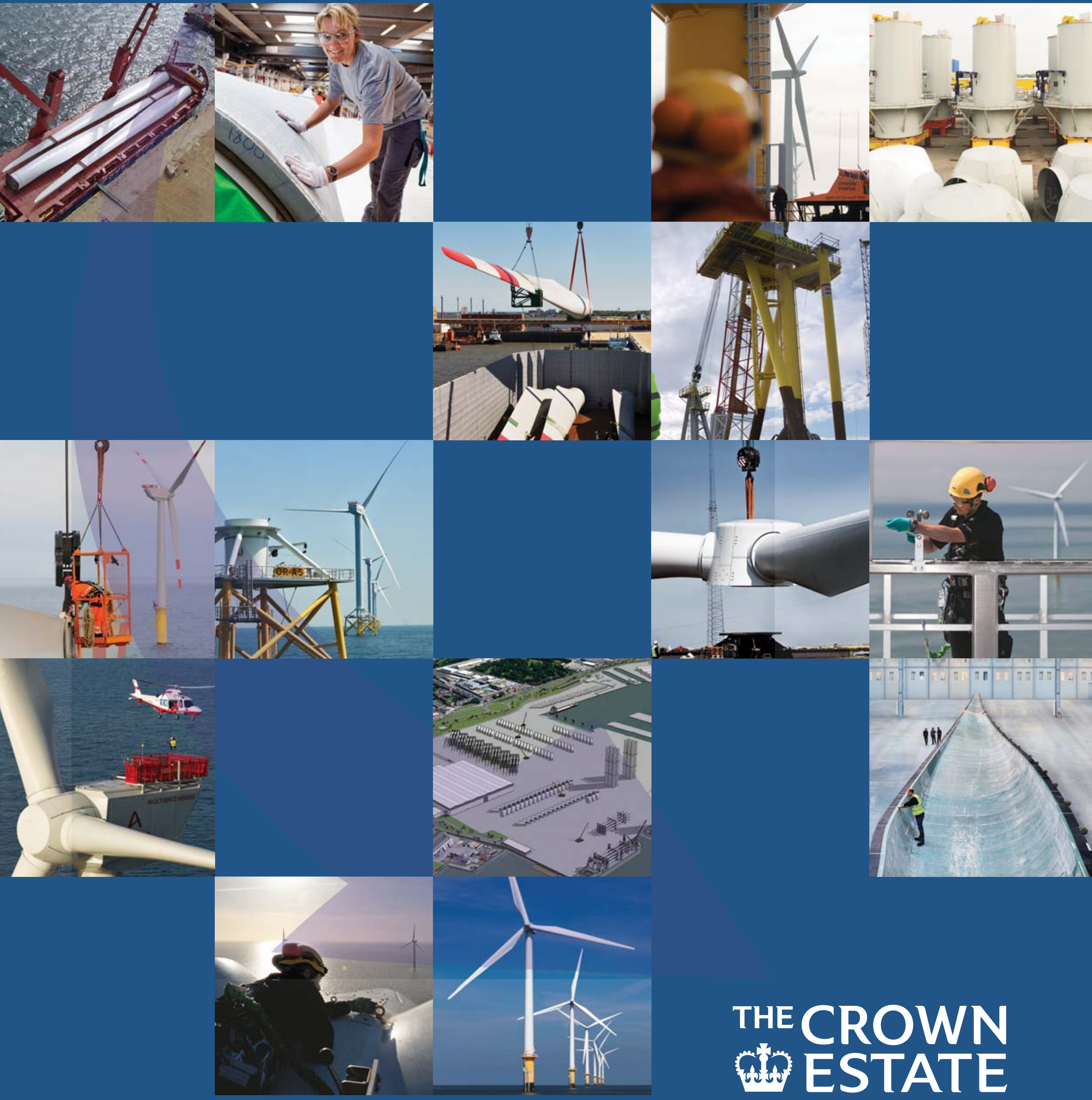
Offshore Wind Cost Reduction
Pathways Study



THE CROWN ESTATE

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For a full list of acknowledgements, please see the acknowledgements section in this report.

Foreword

For the UK, offshore wind is a story of many successes.

We have the world's biggest offshore wind market, the world's most attractive investment environment, and an unparalleled record of deployment. Five of the ten largest offshore wind farms – including the top two – are in British seas.

These successes are fitting: ours is an island nation, blessed with copious wind and shallow seas. If we are to match our clean energy ambitions, we must take full advantage of this potent natural resource.

We believe that the offshore wind industry can and must evolve to be more competitive and forward looking. That in turn will boost the security of our energy supplies, create jobs, and attract further inward investment.

Realising offshore wind's potential is crucial to meeting our 2020 renewable energy targets. But we have a responsibility to deliver a low-carbon future at the lowest cost to consumers.

That is why we welcome the Offshore Wind Cost Reduction Pathways Study, which identifies and quantifies cost reduction opportunities for the offshore wind industry.

An evidence-based study, it enriches the reader's understanding of the drivers and dependencies of offshore wind costs. Through consultation with industry, the study provides a platform for the government, project developers, the supply industry and operators to align future activities and maximise cost reductions.

Opportunities for savings across the finance, technology and supply chain sectors have been identified and quantified, thus allowing a significant reduction in the cost of offshore wind. Overall, it gives us confidence that significant cost-saving opportunities are available and achievable by 2020.

We believe that the Offshore Wind Cost Reduction Pathways Study represents an authoritative and credible way forward. We would like to invite the DECC Cost Reduction Taskforce to apply The Crown Estate's evidence, findings and conclusions to their thinking and in the formulation of an action plan.

Rt Hon Edward Davey MP

Secretary of State for Energy and Climate Change

Alison Nimmo

Chief Executive, The Crown Estate

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Moody's
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MPI Offshore
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NSW GmbH
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Executive summary

The costs of offshore wind in the UK have increased substantially since the first commercial scale wind farms were deployed in the early 2000s, driven both by underlying cost increases (commodity prices rises, currency fluctuations) and by more specific factors such as supply chain bottlenecks, sub-optimal reliability and the move to deeper water sites. Recent wind farm projects have indicated that costs have stabilised at around £140 per MWh (for projects at Final Investment Decision in 2011).
At the same time, Government and industry are facing important decisions regarding the size of the offshore wind industry and investment in new technologies and facilities. Future costs will be critical in determining the future size of the industry in the UK.

