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Offshore Wind

Forecasts of future costs and benefits

June 2011

RenewableUK is the trade and professional body for the UK wind and marine renewables industries. Formed in 1978, and with over 660 corporate members, RenewableUK is the leading renewable energy trade association in the UK. Wind has been the world's fastest growing renewable energy source for the last seven years, and this trend is expected to continue with falling costs of wind energy and the urgent international need to tackle CO_2 emissions to prevent climate change.

In 2004, RenewableUK expanded its mission to champion wave and tidal energy and use the Association's experience to guide these technologies along the same path to commercialisation.

Our primary purpose is to promote the use of wind, wave and tidal power in and around the UK. We act as a central point of information for our membership and as a lobbying group to promote wind energy and marine renewables to government, industry, the media and the public. We research and find solutions to current issues and generally act as the forum for the UK wind, wave and tidal industry, and have an annual turnover in excess of five million pounds.

BVG Associates is a technical consultancy with expertise in wind and marine energy technologies. The team probably has the best independent knowledge of the supply chain and market for wind turbines in the UK. BVG Associates has over 120 man-years experience in the wind industry, many of these being "hands on" with wind turbine manufacturers, leading RD&D, purchasing and production departments. BVG Associates has consistently delivered to customers in many areas of the wind energy sector, including:

- Market leaders and new entrants in wind turbine supply and UK and EU wind farm development.
- Market leaders and new entrants in wind farm component design and supply.
- New and established players within the wind industry of all sizes, in the UK and on most continents.
- Department of Energy and Climate Change (DECC), RenewableUK, The Crown Estate, the Energy Technologies Institute, the Carbon Trust, Scottish Enterprise and other similar enabling bodies.

The views expressed in this report are those of BVG Associates.

Authors

Christopher Willow has worked in the offshore wind industry for more than three years and offers a comprehensive knowledge of both the UK's offshore wind supply chain and port industry. Recent work he has led includes a countrywide "meet-the-buyer" supply chain event for a leading turbine manufacturer and a project modelling the logistical benefits of clustered and distributed supply chains.

Bruce Valpy is the director of BVG Associates. Before founding the company in 2005, Bruce led wind turbine design activities in the UK for NEG Micon (since merging with Vestas). Since then he has created a rapidly growing and diverse client base including the market leaders in the wind turbine and tidal turbine sectors, RenewableUK, The Crown Estate, UK Government (DECC), utility providers and multi-nationals.

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This document contains revisions made on July 4th 2011

Introduction

In 2009, RenewableUK (then the British Wind Energy Association) published *UK Offshore Wind: Charting the Right Course*, which presented a range of scenarios illustrating how capital costs (CAPEX) of offshore wind farms might change over time.[1]

At the time, wind farm CAPEX was seen to be rising rapidly and the authors of the report sought to identify the factors that were driving this increase.

Overall, their conclusions were that they expected CAPEX levels to remain at approximately £3 million per MW with a slight increase between 2009 and 2012, followed by a drop back down to slightly lower levels by 2015. This forecast was qualified with assumptions about confidence within the supply chain, increasing UK content, and the market dynamics between offshore wind and other industries.

CAPEX is indeed a critical element, but the most important measure for the industry is whole-life cost of energy, which is also dependent on operational costs (OPEX) and the energy yield from wind farms.

RenewableUK commissioned BVG Associates to undertake this study into the whole-life costs of offshore wind, producing forecasts out to 2022. This is intended to be a reference document for use by government, industry, investors and the public. It will also be used to brief banks and investors on developments in the offshore wind sector.

A particular focus has been on how these costs will change over the four-yearly periods previously set out for the Government's review of its financial support mechanisms, which also correlate with milestones in the development of UK offshore wind.

These wind farm costs are then set in the context of the wider benefits that the offshore wind industry provides for the UK, including reduced carbon dioxide emissions, significant domestic industry turnover and generation of tax revenue.

Executive Summary

Offshore wind is now widely accepted as the central focus of the UK's plans to increase the amount of energy it produces from renewable sources over the next decade. The creation of a project pipeline of nearly 50GW by The Crown Estate has put the country at the forefront of the world market and is attracting key players to set up design and manufacturing facilities in the UK to serve the sector.

There are still major challenges ahead. The offshore wind industry is not yet mature in either technology or supply chain and, if it is to play a significant, long-term role in the low carbon future of the UK, it must improve costs. A world-class offshore wind supply chain may develop in the UK, but investment is needed in the short term to realise the long term benefits.

This study looks at the whole-life costs of offshore wind projects forecast to be built up to 2022 with a focus on how these costs will change over four-yearly periods. The first period, 2011-14, is associated with early learning and the build out of Round 2 developments; 2015-18 sees volume starting to be delivered though early Round 3 and Scottish Territorial Waters (STW) sites; and 2019-22 looks at the middle phase of STW and Round 3 activities.

Having explored capital and operational costs, the report then sets these costs in the context of the wider benefits that the offshore wind industry can be expected to provide for the UK.

Forecasts of costs to 2022

The focus of the study is an analysis of lifetime costs based on technical considerations, though sensitivity to market dynamics and external factors such as exchange rate variation are also considered. In order to forecast the lifetime cost of offshore wind, overall cost is broken down into five key elements. The cost of each of these elements has been forecast for 67 discrete projects that are anticipated to be installed in UK waters between now and 2022. For each project, specific site parameters such as water depth, mean wind speed and export cable length are considered alongside turbine rating, rotor diameter and foundation and electrical transmission technology.

Trends in capital expenditure (CAPEX), operational expenditure (OPEX) and energy generation due to these parameters and other relevant considerations were peer reviewed by a cross-section of industry, facilitated by RenewableUK. Results of the analysis and conclusions drawn were also peer reviewed, giving further integrity to the following conclusions.

Based on a buoyant market, with a cumulative installation in the UK of more than 30GW by the end of 2022 and an anticipation of growth extending beyond the next decade, we forecast the following:

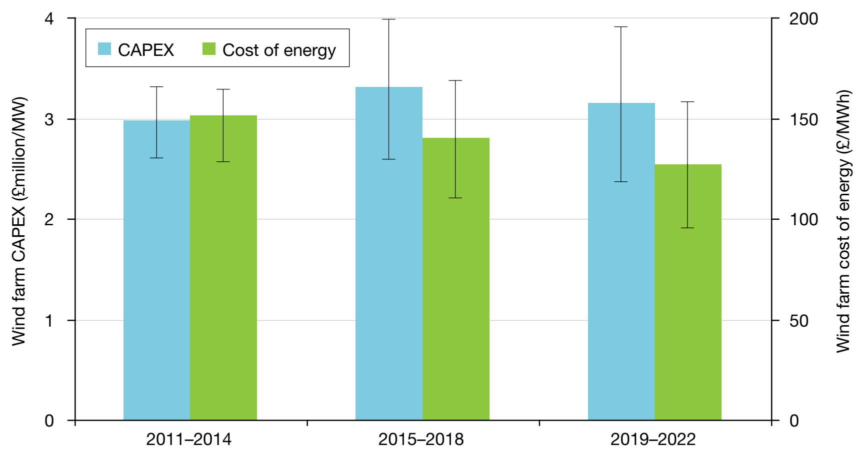
- UK offshore wind farm CAPEX per MW of installed capacity will continue to increase over the next decade as projects are located further offshore and in deeper water. Technology development and industry learning will have a significant impact in offsetting the costs caused by these conditions so that by the third period costs will be improving, despite projects being located in increasingly challenging locations.
- OPEX per MW installed will decrease significantly over the lifetime of wind farms installed in the next decade, primarily due to the use of larger and more reliable turbines.
- The move to sites further offshore will give developers access to improved wind resources. Combined with increases in turbine size, this will increase the energy yield per MW installed by more than a fifth over the period considered.

"Over the next decade, the cost of energy is likely to fall by 15%. With strong competition and innovation, combined with favourable movements in steel prices and exchange rates, costs could fall by 33% to approximately £100/MWh."

- The most important measure for the offshore wind industry is whole-life cost of energy, which is dependent on CAPEX, OPEX and the energy yield from wind farms. This cost of energy from UK offshore wind projects is expected to be driven down by more than 15% in real terms between 2011 and 2022, despite the increase in costs due to working in harsher conditions on later projects. Comparing the cost of energy improvement over the three periods while removing the impact of working in harsher conditions gives an improvement of more than 20%.
- A range of other factors beyond those relating to site conditions and the choice of technology can also affect prices. These include competition, innovation, exchange rates and steel prices. Opportunities exist for cost improvements of more than 15% between 2011 and 2022, with strong competition and innovation able to reduce the cost of energy by a further £20 per MWh. Favourable conditions across all four factors could see costs fall to around £100 per MWh (a 33% reduction). However, this cost reduction could be lost altogether if a lack of Government ambition fails to stimulate competition and innovation, or exchange rates and steel prices move the wrong way.

- In addition, assuming a buoyant market in the UK, elsewhere in the EU and beyond, plus the availability of sites similar to those that will be constructed during the third period, preliminary analysis of technology and process improvements available suggests that a reduction in the cost of energy of a further 15% over the 12 years after 2022 is well within the capability of the industry. This improvement would be in line with the historical trend in cost of energy reduction achieved during the growth of the global wind industry over the last two decades.

Figure 1: Forecast wind farm CAPEX and cost of energy for UK projects installed in each period with error bars reflecting market and economic uncertainties (relating to CAPEX only)



Costs and benefits

It is forecast that the installation of offshore wind farms between 2011 and 2022 will:

- Avoid nearly 800 million tonnes of carbon dioxide emissions by fossil fuel energy generation in the UK.
- Add approximately £60 billion to the UK economy through development, manufacture and installation activities.
- Create a further £20 billion in UK gross value added (GVA) in operation and maintenance over the lifetime of offshore wind farms built during this period.
- Provide approximately £14 billion in Treasury revenue through taxation and The Crown Estate licensing arrangements.
- Trigger £3 billion of investment in the UK supply chain that will support more than 45,000 long-term jobs.

1. Methodology

1.1 Introduction

This report is based upon forecasts of three measures of project cost: CAPEX; OPEX; and cost of energy.

Both CAPEX and OPEX are "real" costs insofar as they represent the expenditure on goods or services. Cost of energy is defined here as the total revenue required per MWh to provide a given rate of return for an investor based on the time-offset CAPEX, OPEX and energy generated by the wind farm.

1.2 Capital expenditure (CAPEX)

For the purpose of this report, CAPEX is divided into five elements: project; turbine; foundations; electrical; and installation. These elements account for varying proportions of the overall spend depending on project parameters. Spend on these elements is typically spread over at least five years prior to the first generation of electricity by an offshore wind farm.

Project
Included within this element are all of the development and consenting processes that are required up to the point of financial close or the placing of firm orders for wind farm construction. It covers activities such as environmental and wildlife surveys, engineering studies, and planning and legal activities.

This element also includes the project management of all other activities up to the first generation of electricity, as well as other administrative activities and professional services such as accountancy and legal advice.

For projects being built in 2011, project costs are forecast to account for around 4% of total CAPEX. Economies of scale are expected to mean that these costs will become proportionally smaller as projects grow in size, so that by 2022 they are anticipated to be less than 3% of costs.

Turbine
This element covers the manufacture and assembly of the turbine components, including the nacelle and its sub-systems, the blades and hub, the tower and the turbine electrical systems to the point of connection to the array cables. This cost is assumed to be ex-works so does not include any cost for transporting the turbine to a construction port or any installation costs.

For projects in 2011, this element is forecast to account for around 40% of total CAPEX, increasing to nearly 44% by 2022.

Foundation
Comprising the manufacture of the foundations of the turbines, this element does not include transportation or installation costs. Time-scales for contracting and manufacture are assumed to be similar to those of the turbines.

For projects in 2011, the foundation is forecast to account for around 19% of total CAPEX, increasing to 22% by 2022.

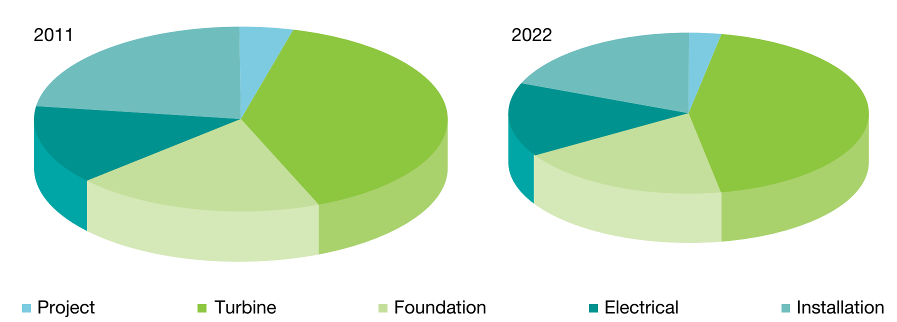
Electrical
This element covers offshore substations and their foundations, array cables, export cables linking the wind farm to the shore, and the onshore electrical systems that include the onshore cables and substation at the point of connection to the transmission system.

