain outlook is strong through to 2015 with several new builds, increased levels of competition and supply likely to meet demand. Through the latter half of the decade increasing pressure may return if no further new investment comes forward.

New generation of installation vessels specifically designed for offshore wind. A key innovation that will contribute to this will be the introduction of floating dynamic positioning (DP) vessels that are larger than the current jack-up vessels and carry more jackets on their deck but are more expensive to charter per day. These new vessels present the following characteristics:

- Are larger in size (148mx42m) and faster.
- Have greater deck space and storage capacity (8,000 t; e.g. 7x6 MW WTG or 12x3 MW WTG, 4 jackets or 7 monopiles).
- Can work in deeper waters (50 m).
- Have improved jacking speed.

Impact on LCOE

Faster wind turbine installation will reduce the total cost of the offshore windfarms. To evaluate the impact that new vessels can have in the LCOE of the offshore energy, and as a reference, we can consider the savings that the new vessels can provide.

As an example, the information provided by BVG in its Technology Workstream Report. New Large floating DP are larger than current jack-up vessels and carry more jackets on their deck, although they are more expensive to charter per day. Considering the values, we obtain a 26% saving using the new type of vessel.

Vessel type	Length (m)	Deck area (m2)	Jacket carrying capacity (# jackets)	Maximum operating significant wave height	Operating day rate (£k)
Large floating DP	250	6500	6	2.5	220
Large jack-up	160	4300	3	1.4	150

Figure 4.15 Comparison between traditional Jack-up vessel and new large floating DP vessel.

Considering that the cost of vessels is approximately equal to 8% of the total cost of the energy, potential savings are around 2% of the LCOE, which in our reference value is:

$$LCOE\ Impact\ (New\ type\ of\ vessels) = 2{,}9\ €/MWh$$

5

OPPORTUNITIES BASED ON EFFICIENCY IN THE SUPPLY CHAIN

5.1 MORE COMPETITIVE SUPPLY MARKETS

Supply market bottlenecks

Competition will be a powerful driver of cost reduction. In broad terms, the number of suppliers and the balance between supply and demand will drive the level of competition in the key supply markets.

As indicated in Chapter 4, in certain areas of the offshore wind supply chain such as wind turbine manufacture and the provision of installation and O&M services (including suitable vessels) there are currently few competitors. These conditions led to bottlenecks in supply and high prices in recent peak years of production. As demand increases post-2015, these conditions could be repeated unless additional investment is made by the supply chain.

The creation of competitive conditions is dependent initially on the attraction of additional investment into the European offshore wind sector. Investment in capacity has been made by vessel operators and by support structure fabricators. Turbine manufacturers have so far invested in product development but have not put manufacturing capacity in place.

In balanced markets, it is reasonable to assume that players will price their products to recover costs (labour, materials and sunk investment in plant and R&D) and earn "normal" profit. Based on segment results from Siemens, Vestas and General Electric, net profit in energy industries has been in the range of 10-20% over the past five years. In constrained or undersupplied markets, high demand will result in higher prices as a result of a combination of increased input costs and increasing margins. This was the case in the CCGT and supercritical coal market where prices increased by the same order of magnitude as underlying costs during a period of supply shortages.

The opposite effect occurs when there is over supply. There is plenty of evidence of falling prices in the wind turbine supply market since 2009 due the increase of players in the supplier´s side.

As reflected in the study of the market developed by PWC, currently there is no expectation for the market to deal with another supply bottleneck, as the high level of investments in supplier´s industries guarantee enough production capacity.

LCOE impact of an increase in the number of suppliers

There are currently only a small number of players in the turbine, installation contractor and jacket foundation markets. Most of the players are based in the UK and the rest of the EU. The only notable presence of low cost countries has been that of Shanghai Shenhua Heavy Industry which delivered monopiles to the Greater Gabbard wind farm.

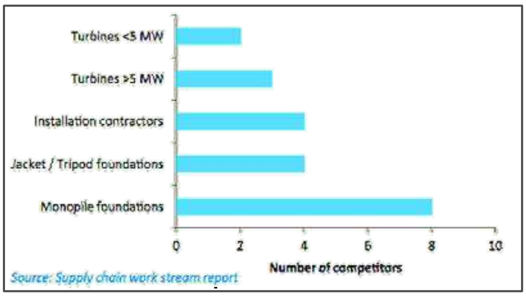


Figure 5.1 Current number of competitors by key supply market. Source: The Crown State.

In a number of key supply markets, it is expected to see an increase in the number of competitors as the European market grows and matures, driving down costs.

Turbines

Ten companies have made announcements indicating an intention to invest in offshore wind manufacturing facilities in Europe; including some interest from companies based in low cost countries such as China, India and Korea. It seems unlikely that all these announcements and interest will convert into actual investments.

According to the predictions of The Crown State, it is expected a long term market for offshore wind turbines in Europe of around 5GW/year through to 2025. With the output of an offshore wind turbine manufacturing facility estimated at between 0.5 to 1GW/year, the European long term market will require about 5-10 factories. Therefore, it can be assumed that the European offshore wind turbine market will support a minimum of 6 competitors by 2020, of which 2 are expected to have a strong base in low cost countries.

A greater level of competition will generate margin compression and increased cost pressures. The vast majority of the cost of an offshore wind turbine is made-up of components that are assembled by the turbine manufacturer. Many active turbine manufacturers have a high degree of in-house component supply, like Vestas and Siemens. Increased cost pressures are likely to generate savings at the component level; either through outsourcing, shift of in-house supply to low cost countries, or increased efficiency in their European component supply operations. Some signs of this are already occurring, with Vestas producing bedplates and generators in China as well as in Europe.

Activity in the onshore wind turbine market has demonstrated the potential to reduce costs through supply from low cost countries. Chinese turbine manufacturers have been successful in exporting onshore wind turbines to Brazil despite high transport costs; typically 200.000$ per turbine, and a 17% import tariff.

Overall, feedback from industry indicates that increased competition will reduce turbine prices by up to 15% from FID 2011 levels by 2030. If we take into account that turbine costs represent approximately 20% of total LCOE, we find that competition could reduce LCOE up to 3%. Applying this percentage to the LCOE calculated in our report, we obtain:

$$LCOE\ Impact\ (Increase\ of\ competition\ in\ turbines\ market) = 4{,}3\ €/MWh$$

Foundations

Turbine jacket manufacturing has so far been undertaken by a small number of fabrication yards such as BiFab (UK), Aker Verdal (Norway) and Smulders Group (Belgium). Other companies such as Offshore Group Newcastle (OGN – UK) and Heerma (Netherland) have announced their intention to enter the market. In addition, there are a number of manufacturers of jackets for applications such as oil and gas or sub-station platforms who are considering entering the offshore wind market. These include Harland and Wolff (UK) and Shepherd (UK).

The monopile market is well supplied, with capacity for around 1,000 units per year, double current demand levels. To date, eight European-based manufacturers and one Chinese manufacturer have served the UK market.

According to the estimations provided by EC Harris Consultancy, the EU demand for offshore wind jackets will be around 800-1,000 units per year from 2017 to 2025. An automated jacket fabrication facility is able to produce around 100 units/year, so up to 10 European fabrication yards are expected to be active competitors by 2020 (including existing players).

In addition, many fabrication yards already engaged in similar work are in South Korea, Singapore and Japan; Chinese yards are expected to enter the market as well. However, there are considerable logistics difficulties, and costs associated with low cost and supply include approximately 35 days shipping duration and potential double handling of preformed large structures.

As the Supply Chain Workstream for The Crown States suggest, suppliers from low cost countries are currently stated to be able to reduce unit cost by 30% for transition pieces and by 50% on a euro/hour basis for pile stoppers and secondary steel, although when shipping and handling costs are added in the net savings are likely to be smaller. Overall, it is expected that greater competition can reduce support structure prices by 7% by FID 2030, reducing LCOE for the whole wind farm by around 1%. Applying this percentage to the LCOE calculated in our report, we obtain:

$$LCOE\ Impact\ (Increase\ of\ competition\ in\ foundations\ market) = 1{,}4\ €/MWh$$

Installations

There are four main parts of the installation supply market:

- Turbine installation
- Foundation installation
- Provision of major installation vessels for turbine, foundation and sub-stations
- Cable installers (inter-array and export).