This study has produced a rigorous and validated assessment of the potential for offshore wind power cost reduction. It is based on unprecedented engagement with and challenge from around 120 companies and organisations and individuals from the offshore wind industry, insurance, academic and finance communities over a period of six months.

Reducing the cost of offshore wind to £100/MWh by 2020 is achievable

DECC has put forward a challenge that offshore wind should reach a Levelised Cost of Energy (LCOE) of £100/MWh by 2020, in order to maximise the size of the industry.
Drawing on input from project participants, we have defined four industry 'stories' reflecting different ways in which offshore wind could develop. These have been used as the basis to develop cost reduction 'pathways', in order to test the achievability of the £100/MWh ambition. Our cost reduction pathways explore the impact on LCOE of the key uncertainties facing the offshore wind industry:

- the rate of offshore wind capacity build
- the pace of technological change
- the maturity of the supply chains serving offshore wind developers
- the depth of financial markets investing in offshore wind.

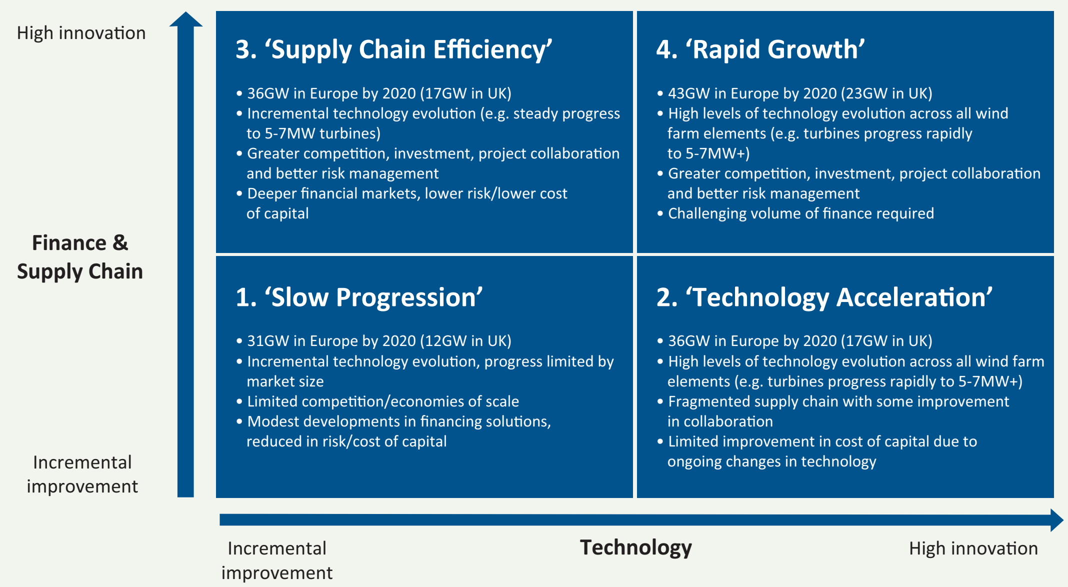
In three of the pathways, offshore wind reaches a Levelised Cost of Energy at or below £100/MWh for projects reaching Final Investment Decision (FID) in 2020, and is well on its way to meeting this benchmark by FID 2017 (see Exhibit A).
The exception to this is the Slow Progression story, where cost reduction is held back by the relatively small market and insufficient intervention by government and industry, and the LCOE remains relatively high.

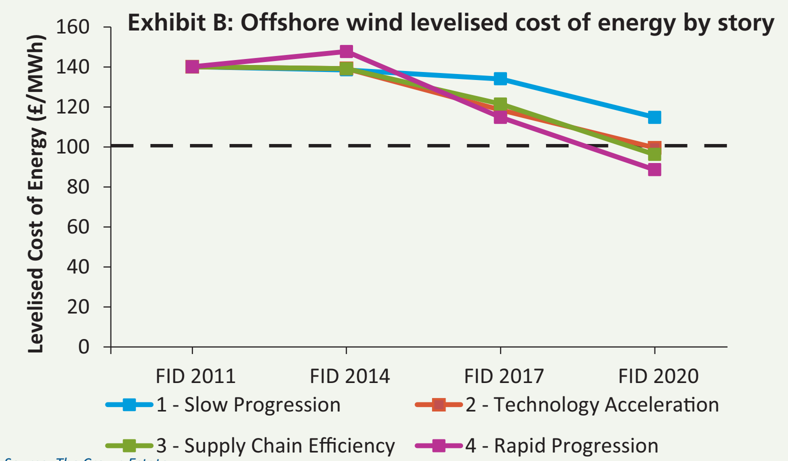
What do we mean by the Levelised Cost of Energy (LCOE)?

In simple terms, LCOE can be seen as the lifetime cost of the project, per unit of energy generated.

It is defined as the sum of discounted lifetime generation costs (£) divided by the sum of discounted lifetime electricity output (MWh). Generation costs include all capital, operating, and decommissioning costs incurred by the generator/developer over the lifetime of the project, including transmission costs. It does not necessarily correspond to the level of revenue (or 'strike price') that would be required to support the project –it is an expression of cost rather than revenue. The discount rate is the Weighted Average Cost of Capital (WACC) over the lifetime of the project; as determined by the capital structure and financing costs. LCOE is calculated on a post-tax basis and expressed in real 2011 prices for all years.

Exhibit A: Industry Stories





Source: The Crown Estate

The cost pathways related to our four industry stories can be summarised as follows.