In the past, the cost of this element was met entirely by the wind farm developer, but the introduction of the Offshore Transmission Network Owner (OFTO) regime means that the wind farm and the electrical transmission systems must now be owned separately ("unbundled").

For owners of existing wind farms, this has meant they have needed to transfer the offshore and onshore substations and the export cable systems into the ownership of OFTOs. For future projects, all of the electrical systems, with the exceptions of the array cables, will either be installed by an OFTO, or by the developer who will then transfer the asset on completion. In all cases, the OFTO will then be paid a fee by the National Grid, which recovers costs through transmission charges to the wind farm owner.

This arrangement means that, for the wind farm owner, these costs will be elements of OPEX rather than CAPEX. It has been decided, however, that these electrical costs will remain as CAPEX in this study, for the sake of consistency with the conventional understanding of the split between CAPEX and OPEX.

Figure 2: Breakdown of CAPEX into key elements (based on forecast 2011 and 2022 project costs)



Again, the time scales for contracting and constructing the electrical system are similar to those of the turbines and foundations. For projects in 2011, this element is forecast to account for around 14% of total CAPEX, with only a slight increase forecast by 2022.

Installation
This element includes the transportation of components to a construction port, onshore preparation and installation.

Today, foundations, substations and cables are usually installed in the year before the turbines, although strategies in the future are likely to evolve. For projects in 2011, this element is forecast to account for around 23% of total CAPEX, reducing to less than 18% by 2022.

As the discounted decommissioning costs for offshore wind farms at the end of their 20 to 25 year operational life are relatively low, and partly offset by opportunities to reuse and recycle much of the hardware, they are not considered further here.

1.3 Operational expenditure (OPEX)

Unlike sources of conventional generation, offshore wind benefits from having no primary fuel costs, but operational costs are a significant element of whole-life cost of energy.

The largest contribution to OPEX are costs relating to the operation and maintenance of the wind farms, including condition monitoring, preventative and reactive maintenance, health and safety inspections and monitoring of the local environmental impact of the wind farm. Direct costs include engineering and technician staff salaries, vessel charter costs and the procurement of spare components, electrical and mechanical tools and cleaning and personal protective equipment.

Other costs include the building rent for the wind farm control building and component warehousing, port berthing fees, insurance, legal and accountancy fees, bank charges, depreciation, audit fees and sea bed lease fees charged by The Crown Estate.

As discussed above, the cost of constructing the electrical systems has been included in the CAPEX, whereas it would be expected to be included in the OPEX of wind farm owners operating under the OFTO regime.

1.4 Cost of energy

The cost of energy is defined here as the total revenue required per MWh of energy, such that the wind farm owner secures a 10% return on CAPEX and OPEX paid from its balance sheet over the project's lifetime. Various models for financing offshore wind are likely to be used over the next decade, but this simple model gives revenues that are representative of those needed to facilitate decisions to allow progress to construction. This revenue may be secured through a combination of electricity price and market support mechanisms. This rate of return is slightly lower than that assumed by Redpoint Energy/Trilemma UK in *Electricity Market Reform: Analysis of policy option* for the Department of Energy and Climate Change (DECC) in 2010.[2]

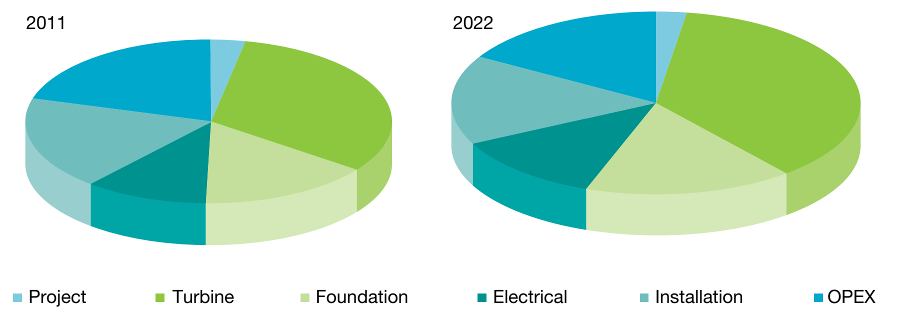
No inflators have been used on either the costs or revenues of wind farm projects. The cost of energy used in this study is therefore not an absolute forecast of expected levels, but an indicator of the impact of physical and technical parameters on whole-life costs over the next decade or so.

The evolution of the combined contribution of CAPEX and OPEX to whole-life cost of energy between wind farms installed in 2011 and 2022 is shown below.

1.5 Forecasting wind farm costs

Wind farm CAPEX, OPEX and cost of energy are influenced by a range of factors, both specific to particular wind farm locations (such as the water depth, wind and wave conditions, and distance to port facilities and point of grid connection) and to the technology used in the wind farm, such as the wind turbine power rating and rotor diameter. In order to model the combined impact of these different factors, we have established the impact of each factor on CAPEX, OPEX and energy output/efficiency of specific elements of the wind farm, then combined these impacts

Figure 3: Breakdown of cost of energy into key elements (based on forecast costs for projects to be installed in 2011 and 2022)



through our knowledge of the cost breakdown of offshore wind farms.

The trends that we developed were then reviewed in two industry workshops organised by RenewableUK, with representatives from offshore wind farm developers, turbine manufacturers, vessel owners and engineering consultancies. For details of the consultation process undertaken for this report, see Appendix A.

As an example of these trends, Figure 4 shows the impact of mean wind speed on wind farm CAPEX, OPEX and cost of energy. The trend is developed while keeping all the other factors that affect the cost of a wind farm unchanged, and equal to those expected for a typical Round 3 project.

Both CAPEX and OPEX increase slightly with increasing mean wind speed as wind farm structures are designed to handle greater loads, there is greater wear-and-tear on the hardware during operation and delays to operational activities. The cost of energy drops, however, as the additional energy generated due to the greater wind resource outweighs these additional costs.

Figure 5 considers the impact of increasing turbine rating on costs. Again, the trend is developed while keeping all other factors fixed to that of a typical Round 3 project. The rotor diameter increases along with the turbine rating, moving from the typical specific ratings (rated power / rotor swept area, W/m²) seen today towards relatively larger rotors that we consider optimum for large turbines in the future. We acknowledge that this move to an optimum diameter will take some time. The trend towards relatively larger rotor diameters is evidenced by announcements from, for example, Alstom, Siemens and Vestas in early 2011.

The trends generated show a reduction in the CAPEX per MW between 4MW to 7MW where the increased cost per MW of the turbine is more than offset by savings on the foundation, but then the trend levels off.

A more significant change can be seen in OPEX as the turbine rating increases. It costs less to maintain fewer, larger turbines than smaller machines with the same combined rating, as many activities have only a small associated cost increase when working with larger turbines.

Finally, larger turbines typically have greater hub heights so they operate in higher mean wind speeds. This means more energy is generated than by a turbine with a lower hub height in the same conditions, which also contributes to the reduction in the cost of energy. In this analysis, due to the relatively low wind shear at sea, hub height has been modelled as the minimum required for a given rotor diameter in order to meet current Marine and Coastguard Agency (MCA) requirements.

Figure 4: Impact of mean wind speed at 100m height above LAT on offshore wind farm project CAPEX, OPEX and cost of energy

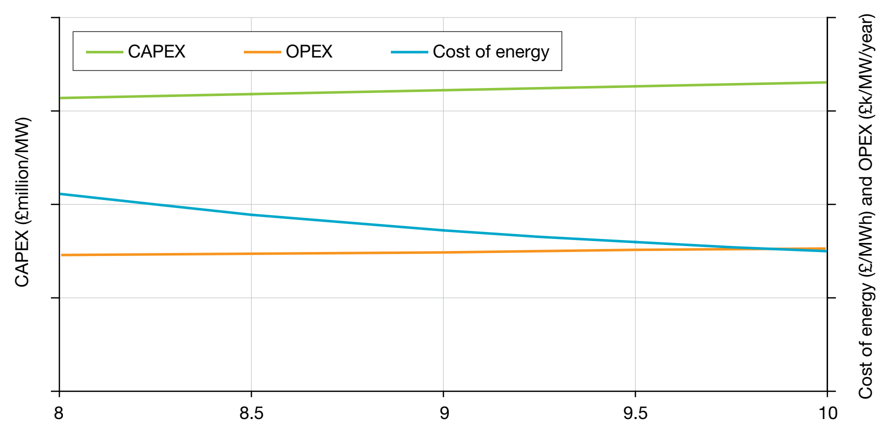
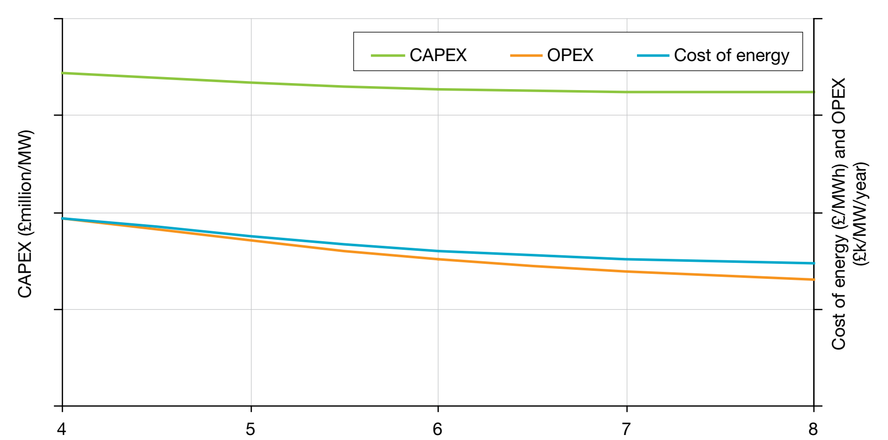


Figure 5: Impact of turbine rating on wind farm project CAPEX, OPEX and cost of energy, taking into account increased optimisation of rotor diameter for larger turbines



2. Review of Costs to Date

2.1 Quoted costs

A key purpose of this report is to forecast the cost of future offshore wind projects. In doing so, it is important to look at the past and understand the trends and factors that have shaped costs to date.

Learning curves and engineering assessments have been used in different reports to predict decreasing capital costs, but these forecasts have subsequently been contradicted by the reality of rising costs, especially in the last three years.

As can be seen in Figure 6, between 2005 and 2010 the average annual CAPEX quoted by project developers has more than doubled.

There are significant uncertainties in these quoted figures, leading to a degree of scatter around the trend line. For example, they have been quoted by a range of developers who may each be referring to a different scope, or using a different accounting system, so it is not possible to know whether they are directly comparable. In some cases, the quoted figures may also hide overspend that supply chain companies have absorbed. This overspend certainly occurred on earlier projects where a lack of application-specific experience meant companies did not accurately estimate the cost of their activities.

2.2 Standardising costs

A further problem with using these quoted costs directly is that the commercial and economic conditions in which the wind farms were built have changed over the years, with different market conditions affecting the prices of services, materials and finished goods.

In order to better understand these conditions, we have used the trends that have been developed for this study to derive an estimated cost for each project based on the wind farm parameters, but using 2010 costs.

As can be seen in Figure 7, there are sizable differences between the quoted and estimated CAPEX, although the difference decreases for later years. Key factors in explaining this discrepancy are the impacts of inflation, exchange rates and steel price variation during the period.

The majority of the equipment and services used in UK wind farms to date have been bought from either the eurozone or from countries with currencies pegged to the Euro. Between 2005 and 2010, the exchange rate between the Euro and sterling varied by almost a quarter, which increased costs significantly for UK offshore wind farm developers who continued to sell energy in pounds. Similarly, steel accounts for an estimated 12% of CAPEX and has also seen similar price variations over the period. Inflation also means that the costs of later projects can be expected to be proportionally higher than those of earlier ones.