The current capacity for the management of foundation installation is sufficient but is limited to a relatively small number of medium-sized contractors. The players involved (Van Oord, MT Hogjaard, Ballast Nedam) are significant mid contractors but may not necessarily have the resources or appetite to expand capacity to meet projected demand from 2015 onwards. Foundation installation specialists provide a key role in supply chain management, logistics and risk transfer. It is important, therefore, that other large engineering businesses are attracted into the market.

The market for major installation vessels is fairly well balanced. There are currently twenty specialist vessels operating in European waters, and a larger number of jack-up barges used for a range of off-shore operations. EWEA calculated that 12 additional installation vessels will be needed to deliver 40 GW of capacity by 2020 in Europe.

The cable installer market is generating the greatest number of insurance claims. This market has been characterised by players with weak financial strength and poor track record with only a few main actors such as Global Marine Systems, Van Oord or Subsea7.

By 2020, EC Harris expects a well-diversified installation contracting market that will eliminate current undersupply and introduce other new players.. Greater competitive pressure will lead to cost reductions through the introduction of more efficient processes.

Overall, information published by EC Harris reflect that increased competition in installation is expected to reduce LCOE by 3% by FID 2020 (including the impacts described above, plus impacts of competition on operations and maintenance costs and array capital costs). Applying this percentage to the LCOE calculated in this report, the impact results in:

$$LCOE\ Impact\ (Increase\ of\ competition\ in\ installation\ markets) = 4{,}3\ €/MWh$$

5.2 Greater activity at development stage

Many of the key decisions that shape a wind farm project and therefore its costs are taken at a relatively early stage, often prior to Final Investment Decision.

Feedback from industry is that greater investment in wind farm design and optimisation at the development stage will yield considerable cost savings later in the project. The cost reductions will come from both technology and supply change influences. New software tools will drive multi-variable optimisation of wind farm array layout. In addition, a combination of greater use of Front End Engineering and Design (FEED), more use of geo-technical and geophysical surveying and earlier involvement of suppliers will design out costs and avoid costly installation overruns. The potential benefits are listed below.

Array optimisation

There are projects that present relatively benign and uniform conditions in the seabed. In this case, array layout is defined by the site constraints and a simple trade-off between capital cost and turbine separation. The larger the turbine separation the lower the wake effects and the higher the energy production per turbine, but requires higher capital investments and operational expenditure and less energy production per unit of seabed.

Other projects call for a more sophisticated set of trade-offs between, for example, wake effects, array cable costs, support structure costs, installation costs and consenting constraints. Implementing these trade-offs will involve the development and use of fast and reliable software tools that optimise the array layout for the lowest cost of energy, or other parameter depending on the targets of the developer.

The overall benefit of this innovation is to reduce the cost of energy through improving the location of turbines. Depending on site conditions, this is likely to involve reduced support structure and installation costs, by avoiding the more challenging areas of the site, reduced electrical array costs by considering the effect on the system cost when optimising, and an increase in energy production through reduced wake losses and/or electrical array losses.

Savings may also be available in operating costs due to, for example, better-spaced turbines causing less fatigue loading and therefore less frequent components replacement or repair. The use of optimisation tools may also lead to lower wind farm development costs owing to a reduction in the time taken to manually analyse and iterate design options.

Based in The Crown State studies, overall optimised array layouts could reduce LCOE by up to 1%, which transformed in the impact of the LCOE calculated is:

$$LCOE\ Impact\ (Incremented\ planning\ in\ array\ cables) = 1{,}4\ €/MWh$$

Greater use of surveys and optimisation techniques

The saving from greater use of Front End Engineering and Design (FEED) and greater use of survey data are highly linked, based on a philosophy of higher pre-FID spend to reduce overall costs.

FEED studies allow developers to choose the basic design concept and the size of the key components, and review a variety of design options to compare the economically viable solutions. At this stage, design options remain relatively flexible. With increased optimisation of design at FEED, decisions about concepts are made following a more detailed analysis of costs. For example by examining costs for a number of complete, installed solutions; considering the impact of array cable arrangements and secondary steel costs, rather than simply comparing basic foundation structure and foundation installation costs on a per-tonne basis.

An improved knowledge of sea-bed conditions, from surveys on the other areas of the site or on soil conditions closer to the surface of the seabed, can lead to cost reductions in array cables and installation capital costs through earlier design work and hence the prevention of conservative overdesign or late design changes. Support structure capital costs savings are also possible with an increased number of core samples taken at turbine locations.

Overall, the technical impact of both these innovations is an increase in wind farm development costs of 5%, but a decrease in support structure, array cable and installation capital costs of around 5%, together with a substantial reduction in installation risk. Following the indications of EC Harris, an investment of £2m in greater FEED and more survey data in a 500 MW wind farm could result in a reduction in LCOE of 1.2%, which applied to our predicted LCOE results in:

$$LCOE\ Impact\ (Greater\ use\ of\ surveys\ and\ optimization\ techniques) = 1{,}7\ €/MWh$$

Earlier planning of supply chain

In addition to the impacts indicated above, early involvement of the supply chain will generate further cost reduction opportunities. These will manifest themselves mainly through:

- Lower installation costs from: joined-up scheduling, more appropriate scheduling of tasks, optimisation of logistics support...
- Reduced over-ordering of steel for support structures through detailed procurement planning
- Reduced operating costs through the early identification and mitigation of key risks. For example, early recognition that certain parts will need frequent replacement will highlight the value of lighter designs so that replacement parts can be loaded onto smaller vessels.
- Better scoping of surveys and improved information flow to component designers.

According to EH Harris, earlier involvement of the supply chain is expected to reduce LCOE up to 3.1%, although in the projects considered in this report already applies some of the measure predicted. Therefore, the impact considered is the half of the proposed, 1.5%:

$$LCOE\ Impact\ (Earlier\ planning\ of\ supply\ chain)\ = 2{,}2\ €/MWh$$

5.3 Economies of scale and productivity improvements

The offshore wind market is still relatively small and dominated by specific design and personalised production. With a steadily and predictably growing market it is possible to unlock investment in the supply chain, developing new capacity (asset growth) and realising economies of scale.

Asset growth indicates the willingness of players to invest in additional production lines or manufacturing facilities, associated infrastructure such as ports and assets all of which have high up-front investment costs, long lead times and long pay-back periods. For example a new installation vessel will typically cost €240m, take three to four years to build and 15 to 20 years to pay back. As supply chain capacity increases, cost savings can be achieved through, for example, productivity improvements (having more vessels reduces the impact of installation delays as it affords increased flexibility) and logistics (if new capacity and its associated supply chain are located closer to the market it is possible to minimise transport costs).

With increased volumes, economies of scale can be achieved and efficiencies obtained in procurements (obtaining volume discounts), implementing procedures that allow repetition in a more efficient manner, standardising processes...

Asset growth and economies of scale will have the greatest cost reduction impact in installation, support structures and turbines.

Installation

A more mature and stable market will allow the supply chain to exploit a number of opportunities in the installation step.

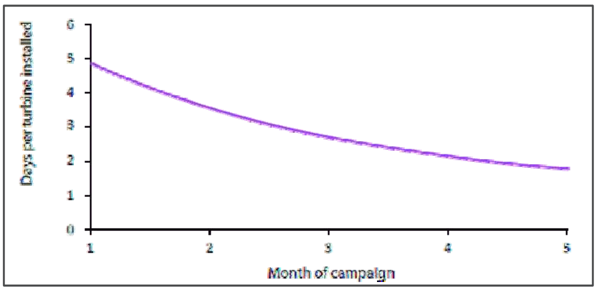


Figure 5.2 Indicative learning during a turbine installation (single project). Source: The Crown State.