- The **Slow Progression** story assumes slow market growth and limited supply chain maturation and technology development. In these unfavourable circumstances, the LCOE of offshore wind power only falls to £115/MWh by FID 2020, and close to £134/MWh by FID 2017.
- The **Technology Acceleration** story envisages a world where new products evolve rapidly, leading to a diverse range of turbines, foundations, cabling, installation methods, and other solutions available in the market. The supply chain remains fragmented in this story, and technology risks, and therefore the cost of capital, remain slightly higher than in other stories. As a result, LCOE falls to £100/MWh in FID 2020, and around £118/MWh by FID 2017.
- In the **Supply Chain Efficiency** story, industry standardises on 4MW class and 6MW class turbines[1] and related key components; invests in new, larger-scale facilities and working methods; and operates in a highly competitive set of markets. The increased supply chain savings and benefits to the cost of capital, coupled with a fair degree of technology progress, leads to a similar set of costs as the Technology Acceleration story (£96/MWh by 2020, £121/MWh by 2017).
- The **Rapid Growth** story assumes a very favourable set of circumstances, including the avoidance of supply chain bottlenecks, and indicates the limit of how far the industry might go in achieving costs reductions. In this story the LCOE falls to £89/MWh by FID 2020, and around £115/MWh by FID 2017.
- The LCOE values represent the 'average' cost for projects reaching FID in a particular year, blended across an assumed mix of sites and technologies used in that year. In reality, no two projects will have exactly the same costs, and we estimate that by 2020, the variability around these central costs will be up to +/- £14/MWh.

Based on the four generic site types we have used in our modelling, there is a relatively balanced LCOE trade-off between shallow water, close to shore sites with lower wind speed, and deeper water and /or further from shore sites with higher wind speed. In other words, the move to deeper water and/or further from shore sites in Round 3 and Scottish Territorial Waters is not likely to result in a material LCOE penalty once the greater energy production due to higher wind speed is taken into account. This presents a more positive view of the viability of projects on these sites compared with the finding of previous reports.

Analysis has shown that our results are sensitive to the assumptions made on exchange rates, commodity prices (steel and copper in particular), the operating life of the wind farm, and interest rates. The cost pathways above are based on fixed external factors (eg commodity prices and exchange rates fixed at average 2011 levels in real terms). Changes in these external factors will also impact the costs of other forms of low carbon generation such as nuclear and onshore wind.

Beyond 2020, we foresee further cost reduction opportunities from both technology and the supply chain. The top technology innovations we have identified[2] are expected to have achieved less than 50% of their potential by 2020, leaving considerable room for further improvements.
In addition, there is the potential for a step change in LCOE through the introduction of radically new technologies beyond 2020. We also expect that competition and collaboration in operations and maintenance will start to generate material cost savings post-2020.

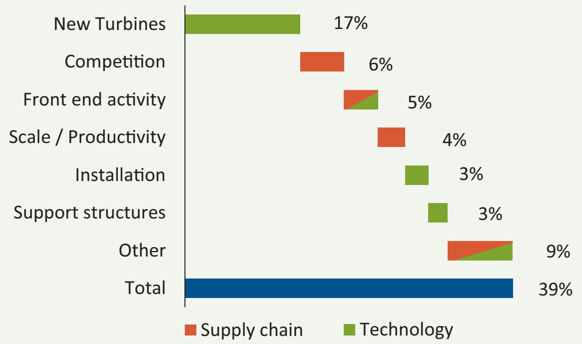
[1] 4MW class turbines refers to turbines in the range of 3-5MW, 6MW class turbines refers to turbines in the range of 5-7MW
[2] For a 6MW-Class Turbine

There are many, diverse ways in which offshore wind costs can be driven down by technology and the supply chain

Up until now offshore wind farms have largely used products adapted from application in other fields, for example marinised onshore wind turbines and foundations designed using oil and gas industry standards for manned platforms. Similarly the supply chain that serves offshore wind farms is immature and operates on a project-by-project basis. Moving to products specifically designed for offshore wind and industrialising the supply chain provides a large number of opportunities to reduce capital and operating costs and increase power generation. Compared with a wind farm project whose FID is in 2011, there could be a reduction in cost of up to 39% for projects at FID in 2020 due to technology and supply chain factors (see Exhibit C).

Exhibit C: Offshore wind power cost reduction opportunities from technology and supply chain

% reduction in levelised cost of energy FID 2011 to FID 2020



Note: FID 2011 refers to a 500MW project whose Final Investment Decision is in 2011. Similarly for FID 2020. The period from FID to completing a wind farm is around three to four years. The cost reduction opportunities above are based on a comparison of a typical FID 2011 wind farm (3-5MW class turbine) vs. a typical FID 2020 wind farm (5-7MW class turbine).

For this comparison the cost of capital is held constant over time, and all costs are in 2011 money. Percentages are multiplicative not additive so the total is the product rather than the sum of the cost reduction elements.

Source: The Crown Estate

The key opportunities for cost reduction are generated by:

- The introduction of turbines which are larger, have higher reliability and energy capture, and lower operating costs.
- Greater competition in key supply markets (turbines, support structures and installation) from within the UK, the rest of the EU, and from low cost countries.
- Greater activity at the front end of the project including early involvement of suppliers, multi-variable optimisation of wind farm layout, more Front End Engineering and Design (FEED) and more extensive site surveys.
- Exploitation of economies of scale and productivity improvements including greater standardisation, capturing and building on learning by doing and better procurement.
- Optimisation of current installation methods.
- Mass produced support structures for use in water depths greater than 35 metres.

The extent to which these cost reductions are realised by the supply chain will depend on how the industry evolves – as explored through the stories and pathways.

Financing costs will benefit from reduced risks, countering upward pressures

Given the capital intensity of offshore wind farms, the cost of capital is a key driver of LCOE. A drop of one percentage point in the Weighted Average Cost of Capital (WACC) is equivalent to a reduction in LCOE of around 6%.

As the offshore wind industry gains experience, key risks (ie installation costs and timings, turbine availability and operating and maintenance costs) will be better managed, and the overall risk profile of offshore wind farm projects will reduce. This will then lower the required returns demanded by providers of capital.

In parallel, increasing rates of offshore wind farm construction between now and 2020 will greatly boost the demand for new capital. Our analysis shows that there is insufficient funding available from the types of players currently in the market, which could result in a shortfall of £7-22 billion depending on the volume of capacity deployed to 2020. It will be necessary to identify additional sources of equity and debt funding, and this will most likely result in an increase in the cost of capital, particularly during the high-risk construction phase.