The upper green bars in Figure 8 show the effect of compensating for the impact of these three factors. The impact of inflation has been calculated using the Consumer Price Index as published by the Office for National Statistics.[3] Exchange rate adjustments have been calculated using data from the Bank of England.[4] The impact of changing steel cost has

Figure 6: Average offshore wind farm CAPEX quoted by developers

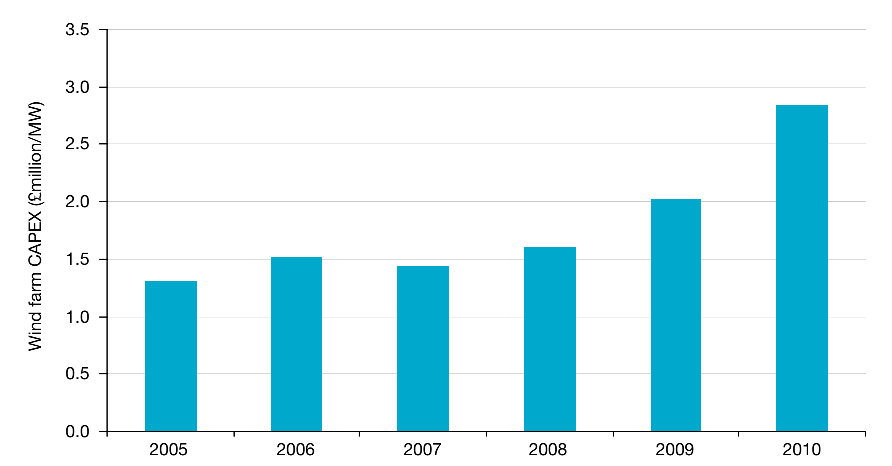
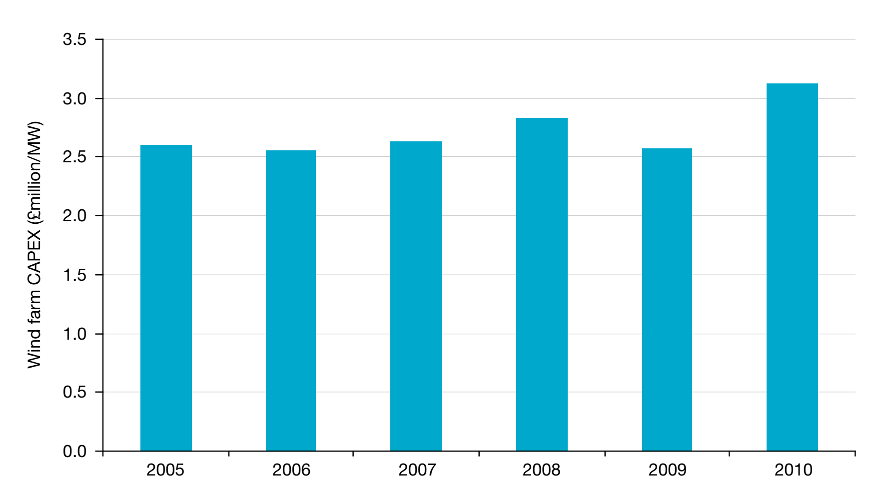


Figure 7: Estimated average annual CAPEX of completed UK wind farms based on 2010 costs



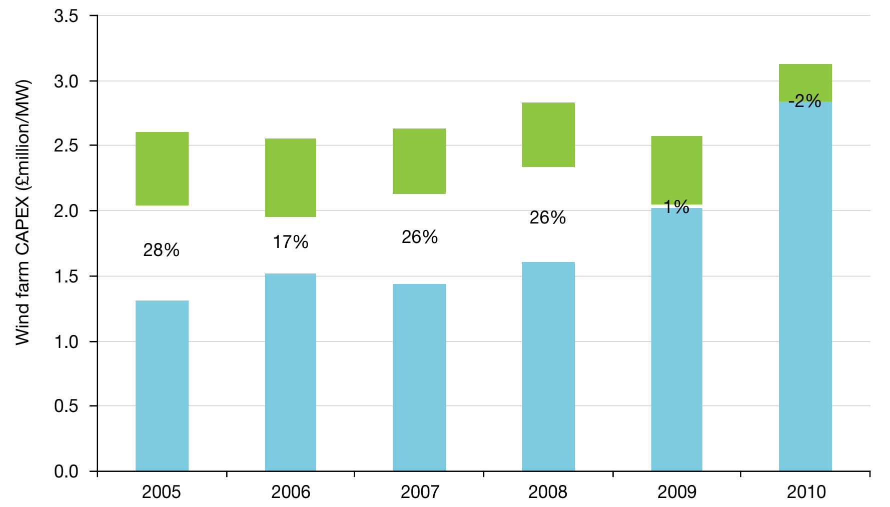
been calculated using the average price of northern European flat product.[5] The impact of these factors has been offset because most CAPEX is spread over the years before installation.

Despite compensating for these key external factors, there is still a gap between these estimated and compensated costs, and the quoted costs (as shown in Figure 8).

In RenewableUK's *Charting the Right Course*, a number of market events and conditions were highlighted that were believed to be factors that have affected the costs of building offshore wind farms. These included strong competition for resources from competing industries such as onshore wind and oil and gas, lack of competition in the supply of offshore wind turbines and limited availability of suitable installation vessels.

In addition, a number of contractors supplying to early projects underpriced work due to the pressures of delivering to an embryonic sector with marginal economics and a lack of understanding of the challenges and logistics involved. This resulted in a number of businesses failing and a lack of competition in various areas of the supply chain. The introduction of banding in the Renewables Obligation eased this situation, making it possible for the supply chain to deliver pioneering work at reasonable levels of profit, compared with the risks it was being asked to take. In its 2007 energy white paper, *Meeting the energy challenge*, the Government announced proposals to increase the number of Renewables Obligation Certificates (ROCs) that offshore wind would receive by 50% for projects that became operational after July 2006.[6] In its 2007 report *UK Offshore Wind: moving up a gear*, RenewableUK noted that most developers were already reporting supply chain cost increases for projects planned for installation from 2009 that were believed to be in response to the anticipated increase in revenue.[7] Along with this distribution of reasonable profits within the supply chain, we have seen significant investments by a range of players, from turbine manufacturers to suppliers of installation services, that are needed to deliver the capacity increases required.

Figure 8: Gap between quoted costs and estimated and compensated CAPEX based on 2010 costs



It is not possible to precisely measure the impact of each of these factors, but the combined impact is likely to be about 20 to 30%, accounting for the gap (shown in Figure 8). In 2009 and 2010 there is a close correlation between the estimated and compensated costs and the quoted costs, indicating that the trends are more accurately including the impact of these factors. Furthermore, greater investment in capacity, increasing competition and longer industry experience means it is expected that these remaining factors are unlikely to have the same dramatic impact on costs as they have had in the past. For this reason, we have not included changes to these factors from 2010 levels in our forecasts.

2.3 Conclusions

Previous reports on offshore wind costs have cited market and financial factors as key causes for the increase in CAPEX. As a result, it has been assumed that, with a stable economic environment and a more confident and innovative supply chain, this trend of rising CAPEX would be reversed.

Even when these factors are removed, by estimating project costs based on 2010 conditions, we still see a significant trend of increasing CAPEX that is due to the specific characteristics of the wind farms constructed.

For example, while the Kentish Flats project was built in 2005 in average water depths of around five metres, its near neighbour Thanet was installed in water depths of up to 25 metres in 2010. An example of the impact of such a difference is seen in foundation and installation costs.

The fact that most future UK projects will be built in even deeper waters and considerably further offshore than either of these projects means it is unrealistic to expect the trend of rising capital costs to be reversed, or to plateau, in the short term.

By constructing wind farms on such sites, better wind resources can be accessed, which will increase energy generation and in turn decrease the cost of energy from these projects, as shown in Section 3.

3. Forecast of costs to 2020

3.1 Market forecast

This report bases its market forecast on the one used in *Towards Round 3: Progress in Building the Offshore Wind Supply Chain*, prepared for The Crown Estate in February 2011.[8] We anticipate that, by the end of 2022, the UK will have an installed offshore wind capacity of almost 32GW, of which more than 30GW will be built between 2011 and 2022. This forecast is based on our understanding of the status of individual projects and the commercial environment in which development and supply chain communities are working.

While this report is focused on UK costs, the available market for much of the supply chain is the whole of the EU so this wider market also needs to be considered in assessing the pace of technology and process development. Using the same market forecast, it is anticipated that, by the end of 2022, there will be a total European installed capacity of more than 60GW.

Figure 9: Forecast of European offshore wind capacity installed in each period (cumulative lines include capacity installed before 2011)

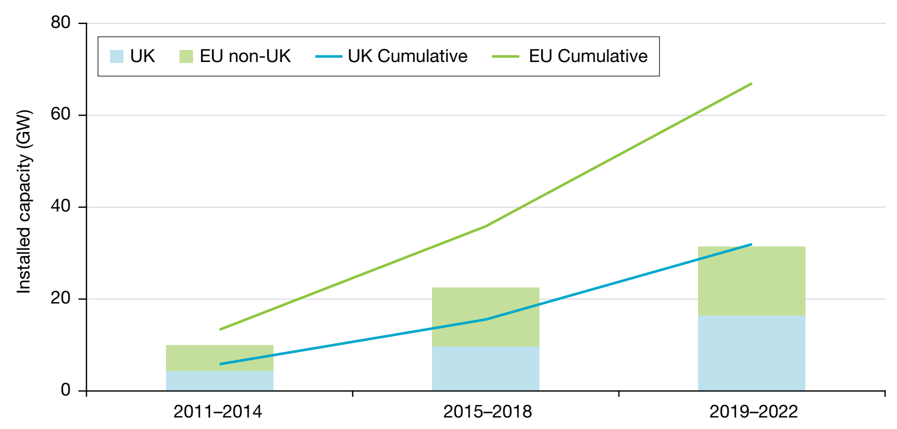
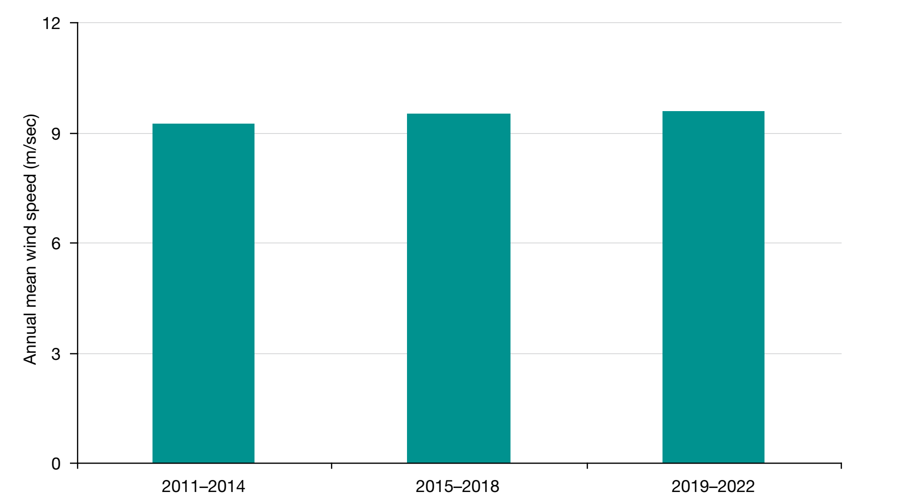


Figure 10: Average annual mean wind speed at 100m above LAT for UK projects installed in each period



3.2 Future trends in wind farm characteristics

The CAPEX and OPEX trends developed for this report are based on a range of wind farm and technology characteristics. These are summarised below for each period.

Wind farm characteristics

The wind speed, water depth, tidal range and wave height have been established for each project and zone using industry databases, government data, industry knowledge and discussion with project developers. The distance to shore for connection to the onshore network has been calculated using the National Grid ODIS reports.[9]

Particularly large zones have been split into projects to reflect the considerable variation in environmental conditions across the zone and the phased construction over a number of years. This means that, for the UK, installation of a total of 33 projects and zones is forecast between 2011 and 2022, which are broken down into 67 projects in this analysis.

Wind speed

The key benefit from moving projects further from shore is an increase in mean wind speed. Figure 10 shows the change in mean wind speed at 100m above lowest astronomical tide (LAT) for projects to be installed in each period. The increase in the average wind speed in the second period is caused by the start of the first projects in Scottish Territorial Waters (STW) and in Round 3 zones. Wind speeds have been derived from the UK Marine Renewable Energy Resources Atlas. Corrections are applied for projects to take account of improvements now available through more detailed analysis.[10/11] The dominant impact of mean wind speed is on energy produced. However, in this analysis the impact of mean wind speed on CAPEX and OPEX, especially for the turbine, is also considered as shown in Figure 4.

Water depth
The water depth for installed projects increases substantially over time. It should be noted that, while there is a strong general upward trend, the average depths mask considerable variation in the water depth of projects during each period.

The second period sees the start of project installations in Scottish Terrotorial waters, which are typically located in deeper water than projects elsewhere in the UK. It is expected that, for economic reasons, Round 3 developers will tend to focus on the shallower areas of their zones during the second period before moving into the deeper water sites in the third period.

The impact of water depth on foundation and installation costs is modelled here. It is a key driver in the choice of foundation type.

Export cable length
Figure 12 shows a mid-decade peak in the export cable length. Again, this is a combination of the start of the installation of Round 3 projects and projects in STW. For a number of projects off the west coast of Scotland, the remote location of these farms means they are expected to need relatively long subsea connections in order to reach mainland connection sites, despite being relatively close to shore.