If investment pay-back on items such as vessels and port infrastructure can be spread over a longer period through longer term commitments as such long term contracts, frameworks, alliancing or part-ownership contract, then prices can reduce significantly. For example, increasing contract period from 1 to 5-7 years can reduce costs by around 25% in the case of charters for installation vessels (for turbines and foundations) and up to 20% in the case of port facilities.

Based on industry feedback and information published by Accenture, it is expected that charting will result in savings for vessels and port facilities to reduce installation costs by 4%, which results in a 0,8% of reduction on the LCOE. Applied to the calculated LCOE, it results in:

$$LCOE\ Impact\ (Economies\ of\ scale\ in\ installation) = 1{,}2\ €/MWh$$

Foundations

Regarding support structures, long term contracts, reduced logistics and standardisation are among the key opportunities:

- **Longer term contracts**, with more certainty over the order pipeline allow investments in new capacity to be recouped over a longer period thus resulting in cost reductions. Increased volume also results in economies of scale brought forward by, for example, rationalisation of the supply chain.
- **Location of new manufacturing facilities.** Locating them in the countries where the projects are built (mostly UK and Germany) as opposed to importing from fabrication yards in the rest of Europe would result in about 1% cost savings, mainly in logistics and transport.
- **Standardisation of the industry and practices.** This will allow increased productivity of assets and labour. A foundation manufacturer suggested during the

Overall, feedback from industry indicates that a 5% reduction in support structure costs is possible by FID 2020 (resulting in a 0.7% reduction in LCOE).

Applied to out calculated LCOE, it results in:

$$LCOE\ Impact\ (Economies\ of\ scale\ in\ foundations) = 1{,}0\ €/MWh$$

Turbines

The savings in the turbine area are expected to be lower as the supply chain is more mature and significant levels of standardisation are already in place.

Increased utilisation of existing production facilities and larger procurement volumes could save up to 2% turbine capital costs. Investment in new capacity and in particular locating new manufacturing in UK and Germany would also result in about 1% cost savings due to logistics and transport.

Overall savings in turbine costs due to asset growth and economies of scale of 3% are possible by 2020 (equivalent to a 1% reduction in LCOE), which applied to out calculated LCOE, it results in:

$$LCOE\ Impact\ (Economies\ of\ scale\ in\ turbines) = 1{,}4\ €/MWh$$

5.4 Reduction in O&M costs

Opex covers all costs incurred after the COD that are required to operate the project and maintain turbine availability to generate power. These expenditures are generally thought to contribute between 20% and 30% to life cycle costs for offshore wind projects, depending on site characteristics. The strongest drivers are distance from shore, accessibility limits related to local meteorological conditions (e.g., wave height), and turbine rating.

To optimize the balance between Opex and availability, operators adopt different logistical strategies for individual projects depending on site conditions. The importance of the potential of O&M costs is based on these facts:

- Efficient, proven O&M concepts are still not available.
- Excellence in O&M is critical to a profitable offshore wind business.
- O&M offers potential for continuous improvement over project lifetime.

Key factors that determine the cost of O&M costs are the following ones:

- **Location of service station**. Station for service personnel onshore or offshore on service platform.
- **Logistics to and on site**. Service vessel concept and potential use of helicopter.
- **Availability of crane or jack-up**. Adequate access to vessels for replacing large components.

The main drivers that will lead the cost reduction are listed below. The impact originated by all of them has already been taken into account in other parts of the study, so in this case no impact in LCOE will be allocated to these improvements. The idea is to reflect that some of the reductions generated by improvements in the supply side or in turbines, cables... affect directly to the O&M costs.

- **Increased rated power of WTGs** that can reduce O&M costs per MWh. Impact considered in Chapter 4: Improvements on turbines.
- **Increased reliability of turbines and components**, which reduces unplanned service activities. Also considered in Chapter 4.
- **Geographical clustering of offshore wind farms** that creates synergies. This impact has been considered in this same chapter.
- **Increased in-house O&M activity by utilities** that will partly or fully replace O&M turbine manufacturers. Also considered in this chapter: economies of scale.

6

OPPORTUNITIES BASED ON REDUCTION OF FINANCIAL COSTS

6.1 REDUCTION OF THE WACC

Importance of the WACC in the overall LCOE of offshore wind

Similar to many other forms of low carbon generation, such as nuclear, offshore wind is characterised by high up front capital costs. As can be seen in figure 6.1, the initial capital cost for offshore wind currently accounts for approximately 70% of the LCOE.

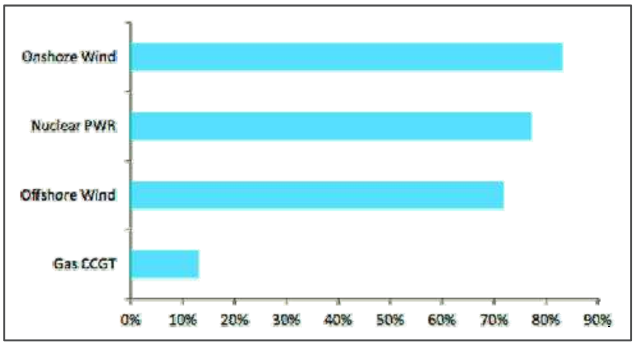


Figure 6.1 Cost of capital for different generation technologies. Source: EWEA.

This makes the cost of capital one of the most important contributors to the overall LCOE for a typical project. By way of example, a 500 MW offshore wind project costing £1.500m to construct, as Wikinger project selected to calculate the initial LCOE in this report, could reduce its LCOE by approximately 6% for every 1% reduction in the Weighted Average Cost of Capital (WACC). The WACC is affected primarily by the investor's view of the risk of investing in the project, the level of competition to supply capital to that particular project and the capital structure (mix of debt and equity).

Assessment of the average WACC in offshore projects

Any assessment of the long-term costs of offshore wind requires an assumption for the cost of capital. This is because, as mentioned in Chapter 3, the cost of capital is used as the discount rate in LCoE calculations.

There are a number of previous studies which have provided an assessment of the cost of capital. PWC, in its Finance Workstream Report for The Crown State, has made a recompilation of several ones. However, one challenge is that they have been calculated in different years and using different assumptions. To allow the comparison between all reports, PWC has made several adjustments, apart from considering real values in 2013 base, reflected in figure 6.2.

Author	Date	WACC (real)*		WACC (nominal)*	
		Pre-tax	Post-tax	Pre-tax	Post-tax
Ernst & Young	2009	*14%*	**10%**	*17%*	*13%*
Oxera	2011	**10 - 14%**	*7-10%*	*13-17%*	*9-13%*
ARUP	2011	**12%**	*9%*	*15%*	*11%*
Redpoint Energy	2011	*10-11%*	*7-8%*	*14-15%*	**10 - 11%**
Range		***10-14%***	***7-10%***	***13-17%***	***9-13%***

* **Values in bold** – published results by author, rounded to 0 decimal places; *values in italics* – authors' results adjusted by PwC

Figure 6.2 Comparative between different offshore WACC calculations published. Source: PWC.

It is important to consider that the WACC calculated for this report in both projects selected (EA1 and WIK) is 6%, lightly slower than the average considered by PWC (7 – 10%), but it is justified for the relevant size of Iberdrola, that allows financing in a cheaper way, and the latest date of both projects (2015/16 instead 2013).

Alternatives to reduce the WACC in a project

Until now, the alternatives proposed in this report (Chapters 4 and 5) addressed different ways to reduce the costs of the projects, either using improvements in technologies or increasing the efficiency in the supply chain. On the contrary, this part of the thesis does not try to reduce the costs of the projects. Instead, it tries to reduce the LCOE of the energy focusing in alternatives to reduce the cost of capital (WACC) used in the LCOE calculation.

The Crown State identifies four different ways to reduce the cost of capital. These are policy and regulation measures, risk reduction, attract of new investors and facilitate debt funding. Each ways comprises different measures that are explained below.

Policy and regulation

The regulatory framework impacts the type and level of support made available to UK offshore wind projects. Regardless of how long an investor anticipates remaining tied to a project, it needs a clear signal from government that any subsidies put in place to support a project over the whole of its lifecycle will remain in place. Failure to provide this confidence will impede investment.