The WACC for wind farms reaching FID in 2011 is just over 10% (nominal, post-tax).[3] For projects reaching FID in 2020, we expect their WACC to reduce to around 9%, in a range from 8.6% to 9.7% depending on the degree of technology risk and the level of market growth. We expect projects reaching FID from 2014 to 2017 to experience an increase in WACC of 0.5% owing to the high demand for capital, which will offset some of the downward pressure on LCOE due to technology and supply chain factors.

[3] It is possible to express the WACC in real or nominal terms, and either pre-tax or post-tax. The baseline figure is 10.0% post tax nominal, which equates to 9.2% in pre-tax real terms.

A steadily increasing market and predictable project timings are critical

In order to realise cost reductions, the single most important prerequisite is a steadily increasing market for offshore wind power, together with a predictable set of project timings. Our stories and pathways demonstrate that increased levels of cost reduction are possible in a larger market, but this needs to be coupled with predictability and permanence of the market in order for cost reductions to be maximised.

The key issues to address to achieve this are:

- A smooth and timely transition to the new electricity market arrangements specified under the Electricity Market Reform (especially feed in tariff allocations and strike prices), and clarity on public funding for renewable energy beyond 2015 as defined by the Levy Control Framework.
- Reliably meeting the clear timetable for planning determination in England and Wales, as proposed under the Planning Act 2008 (as amended), and in Scotland (as administered by Marine Scotland).
- A clear and predictable regulatory framework for offshore transmission.

Supply chain companies are now considering building facilities and vessels and developing new products to supply wind farm projects in the second half of this decade. These investments will typically need more than ten years to generate an adequate return. Investors, therefore, require a line of sight on the offshore wind market to at least 2025. Steady market growth is essential as it avoids the stop/ start cycles that are detrimental to investment decisions and efficient working. Our analysis suggests that a UK market of at least 2GW/year from 2015 to 2025 (ie that seen in the Technology Acceleration and Supply Chain Efficiency stories) is needed to ensure significant cost reduction, assuming market development plans in the rest of the EU remain on track.

Ensuring that project timings are predictable is also crucial to achieving cost reduction. This will encourage greater collaboration, ease the new entry of innovative new products and capital, and shorten project timetables.

Reliable planning, timely market reform, and clarity on offshore transmission, were all seen by project participants as the fundamental building blocks for the market going forward.

Other prerequisites

In addition, Governments should continue to play a key role in encouraging technology development by continuing Research, Development and Demonstration support, including testing and demonstrating projects and ensuring effective use of planning flexibility.

Developers should be more proactive in further developing and funding full scale demonstration projects.

The ramp-up in offshore wind deployment which will drive down costs depends on the availability of coastal manufacturing and assembly facilities. Manufacturers, developers and consenting bodies must work closely together to ensure the timely availability of suitable sites.

Within this context, wind farm developers and their suppliers must work together to deliver continuous, end-to-end cost and risk reduction. This will mean a shift from working on a project-by-project basis to managing a pipeline of projects to drive down cost, including:

- developers making a steadily increasing market for offshore wind farms visible to the supply chain, to support investment in facilities and new methods of working
- willingness to work together to achieve best practice and share risks and incentivise improvements appropriately with a particular focus on the key risk areas of installation and operations and maintenance
- being open to standard solutions rather than insisting on internal standards or bespoke approaches
- grasping opportunities to introduce new products
- jointly managing supply and installation hitches.

Developers, key suppliers and the finance community must collaborate to access new pools of equity, debt and bond finance (recognising the not inconsiderable lead time involved), involve insurers early in technology development to avoid delays and ensure risks are identified and understood quickly.

Finally, a wide variety of stakeholders need to work together to ensure an adequate supply of people with the right skills and experience.

Public commitment to the future of offshore wind is now essential

The cost pathways we have developed, based on unprecedented input from industry, indicate a strong potential for offshore wind to achieve DECC's benchmark cost of £100/MWh by 2020. We believe the prerequisites to achieving cost reduction are both proportionate and achievable. We therefore call on industry and government to commit publicly to putting those prerequisites in place in a timely manner and to working together to achieve a sustainable industry

Introduction

1

The UK has stretching renewable energy and emissions targets

The use of renewable energy has many potential benefits, including greater energy security and protection from fossil fuel price fluctuations, as well as reduction in greenhouse gas emissions. The growth of renewable energy sources has the potential to stimulate employment through the creation of jobs in new 'green' industries.

In order to reap the benefits of renewable energy, at an affordable cost, the Government has published its UK Renewable Energy Roadmap charting a course towards 15% of final energy consumption from renewables by 2020, equivalent to some 234 TWh/year.[4] This is consistent with the EU Renewables Directive which has set a target of 20% of EU energy to come from renewable sources by 2020.

The UK has more than doubled its use of renewable energy since 2006 (from 1.5% to 3.3% in 2010).[5] However, meeting the 2020 target represents a considerable challenge as the UK has the largest renewable energy 'gap' of all EU countries (ie the difference between the current level of renewable energy and the indicative 2020 target).

The UK could meet this target through greater use of a mix of renewable electricity, renewable heat and biofuels. DECC has most recently reviewed these options in the UK Renewable Energy Roadmap. Their central view of deployment highlights renewable electricity as delivering a high portion of the renewable energy gap, with at least 40% of 2020 renewable energy coming from electricity.

The UK has also enshrined emissions targets in law through the Climate Change Act, a legally binding long-term emissions reduction framework operating through a series of five-year carbon budgets. The currently legislated budget commits the UK to cutting greenhouse gas emissions by 34% by 2018-22 over 1990 levels (or 21% compared with 2005).[6] Analysis by the Committee on Climate Change has identified decarbonisation of the power sector as one of the main ways of meeting the 2018-22 budgets, with a 40% emission reduction realistically achievable through the deployment of low carbon generation including offshore wind.[7]

Offshore wind is poised to grow rapidly and become a major source of electricity in the UK

Against a backdrop of legislative changes encouraging the use of renewable and low carbon electricity, offshore wind has the potential to become a significant part of the UK generation mix.

Offshore wind is a proven technology. The first turbines were installed more than 20 years ago off the Danish coast. After a period of small-scale testing in the 1990s, mainly in Dutch and Danish waters, commercial mega-watt turbines began to be used in 2001.