The effect of export cable length on cable supply, installation and operational costs is modelled, along with the impact on transmission system design, with knock on impact on substation costs and transmission system losses.

Figure 11: wind farm water depth for UK projects installed in each period

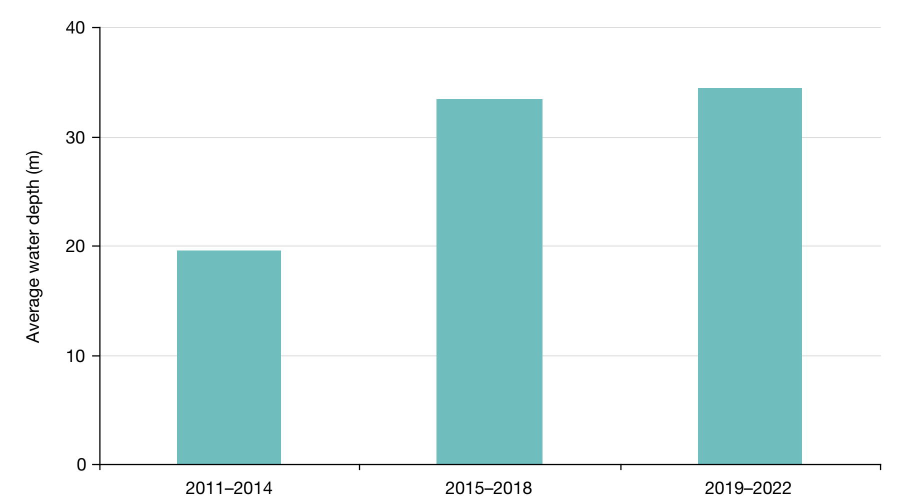
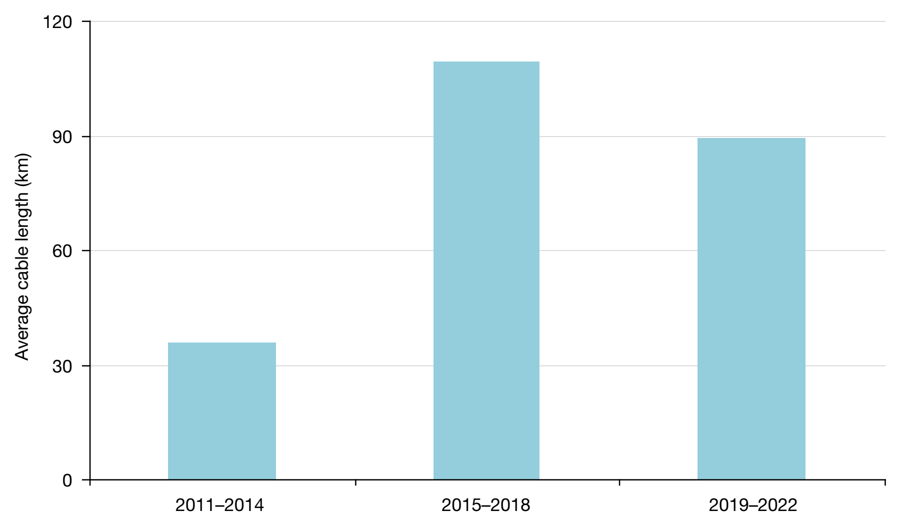


Figure 12: Average export cable length for UK projects installed in each period



3.3 Technology characteristics

In addition to changes in wind farm characteristics, there will be significant changes in technology that will impact upon the costs of wind farms in the next decade.

Turbine rating
Figure 13 shows the anticipated change in the average rating of turbines over time and is based on both public information and technology forecasts. It is expected that, until 2014, the average rated power will be broadly similar to that of today, with the market continuing to be dominated by Siemens 3.6MW and Vestas 3MW turbines, and the gradual growth of market share for 5MW to 6MW turbines.

By 2015, however, it is anticipated that more turbines with ratings of 5MW to 7MW will be installed in commercial projects. This is expected to cause a jump in the average rating. The average turbine size will continue to increase as still larger turbines are introduced to the market and the sales cycles of today's state-of-the-art turbines come to an end.

Alongside the increase in the turbine rating, we have incorporated a significant increase in the rotor diameter over time, as discussed in Section 1.5, which also considers the impact of turbine size on CAPEX, OPEX and the cost of energy.

Figure 13: Average turbine rating for UK projects installed in each period

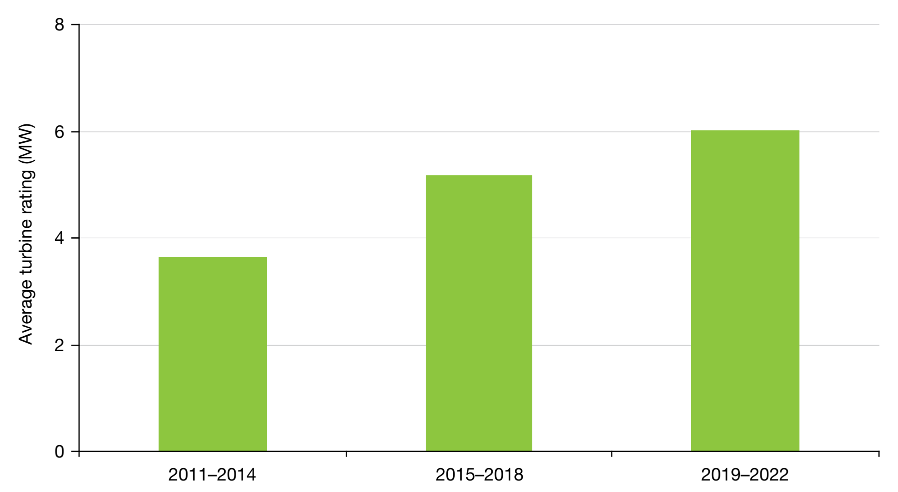
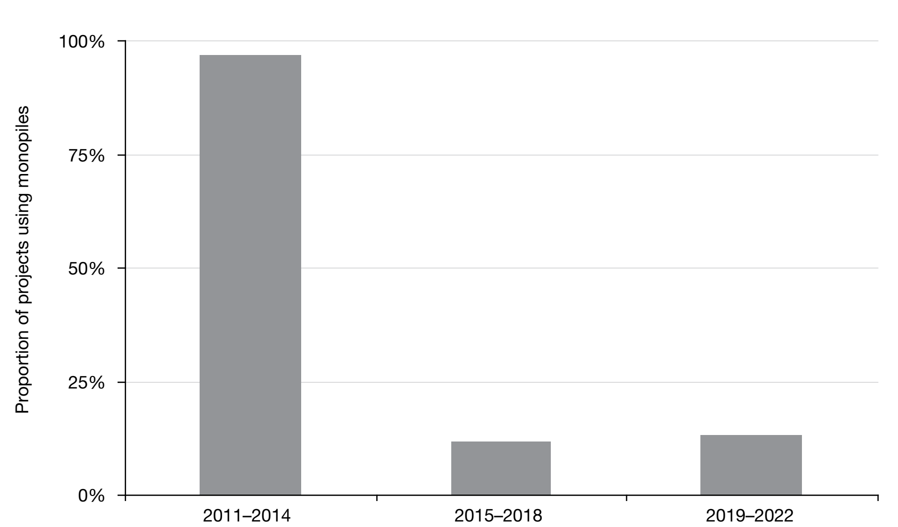


Figure 14: Proportion of UK projects installed in each period using monopiles



Foundation type
The consequence of the increasing water depth seen in Figure 11 and the increase in turbine size seen in Figure 13, is the need for a new generation of foundation designs. To date, foundations have typically been cylindrical, steel monopiles but these structures become uneconomical once larger turbines are used in deeper water. This is due to the diameter and wall thickness that is required in order to provide resistance to the larger loads imposed on them and to provide the required stiffness to ensure a satisfactory structural dynamic response. For such projects, other designs such as jackets (space-frames), tripile and concrete gravity-based foundations are more likely to be used. The transition between monopile and other foundation designs is assessed here using a model of foundation costs incorporating material mass and cost, manufacturing and installation cost as well as the availability of suitable installation tooling.

As can be seen in Figure 14, the combined impact of larger turbines and deeper water means that from the second period it is expected that monopiles will only be used in a limited number of projects. We do not anticipate a need for floating turbine support structures in the delivery of any currently planned commercial offshore wind projects in UK waters.

High voltage transmission system type
All UK projects built to date have been located relatively close to shore and have either been linked directly to an onshore substation or connected via an offshore substation to shore using alternating current (AC) export cable.

High voltage direct current (HVDC) systems currently provide a more cost-effective solution for export connections above approximately 80km, so will be used in many upcoming projects. As can be seen in Figure 15, in the third period approximately half of UK projects will use HVDC technology.

3.4 Learning rates

Learning rates are used to reflect the underlying impact of improvements in designs and processes within industries as they carry out broadly repeated activities, independent of the effects of short-term market dynamics.

Learning rates are usually expressed as the percentage of cost reduction for each doubling of cumulative supply. For offshore wind, reductions may be due to the standardisation of key components, improvements in manufacturing technology and the introduction of new turbine access methods, enabling more timely repairs to turbines and improved reliability.

There has been debate about the extent to which learning rates based on installed capacity are applicable to offshore wind. Previous industry reports have used relatively high learning rates for CAPEX, which have led to forecasts of decreasing CAPEX levels that have later been proved inaccurate. Another important consideration is that offshore wind benefits from the development of technologies and skills in other industries, many of which are much more mature than offshore wind and hence have longer doubling periods associated with them. Onshore wind is in this category, as we anticipate a little over two doublings of installed capacity in the period to 2022 compared with four for offshore wind.

In its report, *Offshore Wind Power: Big Challenge, Big Opportunity*, the Carbon Trust highlighted the range of industries from which offshore wind will adapt existing technologies and the learning rates for each of these industries. This included onshore wind, construction and HVDC electricity distribution with learning rates between 5% and 32%.[12] Our analysis suggests that the learning rate for the cost of energy in onshore wind over the last two decades is around 10%.

In this study, much of the benefit of learning on wind turbines is connected with the introduction of larger machines, with significant associated enabling technology development. The trend for larger turbines is already modelled in the analysis, so it would be inappropriate to apply significant additional learning to this aspect of turbine cost. Other aspects of turbine cost and elements of the wind farm, including balance of plant and installation, have not benefited from such detailed examination here. For these elements a learning rate should be applied to costs to give a realistic forecast.

Discussion with the industry has determined that a learning rate of 3% is appropriate to apply to all elements to account for the additional learning beyond that which is implied in the cost trends.

Figure 15: Proportion of UK projects installed in each period using HVDC electrical systems

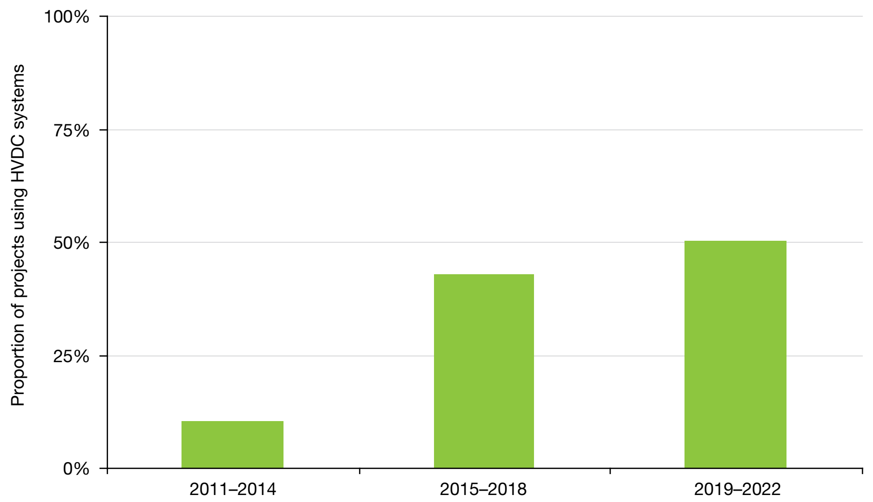
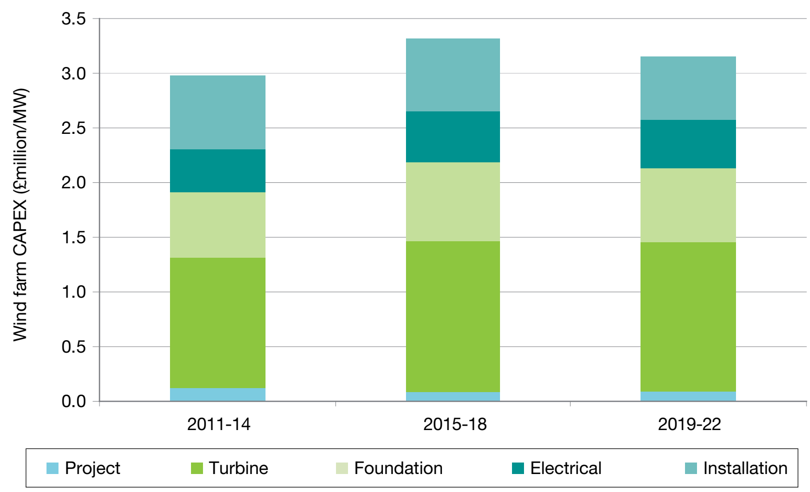


Figure 16: Forecast CAPEX for wind farms installed in each period



3.5 Future costs

Figure 16 shows the predicted trend for CAPEX between 2011 and 2022, with an overall increase in costs over the three periods and a peak in the middle of the decade.