The idea here is that the Government needs to contribute to give confidence to the investors. Some of the alternatives to promote this confidence are:

- Before investing in the industry, potential participants require visibility on the long term growth prospects of the industry. The government needs to provide a clear statement on ambition, including volume targets and interaction with cost reduction to the sector.
- Some support mechanism, such as previous renewables obligation ("RO") scheme in UK, renewable energy developers are exposed to variable power prices and uncertain subsidy provision. Substitution of these schemes by Feed-in tariffs that eliminate completely market risk is a good solution to reduce the cost of capital.
- Regulatory periods have to be long enough to guarantee stability. Future revisions of regulations in renewable sector should contemplate this point and frequent changes in the legislation should be avoided.

Risk reduction measures

Reducing risks, particularly around installation and O&M, should not only reduce the cost of capital required by the existing set of developers. It is also likely to help attract new sources of capital. There are a number of examples that could lead to reductions in the installation, O&M and additional developer equity premiums:

- The offshore wind sector currently uses a variety of methods for the construction phase. Much of this is due to the general inexperience of the sector but until there is confidence among investors that projects will be delivered with lower construction risks, the installation risk premium will not decrease.
- The additional developer risk premium represents a significant component of the cost of equity. Reductions in this premium are more likely to occur when investors are comfortable with the technology risk of their specific projects.

- Currently warranty periods from equipment suppliers typically extend to 5 years, with the project owner being exposed to a further 15 years of operations without the comfort of a service and warranty agreement.
- Developing and building the transmission assets of an offshore project typically take up to four years. There is limited incentive for a generator to bring forward investment ahead of FID as the investment is at risk if a positive FID is not secured.
- There is a need for the development of an O&M supply chain which seeks to optimise the servicing of projects, in order to reduce risks around downtime and cost of repairs.

According to the information published by PWC, the following actions would help overcome these issues:

- The development on one or more standardised installation methodologies for different aspects of project delivery (including foundations and cables).
- A move away from the current multi-contracting approach (which is complex for the developer to manage and has the potential to leave risks unidentified and not mitigated) to fewer, more transparent contractual packages.
- An increased level of competition in the supply of turbines, cables and vessels to ensure that technology and supply chain advancements are passed through to project developers and which will help reduce the developer equity premium.
- Introduction of an incentive mechanism to encourage anticipatory investment in transmission assets and remove stranded asset risk.
- Equipment suppliers to offer longer service and warranty periods, and longer O&M contracts that provide greater certainty on operating costs and performance in the long term.

Attract new investors

Potential new investors in UK offshore wind include both non-financial investors who might be willing to take construction risk (such as utilities and companies involved in the supply chain) and financial investors who are more likely to invest in operational assets (such as insurance, pension and sovereign funds).

- Non-financial investor will enter in the offshore wind market only if the potential financial returns are sufficiently attractive relative to other opportunities and the risks around the regulatory framework and construction are understood and can be managed.
- Financial investors represent a potentially large source of capital. To date they have shown limited appetite for investing in offshore wind generating assets, although there has been a strong interest from infrastructure funds in investing in OFTO assets. This partly reflects their perceived risk of the sector but also constraints in terms of annual capital available for investment which gets allocated according to a pre-agreed asset allocation strategy.

Among the measures to attract new investors to the offshore wind industry, it is worthly to mention the following ones:

- European Governments need to promote the offshore market to potential participants located outside of Europe, and set out specific measures to facilitate investment from the private sector.
- Governments need to ensure there are no unintentional obstacles to institutional investors (pension, sovereign funds...) investing in infrastructure. In addition, the government should look at whether specific incentives (e.g. tax-related) are needed to encourage these investors.
- Regardless of whether these funds choose to invest by taking an equity stake in a project or by investing in project bonds, the offshore sector will need to ensure that it engages more effectively with these investors. The offshore industry will therefore need to work closely with them to understand what needs to be done to ensure funds are allocated to the sector.

Facilitate debt funding

Until the date, it has been challenging for European offshore projects to access commercial bank funding, although debt could provide an important source of capital for the offshore sector in the future.

Apart from the traditional bank funding, an alternative source of debt is project bonds, which have proven to be the best solution to finance offshore projects using debt. It has a number of potential advantages, including the release of bank capital to fund construction of other projects, a lower cost than bank debt, access to potentially greater pools of capital and liquidity (once the sector has sufficiently proved itself to the bond markets).

Independent power producers, who represent a potentially important source of capital, arguably face fewer issues with the credit rating agencies than the vertically integrated utilities and are more able to raise nonrecourse debt finance (as evidenced in the European market).

To enable debt to be raised at the levels required, some required actions include:

- Rating agencies need to clarify their position on financial structures currently in the market. The most positive signal for the market will be for some of these existing projects to reach financial close, as these financings can act as a precedent for further projects.
- Loan documentation, contracts and project structures need to be standardised to facilitate a shorter process to get to financial close. This could also involve some co-ordinated engagement with the ratings agencies on the treatment of potential financing structures.
- Governments, through financial institutions, need to engage with both investors and the offshore wind sector to identify how the introduction of project bonds can be expedited.

LCOE impact of a reduction of WACC

Increase in WACC motivated by the introduction of new technologies

In the first place, it is important to underline that the introduction of new technology increases risk until it demonstrates performance in line with expectations. The uplift in WACC needed to compensate for this extra risk will depend on a number of factors like the track record of the technology developer, performance guarantees and the degree of testing of the technology.

Figure 6.3, elaborated by PWC, compares the WACC of a 4MW turbine with a newly introduced 6 MW turbine. This shows that the introduction of a new turbine is expected to increase WACC by 0.5 percentage points.

Figure 6.3 Increment of WACC due to introduction of new turbine. Source: PWC.

As stated at the beginning, a project could reduce its LCOE by approximately 6% for every 1% reduction in the WACC, so in this case the impact in LCOE is about 3%, although this uplift will erode with time, reaching only 0.2% of LCOE in five years.

Overall reduction of finance costs

The Finance Workstream Report elaborated by PWC has made an analysis of the variations that WACC in offshore projects can experiment in the following years. Figure 6.4 represented below reflects the different factors that affect WACC. As can be checked in the image, funding shortfall and the technology risk mentioned are the only factors that increase the WACC.

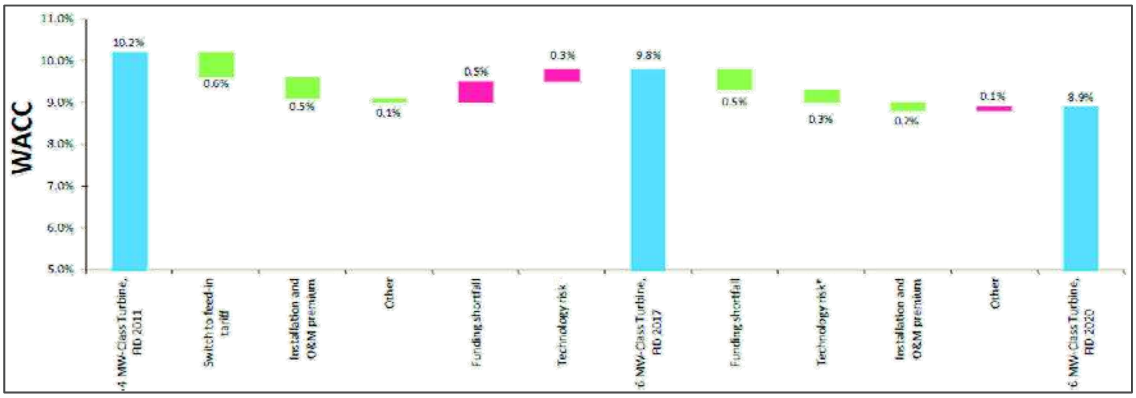


Figure 6.4 Potential reduction in WACC for offshore projects. Source: Finance Workstram Report. PWC.