By mid-2011 the technology reached industrial scale with global capacity of over 3GW and the UK home to just under half of all capacity.[8]

UK waters have huge offshore wind resource, considered the best in Europe. The UK has a long term potential of up to 1940 TWh of offshore wind generation,[9] of which some 400TWh/year is possible from fixed foundations – the currently established technology. The remainder of the resource could be exploited using floating foundations, but this has not yet been proven at scale. This high level of resource based on fixed foundations comes from the combination of high wind speeds and large areas of water of a suitable depth (<45 metres depth) in the North Sea, Irish Sea and the Channel.

Offshore wind is generally less subject to planning delays and rejections than onshore wind, the only other mature renewable technology with significant resource potential in the UK. Over the last five years onshore wind consenting decision times have typically been 20-25 months (although currently decision times for large projects – over 50MW – stand at 52 months) and approval rates in the year to July 2011 were 51%.[10] The consenting period for offshore wind has been 22 months for approved projects and approval rates have been around 90%.[11]

Consequently, offshore wind has the opportunity to grow rapidly. The UK Renewable Energy Roadmap indicates that offshore wind could generate between 14 and 25% of the UK's renewable electricity by 2020 (or 33-58TWh) with a capacity of between 11 and 18GW, compared with 1.5GW in mid-2011.

Offshore wind is also poised for growth outside the UK. The coastal countries in the rest of Europe are expected to be a major market, with the European Wind Energy Association projecting 40GW of capacity by 2020 underpinned by a pipeline of over 5GW of projects under construction and 17GW consented.[12] Outside of Europe, significant growth is expected in China[13] and the US.[14]

To capitalise on offshore wind it is critical that the costs come down radically

Electricity from offshore wind currently costs significantly more than that from either onshore wind or Combined Cycle Gas Turbines (CCGT), currently the main alternative technology albeit with significant carbon emissions. Offshore wind is viewed by some as less cost-effective than alternative low carbon technologies that may be deployable at scale from the end of this decade, such as new nuclear and future combinations of Carbon Capture and Storage technologies with fossil fuel plant.[15]

Furthermore, offshore wind has a history of cost escalation, with capital costs doubling from £1.5m/MW in 2006 to over £3m/MW in 2009.[16] Part of this cost increase has been

[4] Source: DECC, 'UK Renewable Energy Roadmap', 2011
[5] Source: Eurostat (table t2020_31); DECC Energy Trends June 2011. Measured using Renewable Energy Directive methodology
[6] Source: Committee on Climate Change, http://www.theccc.org.uk/carbon-budgets/1st-3rd-carbon-budgets-2008-2022
[7] Source: Committee on Climate Change, 'Building a low-carbon economy –The UK's contribution to tackling climate change', 2008
[8] Source: European Wind Energy Association, 'The Wind in Our Sails', 2011
[9] Source: PIRC, 'The Offshore Valuation Project', 2010
[10] Source: RenewableUK, 'State of the Industry Report', 2011
[11] Offshore wind approval rates exclude projects awaiting a decision, covers Round 1 and 2, is calculated by project (rather than by capacity) and is correct as of January 2012. Source: RenewableUK, 'Consenting Lessons Learned', 2011, The Crown Estate analysis.
[12] Source: European Wind Energy Association, 'The Wind in Our Sails', 2011
[13] Source: New York Times, September 7th, 2010
[14] Source: U.S. Department of Energy, 'A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States', 2011
[15] Source: Mott MacDonald for The Committee on Climate Change, 'Costs of low-carbon generation technologies', 2011 and Parsons Brinckerhoff for DECC, 'Electricity Generation Cost Model Update 2011', 2011
[16] Source: UKERC, 'Great Expectations – The cost of offshore wind in UK waters', 2010

caused by commodity price increases and currency fluctuations that have also affected other electricity generation technologies. However, the cost of offshore wind has increased further owing to supply chain bottlenecks, lack of competition, sub-optimal reliability, and deployment in deeper water.[17] This is in stark contrast with the expectations of declining costs in the late 1990s and early 2000s.[18]

Looking to the future, Government is in the process of reforming the electricity market, including the financial support mechanism for the deployment of low carbon generation technology. The way these changes are implemented will largely set the size of the offshore wind market up to 2020 and beyond. These changes are driven by a desire to minimise costs to consumers. 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.

In a significant step, DECC has directly linked its expectation of the size of the offshore wind market with cost reduction – stating that the delivery of 18GW of offshore wind capacity by 2020 can only be achieved if costs fall to £100/MWh.[19] This makes offshore wind power cost competitive with DECC's forecast for other low carbon generation which will be necessary in the 2020s. With current offshore wind costs in the order of £140/MWh, the magnitude of the cost reduction challenge is enormous.

The interdependence between market size and cost

Future costs and future market size are inextricably linked. The costs of offshore wind 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. Industry will, however, only invest if it perceives there is a sustainable and viable market for offshore wind. Full realisation of the cost reductions will be achieved through industry building on real experience which again depends on a sustained, growing market.

We are faced, therefore, by a dilemma: Government will only provide for a sizeable offshore wind market if it has confidence that costs will drop significantly, but industry will only invest to reduce costs if it has confidence in the long term future of the offshore wind market.

This is an urgent issue. To make significant progress by 2020, industry needs to begin investing now. It can take 7-10 years to develop, approve and construct an offshore wind farm, and supply chain investments such as expanding ports, building new manufacturing facilities, and establishing grid connections, often need to be made even earlier.

This project – building confidence in the future of offshore wind costs

This project seeks to resolve this dilemma by producing an authoritative and credible analysis of the future development of the costs of offshore wind energy consistent with a large-scale, viable, long-term market. Credibility has been underpinned by:

- explicit industry and Government participation in and verification of the cost analysis and the resulting conclusions

- identification of the key developments, dependencies and actions required to realise cost reductions.

This study has explored the costs of offshore wind projects reaching Final Investment Decision (FID) in the period to 2020. As the period from FID to full operations is around 3-4 years, we cover the costs of offshore wind power entering the wholesale electricity market through to 2023-2024. The costs of an offshore wind project entering operations in 2020 are best represented by projects whose FID is in 2017.