If we break down the costs into elements, the cost per MW of turbines increases in the second period due to the introduction of larger turbines. As was shown in Figure 5, all other things being equal, increasing the size of turbines actually reduces the total wind farm CAPEX per MW due to savings elsewhere in the wind farm.

The move to deeper water drives an increase of around a fifth in foundation costs in the second period. The extra costs of projects being installed further offshore causes a similar jump in costs for electrical systems. By the third period, the advantages of learning starts to dominate over the additional costs of working in more difficult conditions and CAPEX per MW starts to fall.

The cost of installation falls slightly in the second period and then again in the last period. The fact that larger foundations and turbines are more expensive to handle is compensated by the fact that fewer units need to be installed per MW, which reduces the number of vessel moves and installation operations required.

Figure 17 shows the forecast trend in OPEX for wind farms installed in each period. The trend shows a reduction of almost a quarter between 2011 and 2022 despite the significant increases in the distances of projects from shore. The distance of a wind farm from shore affects the OPEX of a wind farm because, once a project reaches a certain distance from shore, the transit time means it becomes inefficient to send technicians out by boat from the mainland. In this case, offshore hotel solutions are expected to be used along with a fleet of daughter vessels. This will have an associated increase in cost compared with near shore solutions.

This upward pressure on OPEX is more than compensated, however, by anticipated savings due to the use of larger and more reliable turbines. Many maintenance activities are at an almost constant cost per unit, independent of turbine size. Others do increase in cost for larger turbines but few scale as quickly as the turbine rating. As CAPEX relating to grid connection has been incorporated into Figure 16, OPEX relating to grid connection is for maintenance of the transmission assets rather than fees payable for use of the assets. Note that the OPEX stated is an undiscounted average for the whole of the lifetime of the wind farms installed in the given period. We anticipate that, especially with the introduction of the next generation of larger turbines in the period 2015-18, OPEX in the early years of these wind farms may exceed OPEX today. Over the lifetime of the wind farm, however, assuming a buoyant ongoing market extending beyond the period forecast in Section 3.1, we anticipate significant savings as improved reliability and learning impact ongoing costs.

A key benefit of installing projects in the harsher conditions of STW and Round 3 zones is access to the increased mean wind speeds associated with such locations. Under UK offshore wind conditions, a 1% increase in mean wind speed enables more than a 1% increase in energy generation. One measure of this energy generation is capacity factor, which is the ratio of energy generated to the theoretical energy generation if all wind turbines ran at rated power, at all times. Larger turbines generally have an increased hub height which also enables access to higher winds. This effect is not significant, however, as discussed in Section 1.5. Improved reliability in turn also increases the time available for generation.

Also impacting on capacity factor are wake losses due to interactions between rows of wind turbines in a wind farm and between wind farms located close together. We have considered these effects along with likely improvements in optimising the layout of wind farms. As shown by Figure 18, the impact of these factors is that capacity factor increases by more than a fifth over the three periods.

Figure 17: Forecast undiscounted average annual OPEX for wind farms installed in each period

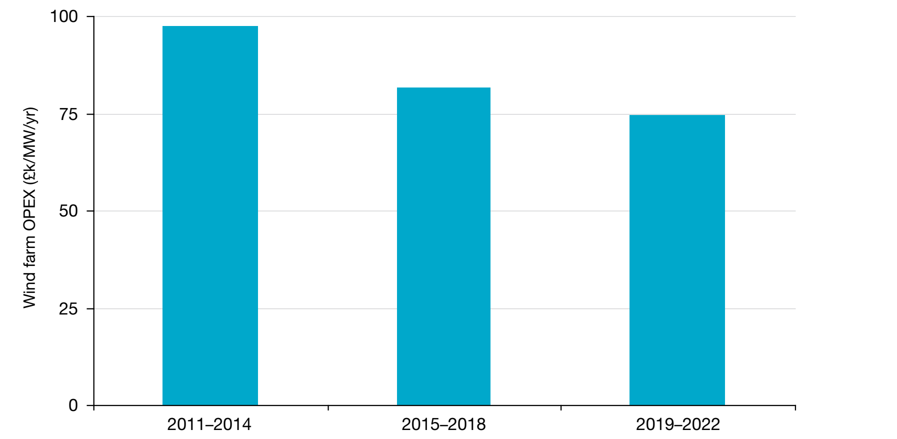
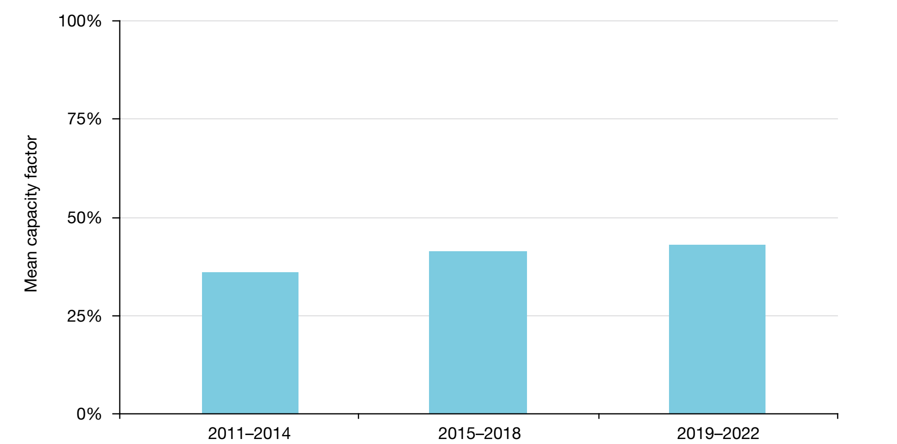


Figure 18: Forecast capacity factor of UK offshore wind farms installed in period based on forecast wind speed, hub height, reliability and wind farm layout



Cost of energy

Figure 19 shows the cost of energy from UK offshore wind farms (as defined in Section 1.4) being driven down by more than 15% in real terms over the three periods. The increase in capacity factor, combined with the reduced OPEX, outweighs the impact of rising CAPEX so that the overall cost of energy is reduced. Comparing the cost of energy improvement over the three periods while removing the impact of working in harsher conditions gives an improvement of over 20%.

This improvement is dependent on the levels of deployment forecast in Section 3.1. A reduction in Government ambition or gaps in activity caused by planning delays would discourage investment by the supply chain and reduce innovation and competition. This could remove the cost reduction altogether. Investment, innovation and competition are essential for creating sustained cost improvements. Opportunities exist for improvements greater than 15%, provided there remains long term Government commitment, industrialisation and strong competition in the supply chain.

In addition, assuming a buoyant market in the UK, elsewhere in the EU and beyond and the availability of sites similar to those that will be constructed during the third period, preliminary analysis of the technology and process improvements available suggests that a reduction in the cost of energy of a further 15% over the 12 years after 2022 is well within the capability of the industry. This improvement would be in line with the historical trend in cost of energy reduction achieved during the growth of the global wind industry over the last two decades.

In order to most clearly demonstrate the impact of the wind farm parameters and technical factors considered, the impact of inflation on either costs or revenue has not been incorporated. The relative costs therefore are of most interest and care should be exercised in comparing absolute costs with costs from other analyses that may have different base assumptions.

3.6 Other influences on costs

As discussed in Section 2, a range of factors beyond those relating to site conditions and choice of technology have affected the CAPEX of offshore wind projects over the last decade.

Figure 19: Forecast wind farm cost of energy for wind farms installed in each period (excluding sensitivity analysis, considered in Section 3.6)

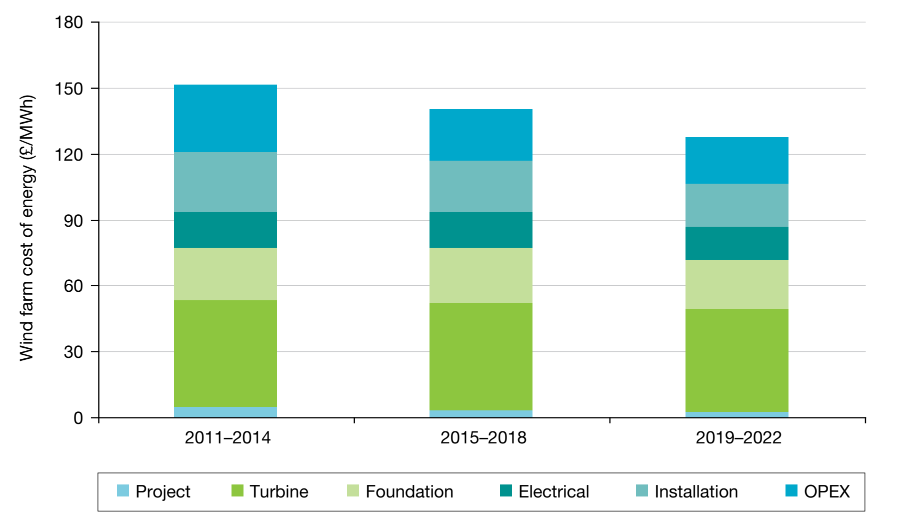
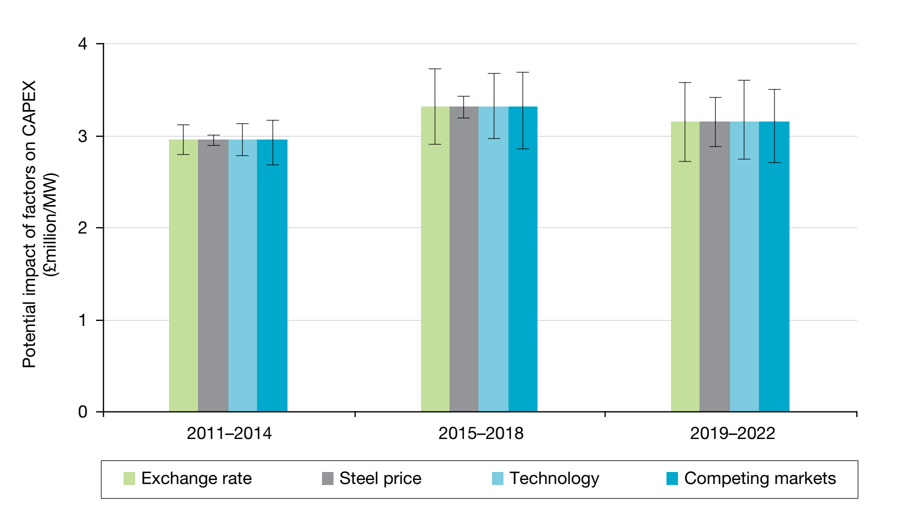


Figure 20: Sensitivity of CAPEX to variation in exchange rates, steel price, technology development and competition



For some factors, such as exchange rates and steel prices, historical data can be used to give an indication of the possible range of impact that could be seen in the future. For others, such as competing markets, the impact can be determined by industry experience and an awareness of expected future developments within the supply chain. In both cases, the scale of the impact is affected by both the proportion of the project value that is affected by a change in factor and the potential for change in that factor, as discussed in more detail in RenewableUK's 2010 report on future CAPEX levels, *Charting the right course*. The impact of inflation has not been considered. While it is likely to have a significant impact on both CAPEX and OPEX over the life time of the offshore wind farms considered, energy prices are also likely to rise, which would increase revenue and offset these cost increases. It is beyond the scope of this report to consider the net impact of such effects.

Error bars should be taken as standard uncertainties so that it is assumed that approximately 70% of values will fall within the limits stated.

Figure 20 shows the forecast levels of CAPEX as derived in Section 3.5 with the potential impact that some of these key factors could have on costs. In the short-term, market dynamics (competition) in the supply of components and services to the sector leads to the biggest single uncertainty but, over time, exchange rates, steel price and the pace of new technology development also have a similar effect.