PWC forecast shows a 1.3% reduction in WACC. However, as the average WACC used in the valuation of projects EAONE and WIK is 6%, much lower than the forecasted by PWC, 10.2%, it is necessary to make an adjustment to the potential reduction that can be achieved. Applying proportions, 1.3% reduction when WACC is 10.2% results in 0.8% reduction if the WACC is 6%.

A 0.8% reduction in WACC results in a 4.8% reduction of the LCOE, which applied to the value calculated in Chapter 3, results in:

$$LCOE\ Impact\ (Reduction\ of\ WACC) = 6{,}9\ €/MWh$$

6.2 REDUCTION OF INSURANCE PREMIUM

Insurance has a central role to play in the offshore wind sector. By assuring financial protection from physical damage and delays during the assembly, transport, construction, and operational stages of a project, it provides comfort to both equity and debt funders that can result not only in attracting capital but also doing so at a lower cost. However, the cost of purchasing insurance represents a significant cost and the relative immaturity of the sector means that there are a number of areas where there is scope for development.

Cost reduction opportunities

Discussions with industry stakeholders indicate that, although purchasing insurance represents a significant cost, a there is scope for development, cost reductions that can be achieved are limited.

However, the offshore wind industry needs to be assured that the requisite products will be available to the sector and at an acceptable cost. The Crown State, in its Cost Reduction Pathways study, has identified a number of development areas, which are listed below.

Competition and market capacity

There are currently only a limited number of providers in the market. A significant increase in the volume of total offshore wind capacity in Europe and beyond could create a constraint going forward, which is likely to result in certain risks not being covered or at a higher cost. It will take time for new entrants to build up this knowledge of the sector in order to compete, but at the end they will provide more capacity insurance. New entrants from Asia could enter the market along with new turbine technologies and new investors.

Market coverage

If new sources of capital are to be attracted to the market, then there are certain insurance products that need to be in place. For example, project financiers generally require, as a minimum, cover for business interruption and delay in start up.

There are a number of factors that influence the price and extent of the cover.

- Due to the relative infancy of the sector, there is a view amongst insurers that there is insufficient data and experience on how to price insurance as efficiently as compared to, for example, the oil and gas sector. Consequently, insurers commonly add an extra 20% onto the premium to take account of unknown risks and uncertainties of wind farm resilience.

- The strength of the turbine warranty is taken into consideration when determining insurance cover. There is often an overlap between the warranty and the insurance package giving lack of clarity and transparency of the warranty cover. There is a need for greater clarity of the inclusions of the warranty and it’s response to defects and interaction with the insurance contracts.

As the offshore wind sector develops with greater volumes of installed capacity and operating hours on which to assess risks, insurers will become increasingly better equipped to price appropriately.

Technology

Offshore wind will continue to see significant levels of technical innovation over the next decade and beyond. From the insurer's perspective this creates additional risk that needs to be reflected in insurance premiums.

Main considerations regarding this point are that new technology is likely to drive up the premium, as it happens with the WACC, and that, as technology advances, the cost of maintenance is likely to increase as existing technologies become obsolete.

Other

In addition to the above considerations, there are other issues that will continue to impact insurance coverage and premiums:

- There remain significant 'unknown risks' in the offshore wind sector that have not yet come to light, and that´s why some insurance companies are conservative when fixing premiums.
- In the case of UK, contingent business interruption covering OFTO assets will be a big driver of risk, and therefore premium will be increased. Windfarm developers do not have any control on OFTO assets, and the owners of OFTO are not incentivised to expedite a failure quickly as they are not affected. The industry needs to work to quickly rectify issues that come to light to raise confidence. More open collaboration between the OFTO and the generators is required.

LCOE impact

As stated at the beginning, although purchasing insurance represents a significant cost, the reductions that can be achieved have a limited impact on the LCOE of the company. Indeed, insurance contribution of an offshore wind project's total LCoE is below 4%, as reflected in studies for The Crown State.

Earlier engagement of project developers with insurers will help provide both companies with additional comfort, and therefore it could revert in a reduction of prices. According to PWC, the implementation of the measures suggested could help to reduce the costs of the insurance up to 30%, which in the total LCOE of the project is equal to 1.3%. This result in the following impact in the LCOE calculated in this report:

$$LCOE\ Impact\ (Reduction\ of\ insurance\ costs) = 1{,}9\ €/MWh$$

7

PUBLIC SUPPORT MEASURES

7.1 Importance of public support

This chapter is focused in the measures that European governments could implement to favour the reduction in the cost of energy of the offshore wind.

Offshore wind is on a cost reduction trajectory to compete in volume against other non renewable sources within the next 15 years. If the industry can achieve this ambition, offshore wind will become an increasingly important part of the European energy mix, contributing to decarbonisation and affordability goals. Until then, however, the policies of European governments remain critical to the industry's development.

In this report, the opportunities for cost reduction in the LCOE of the offshore energy have been classified in the categories:

- Opportunities based on technology acceleration.
- Opportunities based on changes in the supply chain.
- Opportunities based on reduction of financial costs.

} PUBLIC SUPPORT

All these reductions are highly dependent of a favourable regulatory environment that promotes investments in the sector and gives confidence to the companies involved. Therefore, the role of the governments is crucial.

In this section are defined the key government policy drivers that will affect the cost of offshore wind energy until the end of 2030. However, the specific impact of each measure is not calculated, to avoid overlapping with the impacts calculated in the other sections. For example, the impact of the increase of competence in the turbine manufacturer sector has been valuated in 7€/MWh in chapter 5. This value assumes that to increase the competition some political and regulatory measures will be needed, such as for example a reduction on tax, or the elimination of importing tariff. If these measures are not implemented by the corresponding government, the forecasted reduction probably will not be achieved.

Therefore, is important to underline that all the opportunities analysed in this report assume that every political or public measure needed will be implemented, and in consequence they are computed in the LCOE impact calculated.

7.2 PUBLIC SUPPORT MEASURES FOR COST ENERGY REDUCTION

Market size, visibility and confidence

The most direct influence that governments have on offshore wind is the market size they facilitate through support mechanisms. Governments base their decisions about market size on factors including decarbonisation targets, cost to electricity users, security of supply, local jobs and economic benefit.

According to the information provided by BVG Associates in the *Approaches to cost reduction in offshore wind report*, feedback from almost all major players in the industry is that companies base most of their main investment decisions on a European-wide consideration of market scale, rather than the markets of individual countries. The main exception is the finance community, which invests on a project-by-project basis and looks more closely at the risks associated with different national markets.

Regarding visibility, it depends on how governments decide to communicate their policies to the industry and the structure of the market mechanisms in place. Visibility of the European market size is critical to timely industry decision-making and is composed of a number of discrete national markets and, as such, whole market visibility is the aggregate of visibility of national markets.

Finally, the confidence of industry in market scale is based on the perceived sustainability and logic of government plans, their track record of consistent support in the past and the likelihood of future shifts in political support. Again, industry typically bases its confidence on a European-wide aggregate of discrete national markets.

As can be seen in figure 7.1, BVG Associates quantifies in a 13,4% the cost reduction in LCOE that is dependent on public measures related with market size, visibility and confidence. As stated in the introduction, in this report this impact is not considered as it has been included in the correspondent technology, supply chain and finance opportunities.