We have covered in detail how technology, supply market, and finance can reduce the costs of energy delivered to the offshore substation connection point. Different ways of developing and charging for the offshore transmission network are being jointly assessed by Government and industry. The outcome of this work may have a considerable impact on the future costs of transmission of offshore wind power, so detailed analysis is premature. Consequently, we engaged a group of experts, under the aegis of RenewableUK, to provide a high-level assessment of the potential for cost reduction in transmission.

Our analysis has predominantly focused on achievable cost reductions from technologies, methods and services that are known, or can be reliably projected, for the period to 2020. There is also potential for game-changing technology (often referred to as 'disruptive' technology) to begin to shape further cost reductions towards the end of the periodand out to 2030. The study has only considered disruptive change where the weight of industry opinion judges it appropriate.

The remainder of this report sets out the approach and methodology we used to assess the potential for cost reduction (Chapter 2) and quantifies the major gains that could come from new and improved technology, a more efficient and effective supply chain and changes in the financing of offshore wind farms (Chapter 3). These are then drawn together into four self-consistent cost reduction pathways (Chapter 4). The key requirements, or prerequisites, to achieve those cost reductions, are outlined in Chapter 5, in Chapter 6 we review the implications on health and safety, and our conclusions are presented in Chapter 7.

[17] Source: UKERC, 'Great Expectations – The cost of offshore wind in UK waters', 2010 and GL Garrard Hassan for the Ministry of Climate and Energy, 'Background report 2: Analysis of competitive conditions within the offshore wind sector', 2011
[18] Source: Garrard Hassan for the Department of Trade and Industry and the Carbon Trust, 'OFFSHORE WIND – Economies of scale, engineering resource and load factors', 2003
[19] Source: DECC, 'UK Renewable Energy Roadmap', 2011

How we conducted the study

2

A distinctive approach

This study has built upon a large body of work on the current and potential future costs of offshore wind (see Appendix A). In order to create a credible analysis of the future development of the costs of offshore wind energy, we have used an approach that has four distinctive features:

- involves a **high level of engagement** with both the industry wind industry and the finance community
- is **highly transparent**
- **focuses on the key decisions** made by industry to drive down costs
- shows multiple, alternative, coherent **pathways to cost reduction** which examine all the key cost drivers and allow like-for-like comparison with actual costs in the future.

Engagement

The whole project has been underpinned by a high level of engagement with industry and the finance community. Overall 119 companies and organisations participated in the project including:

- 10 of the wind farms developers active with UK offshore wind projects
- 6 existing offshore wind turbine suppliers and many of those considering entering the market
- 9 of the major foundations manufacturers and many of the leading developers of new foundation concepts
- 8 the key installers currently actives in UK waters
- 8 the main suppliers of cabling and electrical equipment
- 9 of the suppliers of key sub-components
- 6 banks involved in or considering the financing of offshore wind projects including both commercial banks and multilateral agencies and government backed institutions
- 4 insurance brokers, rating agencies, export credit agencies, etc
- 4 of the major port companies
- 2 of the leading transmission companies
- 25 key industry consultants and observers.

Participation initially involved detailed one-to-one discussions (often over a number of meetings) to identify and evaluate cost reduction opportunities and to solicit underlying evidence. In many cases this resulted in the disclosure of confidential internal company data. Insights from this data have been drawn into the conclusions in this report without breaching confidentiality. Companies were further involved in a series of workshops to review and then validate the identified cost reductions, ensure consistency and avoid duplication.

Transparency

In addition to publishing the results of this study, we are making public the underpinning basis and data for the assessment of cost reduction so that it is available to all stakeholders and is open to scrutiny. We believe that this will encourage greater openness within the industry in the future and will facilitate a healthy process of challenge.

The specifically commissioned reports on the opportunities for cost reduction from technology, the supply chain and finance, which provide the majority of the data for this report, are now available on The Crown Estate website, together with an assessment of the impact on health and safety.

The quantitative evaluation of cost reduction was developed through a series of interlinked Excel-based models. All the key data inputs and model outputs upon which this report is based have been made publically available - both within this report including its appendices, and within the individual workstream reports.

Key decisions

Our analysis has examined the real world decisions which need to be taken to drive down costs, and makes explicit what needs to be in place to allow those decisions to be taken. The key decision points are:

- The Final Investment Decision (FID) taken by an offshore wind farm developer (which occurs around 3-4 years prior to the wind farm becoming operational).
- The decision by a supplier to introduce a new product, such as a new turbine or foundation system.
- The decision by a supplier to invest in new facilities such as quays, manufacturing facilities or installation vessels, which often have a life well beyond 2020.
- The decision by investors and insurance companies to allocate capital to the offshore wind sector.

Each of these decisions is taken in the context of a wider process. For example a developer will progress an offshore wind project through a series of stage gates for around 4-6 years prior to FID, followed by around 3-4 years of pre-construction and construction work before the wind farm is fully operational. Similarly, the introduction of, say, a new wind turbine, will progress through a series of steps of R&D, testing and demonstration prior to full commercial launch.

Pathways

The future is highly uncertain. This study, therefore, has examined a series of different pathways along which the costs of offshore wind power could evolve bearing in mind the key uncertainties or variables within the industry, namely:

- the rate of offshore wind capacity build
- the pace of technology change
- the maturity of the supply chains serving offshore wind developers
- the depth of financial markets investing in offshore wind farms.

The costs of offshore wind power are influenced by the physical characteristics of the wind farm including the water depth, distance from shore, wind speed and seabed.
Our pathways are based on four generic site types shown in Exhibit 2.1 which cover the range of sites likely to be developed to 2020.

Exhibit 2.1 Generic site types

Site Type	Average Water Depth (MSL) (m)	Distance to nearest construction and operations port (km)	Average wind speed at 100m above MSL (m/s)
A	25	40	9
B	35	40	9.4
C	45	40	9.7
D	35	125	10

Source: The Crown Estate

Site type A is typical of a Round 2 site. Site types B, C and D are similar to Round 3 and Scottish Territorial Waters sites (STW); in deeper water, further from shore, but with higher wind speeds and therefore greater electricity production.