Exchange rate
Currently, a dominant fraction of offshore wind farm CAPEX is linked to the supply of components and services from the Eurozone or countries with currencies pegged to the euro. Variation in the euro to sterling exchange rate therefore has a significant impact on UK offshore wind farm CAPEX. When forecasting the potential impact of variation in this exchange rate, it has been assumed that the maximum deviation (above or below current levels) over a given number of years into the future is equal to the maximum variation seen in the historical exchange rate over the same number of years to today. The source of the historical exchange rate is the same as used in Section 2.

As the UK content of wind farm CAPEX rises, the impact of exchange rate variations on CAPEX decreases, as only the non-sterling portion of CAPEX is impacted by variations in the exchange rate. As discussed in Section 4, the size of the UK's offshore wind market is acting as an incentive to the industry to set up facilities in the country. Here, we assume that almost 70% of UK orders could be captured by the UK by 2022 with a gross value added (GVA) of 40%. Finally, in order to model wind farm contracting more realistically, the impact of the exchange rate on CAPEX has been derived using a forecast a number of years ahead of installation.

Steel price
The process for deriving the impact of steel price variations on CAPEX is in line with that for exchange rate variations described above. As above also, the impact of variations in the steel price is significantly less than the variation itself as, on average, steel accounts for only around 12% of CAPEX.

Technology development
As discussed in Section 3.4, some improvements in CAPEX have been modelled directly through the adoption of larger wind turbines while other improvements have been modelled using an assumed 3% learning rate.

Such a learning rate depends on investment within the supply chain and a steady flow of projects being consented and financed. A market that experiences a series of peaks of activity separated by little investment is unlikely to deliver such levels of cost improvement. On the other hand, based on the size of the market and the significant potential for cost improvements, a higher learning rate is attainable given a buoyant market, strong, long-term supply chain confidence and investment in design and process improvement in an environment in which a sustainable number of companies compete to win orders. Given the interdependencies within the industry, progress is unlikely to be strong in one field but remain slow in another, so it can be assumed that market conditions that promote investment in one sector are likely to be felt across the supply chain. To reflect a low confidence scenario, the learning rate in addition to the impact of turbine size has been removed, while the high confidence scenario sees it doubled.

Competing markets
In *Charting the right course*, considerable importance was rightly placed on the impact that competition in the supply chain for goods and services, from rival markets, would have on the CAPEX of UK offshore wind projects.

The report highlighted that, within the wind turbine supply market, onshore demand still dominates, with offshore wind only representing a few per cent of the global demand. As seen during the last decade, strong demand in the onshore sector could therefore draw resources away from the offshore market and impact prices significantly. The high technical barriers to entering the offshore market have also meant that there have traditionally been a limited number of turbine supply options for developers. This situation is now changing rapidly, as there is clear evidence of a significant number of new players positioning to enter the offshore market, including players such as Alstom, Gamesa, General Electric and Mitsubishi, a number of which have signalled their intent to establish new manufacturing facilities in the UK to serve the market. The eventual establishment of Chinese players in the UK offshore wind market will also likely impact significantly on competition and hence help reduce prices, as we are starting to see in the onshore market.

In terms of balance of plant, we continue to see a significant number of players, whether already in offshore wind or from parallel sectors, investing in new capacity to manufacture, thus increasing competition and leading to downward pressure on prices. The scale of advanced deep water foundation designs and high voltage electricity transmission systems, however, will also limit the number of companies who have the relevant level of expertise and production capacity to deliver and could therefore limit competition. Competing markets such as oil and gas and electrical infrastructure could also divert supply away from offshore wind and increase prices.

The oil and gas industry also has the potential to affect the supply of installation vessels, either through increased activity that could absorb the new capacity being developed or by a reduction in activity, which could see more vessels being made available. Up until 2010 there has only been one purpose built wind turbine installation vessel available. However, since 2010 and the award of Round 3 leases, more than 10 new installation vessels, designed primarily for use in offshore wind, have been delivered or ordered.

This report has used similar methods to *Charting the right course* by combining the potential value that could be affected by market dynamics and forecast volatility of prices for each key element of wind farms to get an overall impact. The volatility has been determined through industry knowledge and discussion with relevant players.

Conclusions
In terms of impact, Figure 20 shows that, while the exchange rate could have a strong impact in the short term up to 2018, the forecast increase in UK content means that its potential impact is stabilised by 2022.

For steel, as a fixed proportion of costs, the impact continues to increase as the potential for variance in steel price increases with each period. Even so, by the final period, the most serious impact is still forecast to be less than 10% of the total wind farm CAPEX.

The importance of technology development progress by a confident supply chain is seen by the fact that, in all three periods, the impact of this factor is equivalent to that of exchange rates. Indeed, the cost improvements achieved in a long-term, high-confidence scenario could even reduce CAPEX back down to below today's levels by the third period.

Competition leads to the biggest single uncertainty in early years, as evidenced by the swings of 20 to 30% in onshore turbine costs over the last decade, much of which can be traced to changes in market dynamics.

As shown in Figure 21, the changes in the levels of CAPEX discussed above impact the cost of energy. We have not investigated the uncertainty of OPEX or looked at the impact of uncertainty in

Figure 21: Impact of CAPEX variation on cost of energy forecast

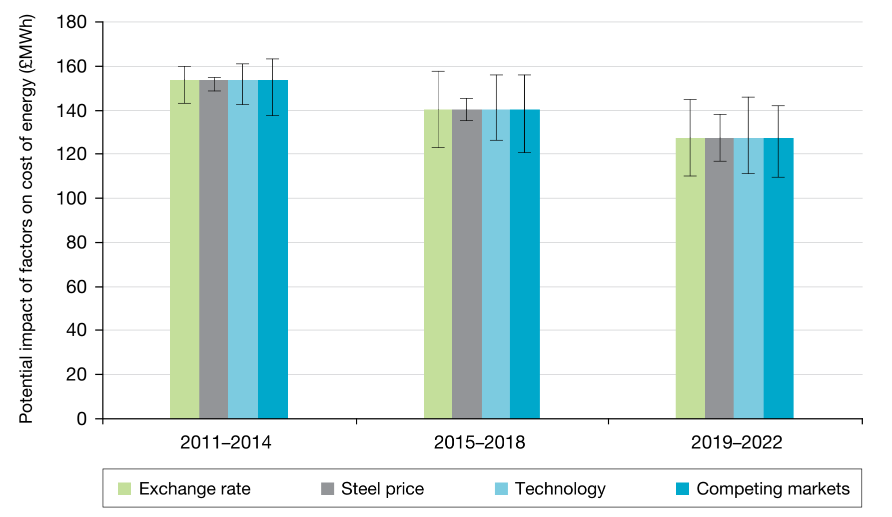
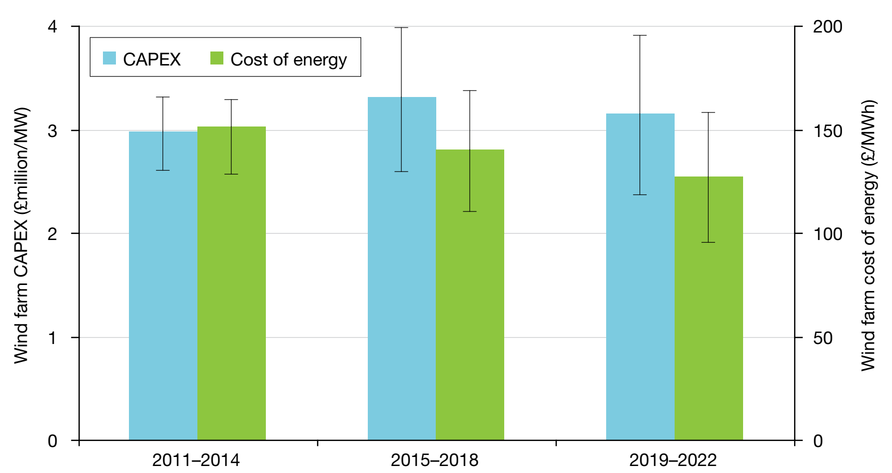


Figure 22: Forecast CAPEX and cost of energy for wind farms installed in each period, also showing uncertainty



wind speed measurement on uncertainty in the cost of energy.

The four sources of uncertainty considered are largely independent, so their aggregate impact may be estimated by calculating a root sum of squares (RSS). This aggregate uncertainty is shown in Figure 22 for both CAPEX and the cost of energy.

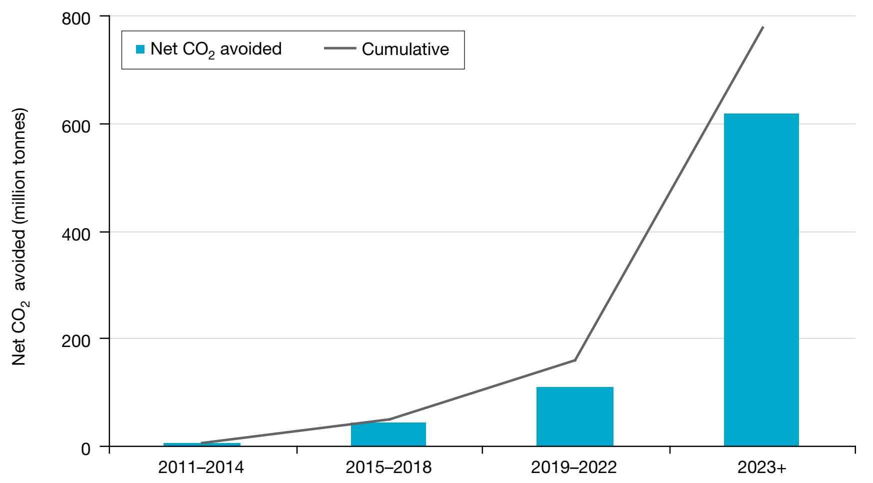
Such an exercise suggests that the average CAPEX in the second period could increase by nearly a third, reaching levels of almost £4 million per MW, excluding the impact of inflation. On the other hand, a positive scenario would see levels of less than £2.5 million per MW suggesting the potential exists for CAPEX to fall well below today's levels.

The analysis suggests that, despite the reductions expected to be generated through larger turbines and increased mean wind speeds, it is possible that the cost of energy remains largely level throughout the periods considered. Favourable conditions could, however, see costs fall to around £100 per MWh.

4. Costs and Benefits to the UK

The UK is established as the market leader in offshore wind and has the world's most advanced pipeline of projects planned for the next decade. These projects will help the Government to meet its legally binding targets to generate renewable energy and also create a range of other economic benefits. This section considers these benefits in more detail.

Figure 23: Net carbon dioxide emissions avoided in each period and the remaining lifetime of offshore wind farms installed 2011 – 2022



4.1 Carbon avoidance

The UK is still heavily dependent on fossil fuels. Coal and gas are the source of nearly 80% of all electricity generation and power stations account for more than 30% of the UK's total annual carbon dioxide emissions.[13] Carbon dioxide, with other greenhouse gases produced by the combustion of fossil fuels, is a key cause of climate change and strong European and domestic laws have been passed to reduce emissions and increase the use of renewable energy sources.

Government figures for 2009 state that coal-fuelled power stations emitted carbon dioxide at a rate of 915kg per MWh while their oil and gas equivalents emitted 633kg per MWh and 405kg per MWh respectively.[14] Electricity generated by offshore wind will replace a mix of fuel types with different carbon footprints. It is likely that coal and oil power stations will be phased out so that, by 2022, low-emission gas-powered plants are expected to be the dominant form of fossil fuel generation. Nuclear power stations will provide a base level of generation alongside renewables while fossil fuels will be used to make up any difference between supply and demand.

Offshore wind farms also have a carbon footprint. In a report investigating the lifetime emissions associated with offshore wind farms using its V90-3.0MW turbine, Vestas calculated a footprint of just over 5kg per MWh considering all activities over an assumed 20 year lifetime.[15] This footprint covered the emissions generated during the manufacture of the turbines, offshore substation, export/array/onshore cables and the onshore substation. It also included the primary production of materials and the entire project's transportation, installation, operation, decommissioning and scrapping activities. This figure is consistent with other wind industry estimates.

To calculate the carbon footprint of the fossil fuels that would have been used in place of offshore wind, an avoided CO_2 production of 430kg per MWh has been used in the first period. This is based on calculations by RenewableUK that assume a mix of coal, gas and oil.[16] To account for the fact that fuels with higher emissions will be used less widely in the future it is assumed that the carbon footprint of this energy mix decreases slightly over the three periods so that it is level with that of gas by 2022.