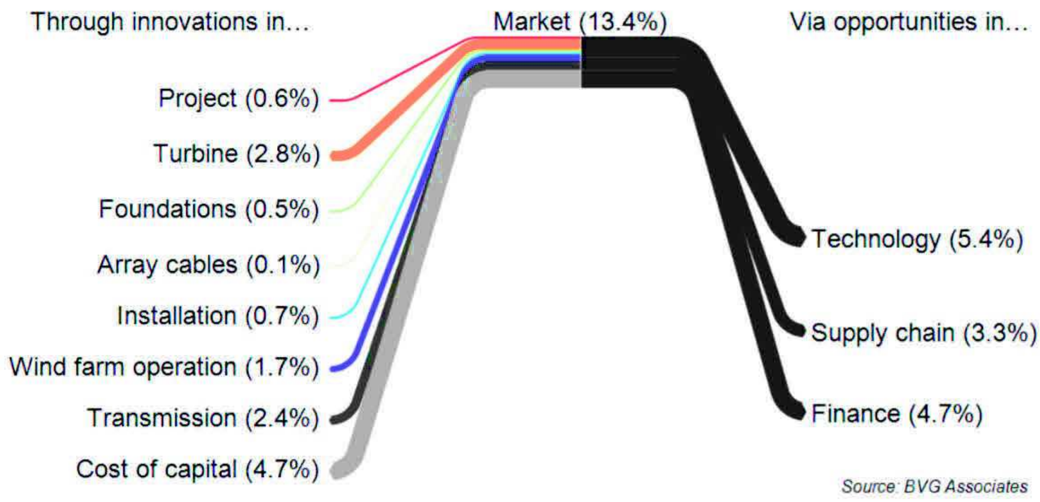


Figure 7.1 Impact of government intervention in market scale, visibility and confidence for a typical project with first generation in 2030, compared with a project with first generation in 2020. Source: BVG Associates.

Research and development programs

Public funding has an important role in some stages of the process of bringing new technology to market, such as concept development and the full-scale demonstration of new foundations and turbines.

Large-scale research and development programmes (R&D), such as the development of a next generation turbine platform, are best delivered by large, commercial players who are already experienced and active in the market and are stimulated through competitive conditions in a sustainable market size with good visibility.

However, governments can support R&D and skills development activities through public funding. This support may be direct, which involves funding to companies or academic institutions to support R&D programmes or collaborative work, or indirect which involves funding enabling bodies that can facilitate and enhance industry efforts or testing facilities that can be used by industry.

BVG Associates reflects that this impact is much lower than the one provided by market scale measures. As can be seen in figure 7.2, it represents only a 2.2% of the potential reduction in LCOE.

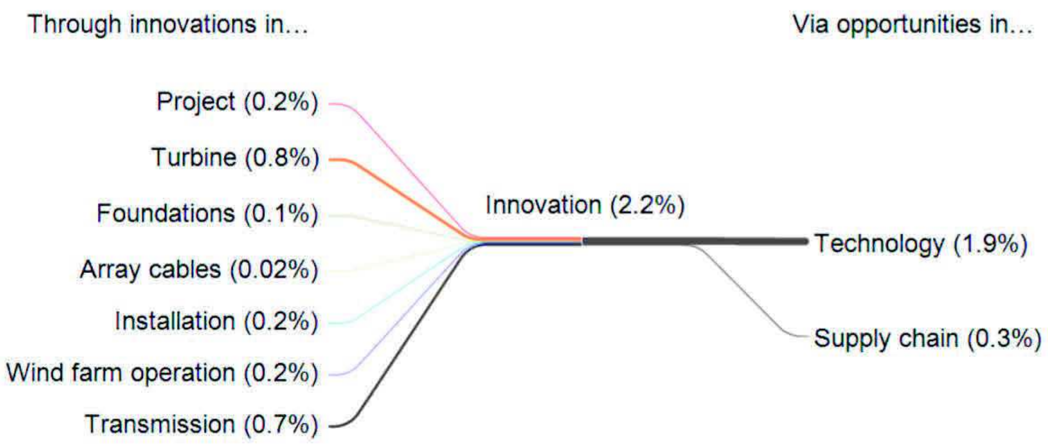


Figure 7.2 Impact of government intervention in public funded R&D for a typical project with first generation in 2030, compared with a project with first generation in 2020. Source: BVG Associates.

Reducing the risk investment in projects

As outlined in previous chapters, commercial offshore wind projects are large-scale infrastructure developments that need significant investment, and therefore the cost of capital has a major impact on the cost of energy of projects.

Governments can help reduce this cost of capital through reforms that reduce the level of risk that developers, equity owners and debt providers face. This can be done through export credit agencies and government infrastructure funds that provides capital at a lower interest.

The impact in the reduction of LCOE of these measures have been considered in chapter 6 through the reduction of the WACC. BVG estimates that it could achieve up to 2.4% of the total LCOE of a project.

Promote the efficiency in the supply chain

A well-structured supply chain with at least three or four strong players in each area of supply is important for reducing the cost of energy.

Governments may seek to intervene in the supply chain if they identify inefficiencies or failures in collaboration or competition. The interventions could be based in support mechanisms or more general industrial engagement and pressure.

BVG asses this impact in 1.5% of cost of energy. As is reflected in figure 7.3, most of the impact has been considered in the opportunities based on competition in the supply chain.

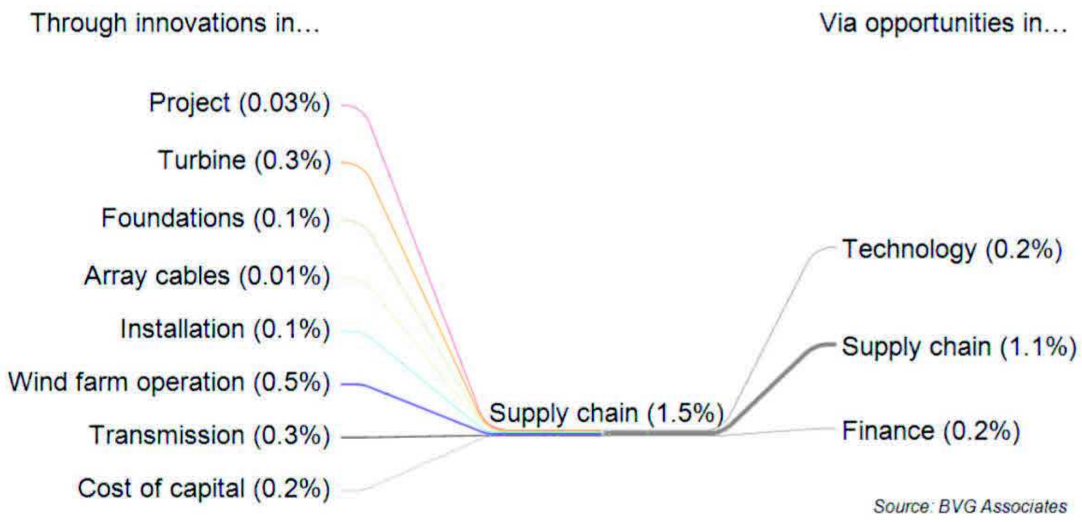


Figure 7.3 Impact of government intervention to improve supply chain efficiency for a typical project with first generation in 2030, compared with a project with first generation in 2020. Source: BVG Associates.

Implement a cost-efficient remuneration mechanism

Efficient remuneration mechanisms can facilitate longer-term efficiencies as long as a balanced level of competition is preserved. A feed-in tariff set by a government risks the industry pricing to the tariff, while a well-run auction at the right stage in project development offers short-term efficiencies, if competition is sufficient.

The structure of the mechanisms used to support the development of new offshore wind capacity can play an important role in driving down the cost of energy and maintaining a dynamic market.

If the system does not put enough competitive pressure on developers and the supply chain, then there is a risk of profiteering, with the benefit of investment only partially passed onto energy users. On the contrary, if there is too much competitive pressure, although there may be short-term benefits, players may decide to leave the sector and the market can become too dependent on a small number of players.

BVG quantifies in 2.9% the effect on the LCOE that an appropriate remuneration mechanism could have, mainly due to the reduction of risks.

8

CONCLUSIONS

8.1 Summary of results and 2030 LCOE

Summary of impacts

After finishing the analysis of the opportunities and measures that could provide a reduction of the cost of energy in the following years, from 2015 to 2030, the objective of this chapter is to make a summary of the measures analysed in each of the three categories and apply the impacts obtained to the current LCOE.

Opportunities based on technology acceleration

Technology acceleration opportunities are the ones that offer the high potential in the reduction of the LCOE, mainly due to the evolution of the turbines. As can be checked in figure 8.1, these opportunities represent a total potential of 24.50% of reduction, that applied to the estimated LCOE results in a reduction of 35.23 €/MWh.