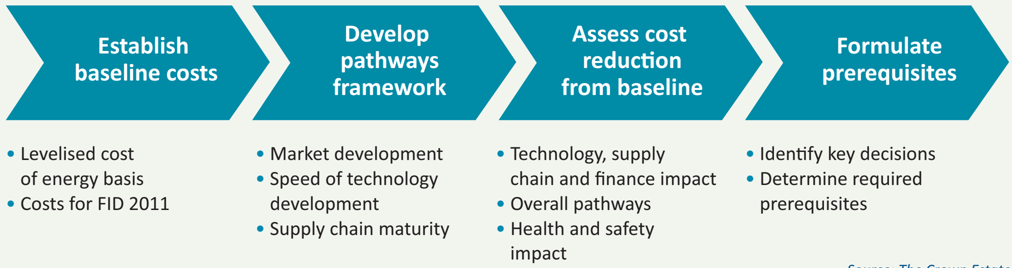
Our pathways cover four different time periods:

- A baseline of projects which achieved FID in 2011.
- Projects with an anticipated FID in 2014. It is expected that these will consist of the remaining Round 2 projects in the consenting system plus the extension sites and early Round 3 sites.
- FID 2017 – projects from Round 3 and Scottish Territorial Waters (STW) sites.
- FID 2020 - projects in the later phases of Round 3 and STW activities.

Our methodology

Our overall methodology for developing offshore wind power cost pathways is shown in Exhibit 2.2.

Exhibit 2.2 Offshore wind power cost reduction methodology



Source: The Crown Estate

Stage 1 - Establish baseline costs

The key metric for the whole-of-life costs of offshore wind power used in this study is the Levelised Cost of Energy (LCOE). The LCOE is defined here as the total revenue required per unit of energy output, so that the wind farm owner secures their target return on the expected capital expenditures and operating expenses incurred over the life of the project. LCOE can have limitations as a metric because it often ignores investment risk.[20] However, to overcome this limitation, we have explicitly explored the impact of risk by:

- identifying and quantifying the key areas of cost risk
- building up the required return based on an assessment of systemic and specific project risks.

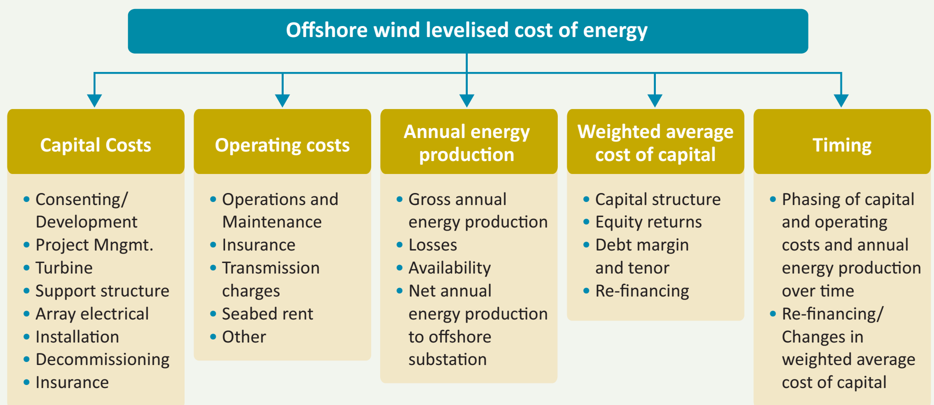
Used in this way, LCOE becomes a good approximation of the way developers and financiers examine the investment case for a wind farm project. It is also used as a metric by policymakers, for example to set subsidy levels and thresholds, as one of its advantages is the ability to make comparisons over time and across energy technologies.

Other key elements of our assessment basis included:

- modelling in real 2011 prices
- commodity prices and exchange rates fixed at average 2011 levels. The impact of changes in these external factors has been tested in our sensitivity analysis (see Chapter 4).
- progression of Energy Market Reform (EMR) as indicated in the July 2011 White Paper, with a Feed-in Tariff Contracts for Difference (CfDs) as the sole support mechanism from 2017 and ROC banding levels to 2017 as stated in consultation document of December 2011.

Our LCOE model for a single 500MW site built in a specific year is shown in Exhibit 2.3. This model is used for baseline costs and the cost of wind power from new projects through to FID 2020. It models the discounted cash costs and energy production from a wind farm through its whole life to give the LCOE.

Exhibit 2.3 Levelised cost of energy model for a single site in a specific year



[20] Source: UKERC, 'Investment in electricity generation: the role of costs, incentives and risks', 2007

LCOE model definitions

- LCOE is defined as the sum of discounted lifetime generation costs (£) divided by the sum of discounted lifetime electricity output (MWh). Generation costs include all capital, operating, and decommissioning costs incurred over the lifetime of the project.
- LCOE is calculated for a generic project at FID at a given year, on a post -tax basis, and is expressed in real £2011 prices (for all FID years).
- Capital expenditures:
  - The cost of consenting and development is considered as a bullet 'success payment' at FID. This factors in the actual expenditures incurred in this phase of the wind farm life, plus a developer premium
  - Project management covers costs from FID to works completion
  - Turbine costs cover rotor and nacelle only
  - Support structure covers both foundation and tower. This reflects the similarity of towers and foundations in technology terms and the potential trend to integrate towers and foundations to a greater or lesser extent in the future.
  - Array electrical covers intra-array cables up to the offshore sub-station.
- Operations and maintenance costs cover both planned and unplanned service.
- Transmission charges cover costs associated with transmission assets and system balancing charges incurred by the generator; these comprise transmission network use of system (TNUoS) charges (both local to the Offshore Transmission Owner (OFTO) assets and the wider transmission system and Balancing Services Use of System (BSUoS) charges (both calculated as an annual charge). It excludes wider system balancing costs.
- Seabed Rent is that charged by The Crown Estate.
- Net annual energy production is the net metered generation at the offshore sub-station after wake and other losses and accounting for wind farm availability.
- The Weighted Average Cost of Capital is calculated over the lifetime of the project, distinguishing between the development, construction and operational phases, each with an appropriate capital structure, equity and debt returns. The model allows the timing of key aspects to be altered, such as the point or points at which re-financing(s) occur.
- The LCOE does not necessarily correspond to the 'strike price' or level of support that would be required to support the project – as it is as expression of cost rather than revenue.
- Taxation is calculated within the model (based on the prevailing rate of taxation and the cashflows within the model) rather than being set as an input to the model in per MW terms.