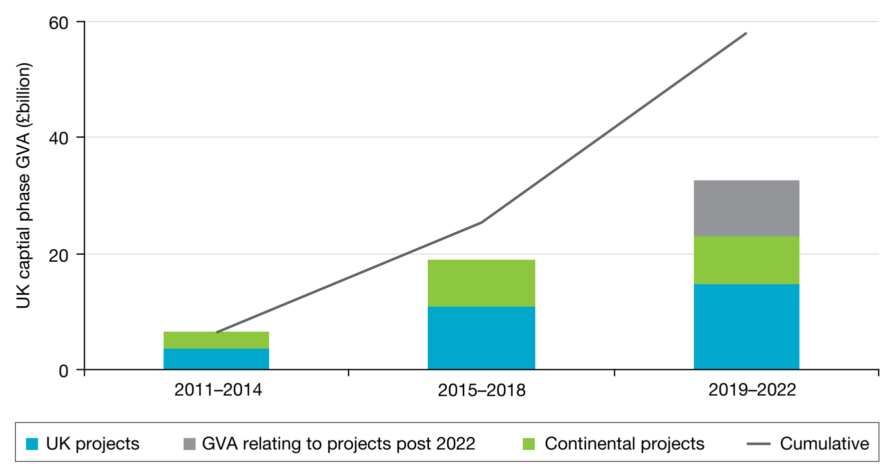
Finally, fossil fuelled power stations act to some extent as a reserve to balance energy production and demand. The requirement for balancing increases with increased penetration of offshore wind due to the variability in energy output from offshore wind farms with time. Providing this extra functionality means that some power plants will not operate consistently at full load and therefore will have a lower thermal efficiency that will mean higher emissions. Studies suggest that even at penetration levels of 20% (equivalent to 80TWh or more than 20GW installed offshore wind capacity) this would only reduce the amount of avoided CO_2 by a little over 1% while even higher penetration levels up to 40% have an impact of around 3%.[17]

In total, this means that up to 45 million tonnes of CO_2 per year is avoided, which is the equivalent of almost a third of estimated UK power station annual emissions in 2010.[18] Figure 23 shows the net carbon dioxide emissions avoided in each period due to the offshore wind farms installed between 2011 and 2022. Assuming an offshore wind farm lifetime of 20 years, it is predicted that nearly 800 million tonnes of carbon dioxide emissions are avoided due to the offshore wind farms built during the three periods with the majority of the benefit occurring after 2022.

Carbon capture and storage (CCS) is a method of reducing fossil fuel emissions by capturing carbon dioxide and storing it in deep geological formations in such a way that it does not enter the atmosphere.

This technology is currently still under development but it is anticipated that it could be implemented on an industrial scale in the UK. Due to the uncertainties with its development, the impact of CCS has not been included in Figure 23. To understand its impact, a scenario has been drawn up in which the use of CCS technology capable of capturing 90% of carbon dioxide increases linearly between 2020 and 2050 until it is used on all gas fuelled power stations. Under such a scenario, it is estimated that this would reduced the avoided carbon dioxide emissions discussed above by approximately 20%.

Figure 24: UK GVA during the capital phase in each period



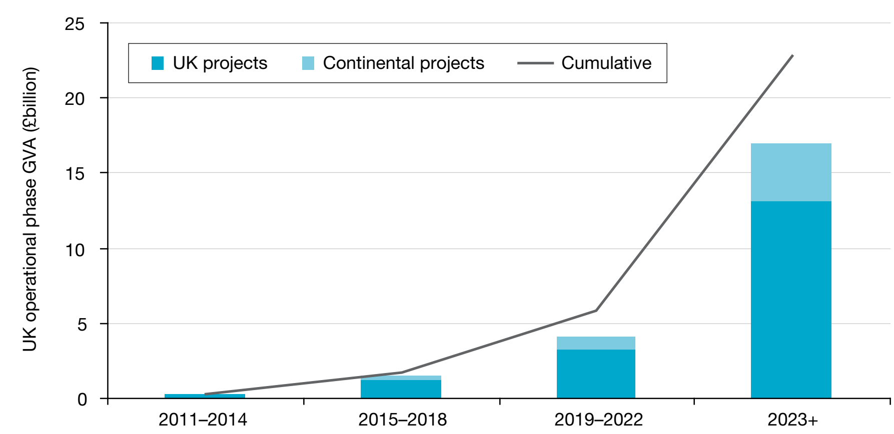
4.2 A healthy UK offshore wind industry

To date, UK content in UK offshore wind farms has been relatively low and this has caused some projects to attract negative publicity. In the future, it is in the interests of both the UK Government and the offshore wind industry itself to address this situation and increase UK content in offshore wind projects.

For the offshore wind industry, the logistics savings from growing a focussed supply chain in and around the ports closest to offshore wind sites are significant, as are the benefits of tapping into the experience of companies in the UK's oil and gas sector. In addition, the more UK jobs that are created, the more stable the political support for the industry is likely to be. Finally, revenue from UK wind farms is in pounds, so maximising UK content minimises the exchange rate risk for wind farm developers.

For the Government, companies with facilities in the UK are more likely to serve domestic rather than overseas markets which will increase its chance of meeting its renewable targets. Furthermore, as well as the direct economic impacts of job creation and tax revenue discussed in this study, a vibrant domestic offshore wind industry will create more opportunities for diversification for existing UK industries such as oil and gas and aerospace.

Figure 25: UK GVA during the operational phase in each period and the remaining lifetime of offshore wind farms installed 2011 – 2022



Finally, as well as serving the UK market, companies setting up facilities in the UK will be able to export goods and services to the Continental and worldwide markets.

A period of rapid and sustainable growth

There is now clear evidence of the UK supply chain starting to take shape as the scale of the UK market attracts investment from companies around the world. In January 2011 Siemens announced that it had signed a memorandum of understanding with Associated British Ports for a £180m deepwater berth and turbine production facility at the port of Hull. In May 2011, Vestas announced that it plans to establish nacelle and blade production facilities and a deep water construction berth at Sheerness. Gamesa and Mitsubishi have both announced plans to set up research and development facilities in Scotland with the expectation that full manufacturing facilities will follow in due course. General Electric (GE) has also committed itself to developing a £100 million UK facility while fellow American company Clipper has already set up a Tyneside blade facility. A number of other players are also understood to be finalising plans for facilities in the UK.

Other examples of supply chain activity include foundation supplier Burntisland Fabrications (BiFab), which is progressing a major investment programme at its facilities in Methil and Arnish, and Tees Alliance Group (TAG) which has set up a monopile manufacturing facility on the Tees. JDR Cable Systems has established a new production facility in Hartlepool while Rugby-based Converteam plans to invest £60 million in offshore wind permanent magnet generator production and £15 million in the production of large scale power conversion technology, including DC offshore wind farm architecture. Converteam was itself acquired by GE for £2 billion in March 2011.

A wide range of factors will affect the level of future UK content including Government support, the confidence of the UK supply chain to invest in facilities and an effective planning approval process. For the purposes of this study we have assumed that by 2022 almost 70% of orders relating to UK offshore wind farms during the capital phase will be sourced from UK Tier 1 suppliers compared with around 20% today. Furthermore, we assume that by 2022 around half of orders relating to Continental projects will also be sourced from the UK compared with around 10% today. Note that not all of the headline value of orders placed in the UK will remain in the UK.

This scenario is indicative and has been drawn up in dialogue with industry as a means of exploring the wider benefits that an established UK offshore wind industry could generate. It is a positive scenario and the levels of supply may not be achieved if the Government is not clear in its support for the supply chain or UK companies do not choose to take the opportunities that the market offers. Such a scenario would see a UK turbine production capacity of around 5.5GW per year by 2022, of which a third would be exported. Foundation and cable production capacity in the UK would also increase, although it is expected that existing overseas production centres are likely to continue to serve the market so UK content in these areas will be less than for turbines. The international nature of installation vessel chartering means the UK share of the installation and construction market would also be lower.

UK offshore wind gross value added

The offshore wind farms that will be built across Europe between 2011 and 2022 are expected to cost well over a hundred billion pounds to develop, manufacture, install and operate over their lifetime. As discussed above, we expect that much of this business could be captured in the UK, especially looking towards 2020.

It is important to recognise that a significant fraction of contract value ultimately will be spent overseas, even for orders secured by UK companies. This is due to the worldwide supply chain that feeds materials, tooling and sub-components to Tier 1 suppliers. The economic value of this business can be expressed as the gross value added (GVA), which measures offshore wind turnover by companies in the UK less imported costs.

While the effect of this will be relatively limited for the project element of the offshore wind farm, the impact is more significant for the turbine, foundation and electrical elements because either the UK is unable to supply many of the raw materials that are required, such as steel for towers, or the specialist suppliers of key components are located overseas. For the installation element, all of the next generation jack-up vessels currently on order are being built in overseas shipyards and this means that a significant share of the charter contract value ultimately is spent outside of the UK.

To reflect this, here we assume that, for a headline figure of 70% of capital orders won from UK projects by 2022, the UK could expect the GVA to be approximately 40 per of CAPEX. For Continental projects, winning half of the Tier 1 orders by 2022 is forecast to generate 30% of the CAPEX as UK GVA.

Total UK GVA is calculated using the CAPEX forecast derived in Section 3. This is based on the specific characteristics of planned UK wind farms. Continental projects have different site characteristics and therefore different associated costs. To accurately reflect this difference, the costs of a representative selection of Continental projects covering different markets, installation dates and site conditions have also been estimated using the same methodology as for UK projects to give an indicative CAPEX and OPEX for the non-UK market.

For all projects, CAPEX has been spread over the years before the wind farm starts generating energy to reflect observed trends in contracting for services and components. No account is made for inflation.

Figure 24 shows that, while UK wind farms makes up nearly two-thirds of UK GVA, the impact of Continental projects is also significant. Activity on projects is spread out over a number of years before installation so UK and Continental projects built after 2022 also contribute to UK GVA during the third period. In total, the UK capital phase GVA is expected to total almost £60 billion by 2022.

More of the activity during the operational phase is necessarily local to a given project, so the opportunity for capturing domestic business is greater. The UK is expected to capture around 80% of Tier 1 orders by 2022 with a UK GVA of nearly 60% of OPEX for UK projects. For continental projects, the UK is forecast to win approximately 30% of Tier 1 orders with a GVA of around 20%.

Figure 25 shows that most GVA will be generated outside the periods because the activity is spread over the operational life of the wind farms. This study does not take into consideration the cost of maintaining wind farms installed before or after the three periods.

In total, UK GVA from the operational phase of European wind farms installed between 2011 and 2022 is predicted to total almost £23 billion by the time the last project is decommissioned.

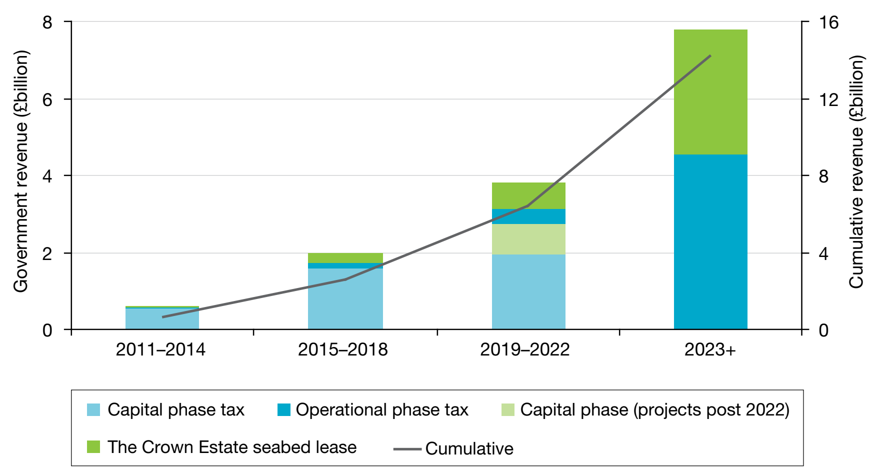
Government revenue

The UK Government has indicated that it sees offshore wind as a key opportunity to re-establish manufacturing jobs in the UK. This brings the double benefit of reducing unemployment and generating tax revenue. Figure 26 presents a forecast of Government revenue due to UK-based activity in wind farms installed between 2011 and 2022. The tax revenue generated within the supply chain to the offshore wind industry has been calculated using the predicted levels of GVA captured during the capital and operational phases as explained above.

These headline costs have been broken down to isolate the portion spent on labour, based on information gathered through a survey of industry players that are representative of the whole supply chain. The labour content is approximately a third of total costs and covers direct and indirect full time equivalents (FTE) including UK office staff and supply chain staff contributions that could be realistically associated with offshore wind activity.

This is then divided by an average cost per employee to establish the number of FTE jobs created. Average total annual remuneration of £40,000 has been used for employees working during the capital phase. This recognises that, while an increasing number of factory workers may be facing a downward pressure on their average salary, there will also be large numbers of skilled engineers and project managers required. During the operational period, an average

Figure 26: Treasury revenue from offshore wind industry in each period and the remaining lifetime of offshore wind farms installed 2011 - 2022



remuneration of £50,000 has been used, reflecting the need for many of the staff to work significant shifts offshore.