Turbines present an enormous potential of cost reduction, mainly because technology that is currently used shares most of its characteristics with the onshore wind market. The fast growth of the offshore market is allowing turbine manufacturers to make huge investments in improved turbines that are adapted to the offshore conditions, obtaining relevant reductions in investment costs and higher levels of energy production. Impact of wind turbines represents almost 70% of the total reduction potential of the technology based opportunities. This is 17.00% of the LCOE, equivalent to 24.45 €/MWh.

Opportunities regarding substructures also provide an important contribution to the reduction potential. Together, improvements in fixed substructures and the implementation of new types of floating substructures account for 5% of potential reduction in the LCOE, which applied to our estimated values results in 7.19 €/MWh.

Subsea cables is the element where the potential of reduction is lower, mainly because is a very developed technology. Only reductions in the size and weight of the offshore substation can provide substantial savings. The impact in this part is only 0.50% of the LCOE, what represents a reduction of 0.72 €/MWh when applied to our LCOE.

Finally, the potential reduction in vessels is based on new types of vessels that can carry more loads while diminishing the total transport costs. In this case, the impact is 2.00% of the LCOE, equivalent to 2.88 €/MWh.

	LCOE	% Reduction
Technology	**35,23 €/MWh**	**24,50%**
Wind turbines	24,45 €/MWh	17,00%
Fixed Substructures	5,03 €/MWh	3,50%
Floating Substructures	2,16 €/MWh	1,50%
Cables	0,72 €/MWh	0,50%
Vessels	2,88 €/MWh	2,00%

Figure 8.1 Summary of impacts of opportunities based on technology acceleration.

Opportunities based on efficiency in the supply chain

Efficiency in the supply chain is the second group of opportunities that provide more reduction on cost. Together, all the measures included in this group account for a 13.20% of reduction of the LCOE, equivalent to 18.98 €/MWh when applied to our calculated LCOE.

Inside this group, the increase of competence in the market is the main source of reductions. Increase of the competence in turbines, foundations and installation market could provide a reduction of 9% in the cost of the energy.

Economies of scale are the second source of reductions inside this group. Together, all measures account for a 2.5% of reduction. Finally, other opportunities like surveys at the beginning of the development, array optimisation and earlier planning of supply chain complete the group providing the remaining 3.7% of reduction.

	LCOE	% Reduction
Supply Chain	**18,98 €/MWh**	**13,20%**
Competence - turbines	4,31 €/MWh	3,00%
Competence - foundations	1,44 €/MWh	1,00%
Competition - installation	4,31 €/MWh	3,00%
Array optimistaion	1,44 €/MWh	1,00%
Surveys	1,73 €/MWh	1,20%
Earlier planning of supply chain	2,16 €/MWh	1,50%
Economies of scale - installation	1,15 €/MWh	0,80%
Economies of scale - foundations	1,01 €/MWh	0,70%
Economies of scale - turbines	1,44 €/MWh	1,00%

Figure 8.2 Summary of impacts of opportunities based on efficiency in the supply chain.

Opportunities based on reduction of financial costs

In this group there are only to opportunities considered. The first one is the reduction in the WACC, which is provides the second highest reduction in the whole report. As stated at the in chapter 6, a project could reduce its LCOE by approximately 6% for every 1% reduction in the WACC. In this case, the forecasted 0.8% of reduction in the WACC results in a 4.8% of reduction of the LCOE, equivalent to 6.90 €/MWh when applied to the calculated LCOE.

Regarding the insurance costs, there is still a long way to reduce premiums paid by developers, mainly through the reduction of the risk undertaken by a project. Although the saving in insurance policies could achieve 20%, the final impact on LCOE is reduced to 1.30% due to the low relevance of the insurance costs on the total LCOE.

	LCOE	% Reduction
Finance	**8,77 €/MWh**	**6,10%**
Reduction on WACC	6,90 €/MWh	4,80%
Insurance costs	1,87 €/MWh	1,30%

Figure 8.3 Summary of impacts of opportunities based on reduction of financial costs.

Forecast of LCOE towards 2030

Once summarized all the impacts, to calculate the LCOE towards year 2030, the impacts of each group of alternatives is added to the estimated LCOE in 2015. As can be seen in figure 8.4, the overall reduction forecasted in the LCOE is 62.98 €/MWh, equivalent to 43.80% of the current LCOE. Applying all impacts, **LCOE obtained is 80.82 €/MWh.**

	LCOE	% Reduction
LCOE 2015	**143,80 €/MWh**	
Technology	35,23 €/MWh	24,50%
Supply Chain	18,98 €/MWh	13,20%
Finance	8,77 €/MWh	6,10%
LCOE 2030	**80,82 €/MWh**	**43,80%**

Figure 8.4 Calculation of LCOE in 2030

Results in line with estimations of relevant institutions

Results obtained in the LCOE calculation of this thesis, both current estimation (2015) and future forecast (2030) are consistent with those provided by other relevant institutions. As an example, the conclusions published in the Power Perspectives 2030 study, developed by a consortium of experts with the objective of clarify the European Roadmap 2050 objectives.

As can be seen in figure 8.5, this institution assumes a current LCOE located between 140 and 160 €/MWh, in line with the estimations of this report (143.80 €/MWh). The report also foresee a potential reduction of 35-55% of the costs (43.80% in this thesis), to achieve a final LCOE between 70 and 90 €/MWh in 2030, very similar to our projections (80.82 €/MWh).

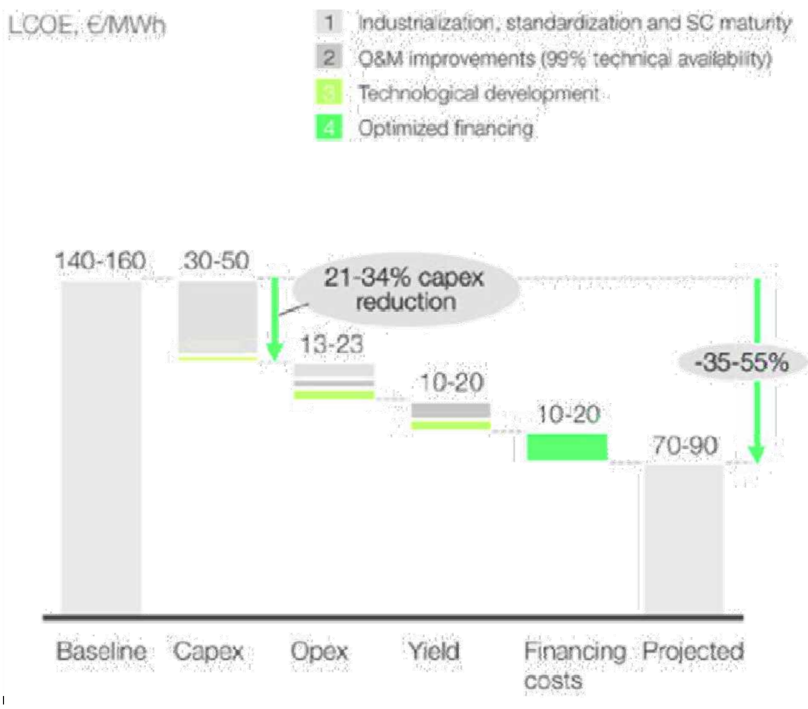


Figure 8.5 Offshore LCOE estimations towards 2030. Source Power Perspectives 2030 study.

8.2 OFFSHORE WIND POSITION IN THE ENERGY MIX

Current situation

The graphic below reflects the LCOE estimated for the different energy sources in 2015. The offshore wind LCOE is the value calculated in chapter 3 of this report: 143.80 €/MWh, and the information of the other energy sources has been obtained pondering the data of reports published by the following institutions:

- International Agency for the Energy of France.
- Fraunhofer Institute for Solar Energy System of Germany.
- Energy Information Administration.

As can be seen in the graph, offshore wind energy is far away from being competitive. Even if we consider only renewable sources, onshore wind and solar PV are more competitive, although they have less reduction potential as they are more mature technologies.