When calculating labour costs, additional costs such as pensions, tax, insurance and the provision of facilities and other benefits are also incurred by companies. To take this into account, this study has assumed the real cost of an employee is two times remuneration. As such, an estimated peak workforce of nearly 40,000 FTE is created for capital phase activities and around 5,000 FTE for operational phase activities.

The income tax and national insurance revenue is calculated by applying the relevant bands of taxation to the average salaries assumed.[19] Corporation tax has also been calculated using an assumed industry profit margin of 5%. Such a figure should be seen as indicative and not representative of industry expectations. The model does not include VAT.

UK Government revenue generated by capital phase activity before the end of 2022 on both UK and Continental wind farms being installed after 2022 has also been included to reflect the ongoing growth taking place in the industry. In total, it is predicted that Government revenue generated from capital activities will be around £5 billion by 2022.

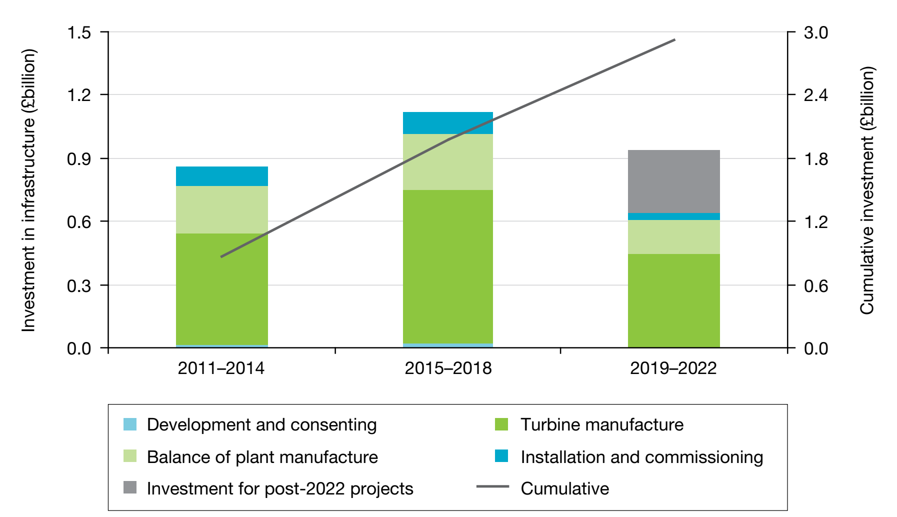
During the operational phase of projects, the Government will benefit from taxes paid both by the supply chain and the asset owners. If utility companies continue to hold offshore wind farm assets long-term, it is likely that early tax liabilities will be reduced or eliminated because of set up costs and accelerated capital allowances on the assets, meaning that tax is likely only to be paid in the last years of project operation. In order to compare with other revenues, these taxes have been discounted back to the year of installation at the current relevant government discount rate of 3.5%. Total discounted tax take in the operational phase is likely to be approximately £3 billion for wind farms installed in the period 2011-2022.

For the operation phase, as well as through taxation, the UK Treasury can also expect significant revenue from offshore wind through the seabed lease contracts agreed between The Crown Estate and wind farm developers. The Crown Estate is an independent organisation that manages the property portfolio of the Crown and which passes surplus revenue to the Treasury. Almost all the UK's seabed out to the 12 nautical mile territorial limit is owned by The Crown Estate, including the rights to explore and utilise the natural resources of the UK continental shelf (not including oil, gas and coal). The Energy Act 2004 also means that The Crown Estate is responsible for developing the generation of renewable energy on the Continental Shelf within the Renewable Energy Zone out to 200 nautical miles. As part of this licensing, The Crown Estate charges developers lease fees for the use of the sea bed. While individual contracts between the parties are confidential, it is understood that developers are charged around 2% of the value of the total wind farm revenue. In order to compare with other revenues again, lease fees paid over the lifetime of the wind farm have been discounted back to the year of installation at the relevant government discount rate.

The cost of energy forecasts calculated in the first half of this study represent the minimum revenue per MWh required for developers to make a suitable rate of return on their investments. Total revenue can be calculated by combining this forecast of the costs of energy with forecasts of installation rates and capacity factors. Assuming lease values of 2% of the wind farm revenue, UK offshore wind farms developed between 2011 and 2022 are expected to generate more than £4 billion via The Crown Estate.

Taxation revenue created by commercial activity between 2011 and 2042 in the operational phase of both UK and Continental wind farms is expected to total almost £2 billion, meaning the overall revenue generated for the Treasury is predicted to be more than £14 billion.

Figure 27: Investment in UK infrastructure to deliver offshore wind capacity in each period



Investment in infrastructure
If the UK is to capture the levels of expenditure discussed above, significant infrastructure investment is required. Due to the size of many of the components in an offshore wind farm and the logistical challenges of moving them, much of this investment will be focused on coastal locations. Manufacturing sites also benefit from being located near existing industrial capacity and labour pools.

Combining the UK and Continental installation forecasts with the expected orders won by UK Tier 1 companies gives the total expected demand for the UK supply chain. There is a gap between the point when money is invested in a facility and when production starts, so this investment has been offset (brought forward) by between two to four years compared with the year of installation. Assumptions have also been made about the level of investment required to build up annual production capacity per MW for various manufacturing operations.

Figure 27 shows the level of investment required between 2011 and 2022 to build the infrastructure required to meet the expected UK demand from UK and Continental markets. As the offshore market is expected to continue growing after the third period, investment made up to the end of 2022 for facilities that will serve projects that are installed after 2022 are included.

In total, it is forecast that nearly £3 billion will be invested in offshore wind infrastructure in the UK by 2022. While this total level of investment is significant, it is only quarter of the expected revenue that the Government can expect through taxing commercial activity over the lifetime of wind farms installed between 2011 and 2022. It is also less than 4% of the total GVA that such investment is forecast to unlock for the UK. We anticipate that the majority of this investment will be privately funded but some is likely to be public, such as the £130 million already allocated to support the development of offshore wind manufacturing facilities at coastal locations.

4.3 Balance of payments

The scale of the UK's offshore wind pipeline means that, even if the domestic supply chain grows rapidly, there will be a need to import a significant proportion of services, vessels and components from established overseas supply chains for some time. Almost £80 billion is predicted to be spent overseas during the capital and operational phases of UK projects built between 2011 and 2022 compared with over £50 billion in the UK.

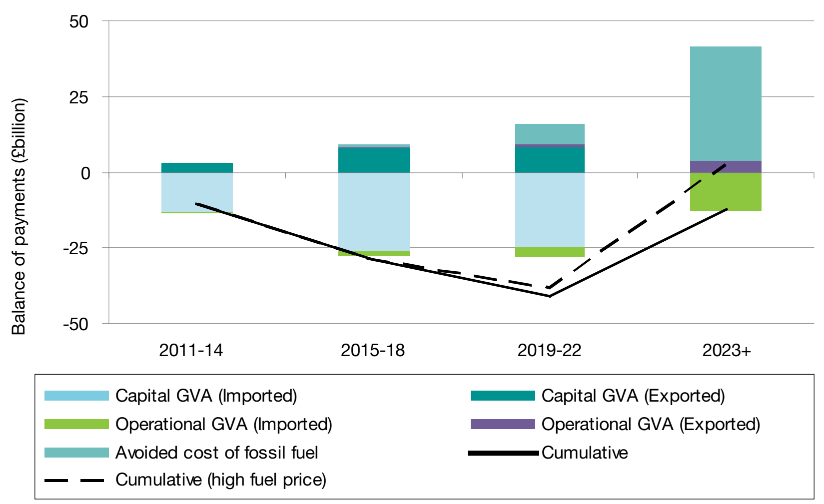
Looking at the overall UK balance of payments, these imports are compensated to some degree by UK exports to continental projects. The supply chain in the UK is growing from a relatively low level during this time but, despite this, we forecast exports to Continental projects of nearly £25 billion.

It is also important to consider the avoided importation of fossil fuels due to energy generation by UK offshore wind projects. The UK currently imports 70% of its coal, with Russia responsible for more than half of its steam coal supply since 2006.[20] For gas, imports are expected to exceed forecast offshore wind energy production throughout this period.[21/22]

The cost of the avoided fossil fuel is calculated by combining the predicted energy generation from UK offshore wind projects installed between 2011 and 2022 with the Government's fuel price forecasts.[23] To reflect the changing nature of the fossil fuel energy mix, it has been assumed that offshore wind is displacing coal between 2011 and 2018. From 2019 to 2022, an increasing proportion of gas is used and from 2023 it is assumed that only gas is displaced.

As seen in Figure 28, using DECC's central price assumptions means the total balance of payments remains negative during the three periods but, by the time the last wind farm is decommissioned in 2042, the balance of payment is only negative by £12 billion. It also shows, using DECC's high fuel price assumptions gives a positive balance of £2 billion.

Figure 28: Balance of payments in each period and the remaining lifetime of offshore wind farms installed 2011 - 2022



These forecasts are based on predictions of long term increases in energy prices. The decreased reliance on imported fuels also protects the country from increasing short-term volatility in the energy markets caused by natural and political crises. Whereas most gas today is delivered to the UK using pipelines connected to Norway and Continental Europe, an increasing proportion is expected to be delivered in ships as liquefied natural gas (LNG) cargo. This means that the UK will be competing for resources with the US and Asian markets at a time when global demand is increasing and prices are expected to be volatile.

For offshore wind, unlike for fossil fuel generation, the majority of lifetime expenditure is known at the point of the financial decision to invest, giving developers a relatively high confidence in the lifetime cost of energy at that point.

Appendix A: Consultation

This report has been prepared and written by BVG Associates with input and peer review from members of RenewableUK, including developers, wind turbine manufacturers and engineering consultancies. This feedback was gathered during two workshops held in December 2010 and January 2011.

Further feedback was also gathered via email correspondence with RenewableUK members and RenewableUK Offshore Wind Strategy Group.

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Endnotes

1. RenewableUK, *UK offshore wind: Charting the right course*, 2010, www.bwea.com/pdf/publications/ChartingtheRightCourse.pdf
2. Redpoint Energy in association with Trilemma UK, *Electricity Market Reform, Analysis of policy options*, 2010, www.redpointenergy.co.uk
3. Office for National Statistics, ‘*Consumer Price Indices*’, www.statistics.gov.uk/statbase/product.asp?vlnk=868
4. Bank of England, ‘*Exchange rate data*’, www.bankofengland.co.uk
5. Steel Business Briefing, ‘Flat products/Pleat/N.Europe domestic Ex-Works £/t’, www.steelbb.com
6. Department of Trade and Industry, *Meeting the energy challenge: A White Paper on Energy*, 2007, www.berr.gov.uk/files/file39387.pdf
7. RenewableUK, *UK offshore wind: moving up a gear*, 2007, www.bwea.com/pdf/offshore/movingup.pdf
8. The Crown Estate, *Towards Round 3: Progress in building the offshore wind supply chain*, 2011, www.thecrownestate.co.uk/supply_chain_gap_analysis_2010.pdf
9. National Grid, Offshore development information statement, 2010, www.nationalgrid.com
10. BERR, *Atlas of UK Marine Renewable Energy Resources*, 2008, www.renewables-atlas.info/
11. Garrad Hassan, *Composite Offshore Resource Mapping Analysis*, 2011
12. The Carbon Trust, *Offshore Wind Power: Big Challenge, Big Opportunity*, 2008, www.carbontrust.co.uk/publications
13. Department of Energy and Climate Change, *Annex B: Carbon dioxide emissions by source*, 2010, www.decc.gov.uk
14. Department of Energy and Climate Change, *Digest of United Kingdom energy statistics*, Chapter 5 Electricity, 2010, www.decc.gov.uk
15. Vestas, *Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0MW turbines*, 2005, www.vestas.com
16. RenewableUK, *Calculations for wind energy statistics*, www.bwea.com/edu/calcs.html.
17. David Milborrow, *Managing Variability*, A report to WWF-UK, RSPB, Greenpeace UK and Friends of the Earth EWNI, 2009, www.greenpeace.org.uk
18. Department of Energy and Climate Change, *Annex B: Carbon dioxide emissions by source*, 2010, www.decc.gov.uk
19. HM Revenue & Customs, *Taxes, National Insurance and Stamp Taxes,* www.hmrc.gov.uk/rates/taxes-ni.htm
20. Department of Energy and Climate Change, *Coal imports* (ET 2.4), (2010) www.decc.gov.uk
21. Department of Energy and Climate Change, *Energy Trends*, (2010) www.decc.gov.uk
22. Department of Energy and Climate Change, *UKCS Oil and Gas Production Projections*, www.og.decc.gov.uk
23. Department of Energy and Climate Change, *Fossil fuel price assumptions*, 2010, www.decc.gov.uk/

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