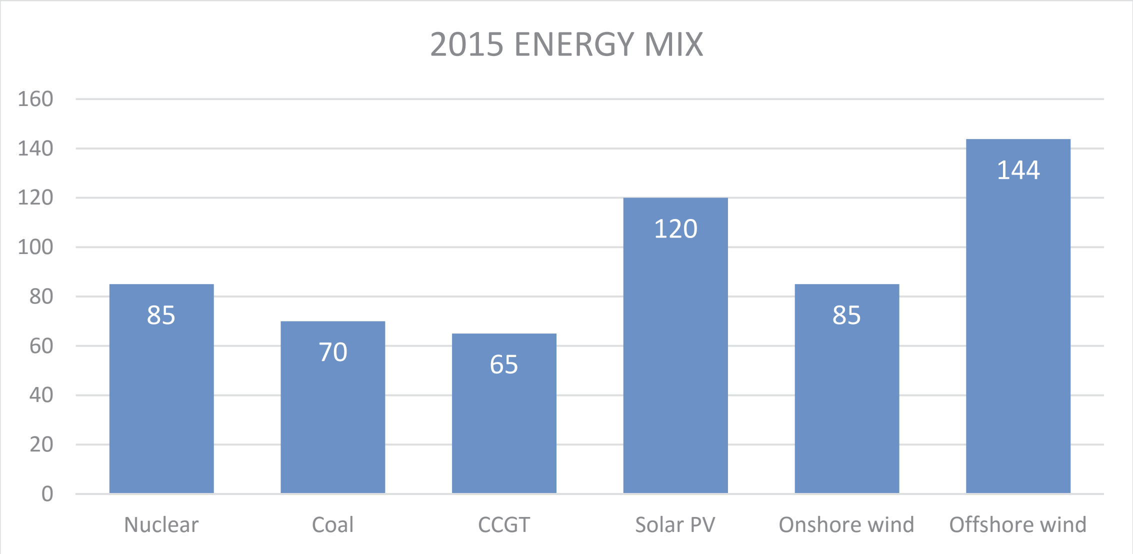


Figure 8.6 LCOE of different energy sources in 2015. Sources: IAE, FISE, EIA and own data.

Solar PV has experienced a significant reduction of the LCOE in recent years, reducing its cost from 160 €/MWh in 2010 to the current 120 €/MWh, mainly due to the reduction in the cost of the material favoured by the entry in the market of Asian low-cost companies. In the case of onshore wind, the growth has been more slow. The main problem of this technology at the moment is the lack of space to build new windfarms, as they present social rejection due to the visual impact and noise that they generate.

Regarding non-renewable technologies, coal and CCGT have experienced a recent reduction in costs, motivated by the low price of fuels during last years. On the contrary, nuclear has maintained its cost constant. None of these three technologies are supposed to experience reduction in costs due to the improvements in technology, as they are mature enough.

Situation in 2030

The graphic below reflects the LCOE forecasted for the different energy sources in 2030. In this case, the offshore wind LCOE is the value calculated in this chapter, 80.82 €/MWh, and the information of the other energy sources has been obtained from forecast provided by the following reports:

- Offshore Wind: Delivering more for less. BVG Associates.
- The real cost of offshore wind. Siemens
- Open EI. National Renewable Energy Laboratory (NREL).

The graph shows that offshore wind energy can achieve a good level of competition. In 2030, offshore wind energy could be more competitive than non-renewable sources such as nuclear, CCGT and coal, even not taking into account possible taxes to emissions that these sources would have to pay. In the renewable sector, offshore wind could surpass solar PV technology in a substantial way. Onshore wind will continue being more profitable, although as mentioned before the lack of space for new windfarms could limit its growth potential.

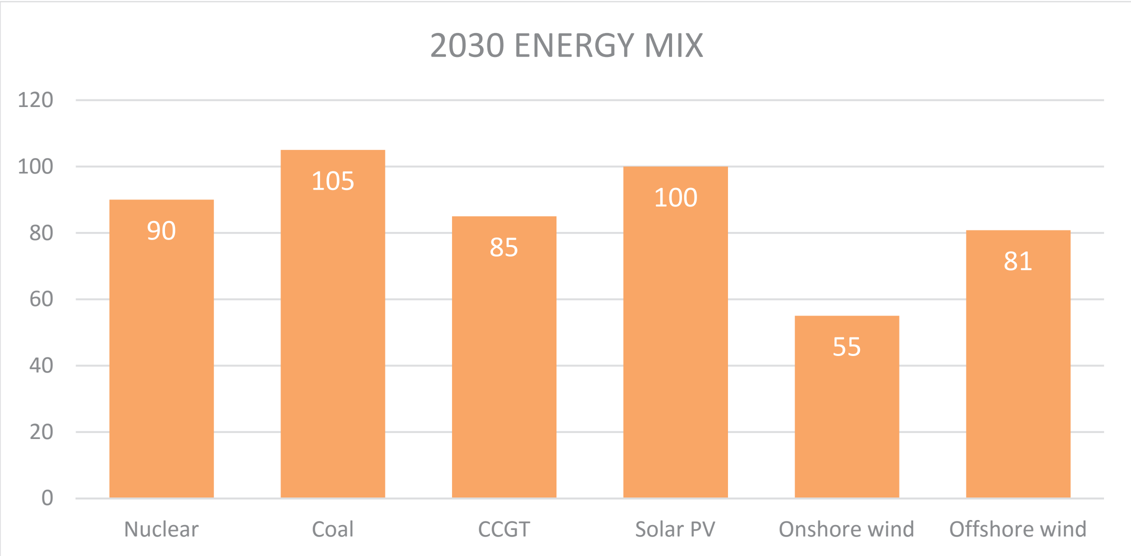


Figure 8.7 LCOE of different energy sources in 2030. Sources: BVG, Siemens, NREL and own data.

The increase on costs of non-renewable sources is mainly due to the expected evolution of fuel prices: coal and gas. Nuclear fuel is not expected to increase in a substantial manner, but in this case the increment in security measures is the main driver of the increase on costs.

In the case of renewable sources, solar PV still has a potential for cost reduction, which is higher in the case of onshore wind. In this case, this technology could benefit from the development in offshore wind, as it happens at the beginning of the century in the opposite direction.

8.3 Personal conclusion

The first value analysed in this report has been the current cost of the offshore wind energy. This LCOE shows that there is still a long way until this technology achieves competitiveness, as today there are other sources of energy, including renewables, like solar or wind, that offer higher returns than offshore wind.

At the end of the day, the competitiveness of an energy source is the fact that determine if investors risk their money in developing projects of this type of energy or not. The only reason why the offshore wind energy is growing in such a fast way is the public support provided by the European governments, which guarantees a high level of return to the investors, and at the same time favours the development of the technology. This support is, therefore, essential when a technology is not mature enough to be competitive.

And this is my first conclusion. Once again, Europe is at the forefront of the international efforts to deal with climate change. Some European governments are spending a relevant part of their national budget in financing and contribute to the development of a new source of energy that could acquire a significant role in the future. The rest of the world will benefit from the development of offshore wind energy, because probably majority of countries will only adopt the technology when the level of competitiveness is good enough to avoid public support.

But for sure Europe will be rewarded for this risky bet. European offshore wind industry is already contributing to the growth of European economy, but in the future it will do with much more strength. The potential rewards are enormous. By 2030, it is expected that more than 30% of the European demand of energy could be meet with this technology, and around 300.000 jobs are expected to be created in the sector.

However, public support cannot remain forever. To become relevant, this energy has to be competitive against other sources of energy, renewables or not, once the public support measures already in place are finished. If not, investors would decline the option of new investments in the technology and offshore wind will be abandoned. And this highlights the importance of the measures analysed in the report, as they build the path to the achievement of a good position in the future energy mix.

My second conclusion is that now, although public sector still needs to improve and make more efficient its support, is the time for the private sector to take the opportunity of the growth of the technology and invest strongly in new technologies, manufacturing facilities, risk reduction measurements and efficiency improvements in the supply chain. Only the combination of an efficient public support with decidedly investments of the private sector will lead offshore wind energy to success.

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