In order to establish the costs of offshore wind power as perceived at FID 2011 we engaged the industry to understand for our generic site types A and B (which are the only ones with actual evidence to date) and for a 4MW-Class Turbine (an average of the 3-5MW turbines currently available in the market) the key cost inputs as seen by a developer:

- Contract prices for the main packages procured by developers:
  - turbine supply (including warranty)
  - foundation supply,
  - array cables supply
  - installation (either one package or split between foundation, turbine and cabling)
  - insurance
  - port facilities
- Developers' contingency.
- The expected costs of operations and maintenance within and outside the usual five year warranty period for the turbine.
- The expected Annual Energy Production (AEP) after accounting for availability and losses.

We also engaged with developers and the financial community to understand the required cost of capital in FID2011 using a:

- Bottom-up assessment of the components which make up the cost of capital, drawing on market data for the cost of equity and cost of debt and quantifying the premiums investors require for project specific risks,
  extreme downside risks and the illiquid and imperfect nature of the market for offshore wind funding. The latter two were combined into a developer return uplift.
  The key areas of specific project risk were identified as:
  - installation costs
  - operations and maintenance costs
- Top-down assessment: Benchmarking returns from completed offshore wind projects and the returns current investors have suggested to us they require to invest in offshore wind projects. These represent 'all-in' return requirements and incorporate the underlying cost of capital and additional risk premia.

A full listing of the key assumptions underlying the base line and our assessment of future LCOE can be found in Appendix B

Stage 2 - Develop pathways framework

There are numerous ways in which the offshore wind industry could develop in the future, each of which would lead to different costs of offshore wind power. This study focuses on a number of discrete cost pathways, built on explicit views of how the industry could evolve, which have been brought together as 'stories' or narratives for the evolution of the industry. The key aspects which vary across these 'stories' are:

- The size of the offshore wind market in the UK and in the rest of Europe through to 2020 and beyond.
- The pace of technology development and hence the mix of products (particularly turbine sizes) in the marketplace.
- The maturity of offshore wind finance and supply chain.

Four combinations of market size, technology development, and supply chain development were selected with industry input as representing the reasonable boundaries within which the industry is likely to evolve and are summarised in Exhibit 2.4.

These four 'stories', were combined with the four generic site types and four time periods to formulate our cost pathways (see Exhibit 2.5).

Stage 3 - Assess cost reduction from baseline

With a cost baseline established and a pathways framework set, we assessed the degree to which costs could be reduced examining:

- **technology** innovations through changes in product or component design and manufacturing process.
- improvements in the **supply chain** for an offshore wind farm development.
- changes in the **financing** of offshore wind farms.

Exhibit 2.4 Four industry stories

Finance & Supply Chain	Technology: Incremental improvement	Technology: High innovation
High innovation	**3. 'Supply Chain Efficiency'** • 36GW in Europe by 2020 (17GW in UK) • Incremental technology evolution (e.g. steady progress to 5-7MW turbines) • Greater competition, investment, project collaboration and better risk management • Deeper financial markets, lower risk/lower cost of capital	**4. 'Rapid Growth'** • 43GW in Europe by 2020 (23GW in UK) • High levels of technology evolution across all wind farm elements (e.g. turbines progress rapidly to 5-7MW+) • Greater competition, investment, project collaboration and better risk management • Challenging volume of finance required
Incremental improvement	**1. 'Slow Progression'** • 31GW in Europe by 2020 (12GW in UK) • Incremental technology evolution, progress limited by market size • Limited competition/economies of scale • Modest developments in financing solutions, reduced in risk/cost of capital	**2. 'Technology Acceleration'** • 36GW in Europe by 2020 (17GW in UK) • High levels of technology evolution across all wind farm elements (e.g. turbines progress rapidly to 5-7MW+) • Fragmented supply chain with some improvement in collaboration • Limited improvement in cost of capital due to ongoing changes in technology

Exhibit 2.5 Cost pathways

Note: Product mix refers to the different classes of turbines defined in this study together with their relevant balance of plant. Refer Appendix B

We also considered the impact of the key changes which could increase costs, notably:

- wind farms moving to deeper water and further from shore.
- potential for supply bottlenecks and limited competition.
- potential constraints in the supply of capital, particularly in the risky construction phase and in industry stories where market growth is rapid.

Technology

Together with industry we identified around 60 separate innovations that are likely to reduce LCOE by FID 2020. The impact of some of these innovations is to increase capital costs (per MW), however they are expected to reduce LCOE by improving reliability, reducing O&M costs and/or increasing electricity production.

In order to understand the impact of technology innovations on LCOE we:

- Assessed the full potential for each individual innovation to reduce LCOE in the most favourable circumstances considering its overall impact on capital and operating costs and on annual energy production.
- Moderated this impact to take account of each innovation's:
  - Relevance – not all innovations are suited, say, in deeper water or further from shore.
  - Readiness – some technologies will be ready at full potential by 2014, others will only reach a proportion of their full potential by 2020.
  - Market take-up – many innovations are compatible but some are not (for example there may be improvements in monopile and jacket foundations, which cannot be applied to the same development but will take a share of the overall market). Innovations are therefore combined into groups and assigned a market share for a given site / turbine / year combination to reflect industry views of the likely take-up.
- Aggregated all impacts (on capital and operating costs and AEP) for a given site / turbine / FID year combination and applied this to the baseline costs to derive a set of LCOE reductions for FID 2014, FID 2017 and FID 2020 compared to the FID 2011 baseline.
- Assessed the overall impact of technology on the key risk factors, and fed this into the finance model.
- Assessed the extent of technology progress across the four stories: the starting point for this analysis was to consider the progress possible in the technology-focused stories (ie 'Technology Acceleration' and 'Rapid Growth'). In order to provide a comparable set of numbers for the other 'stories' we have imposed a delay in the rate of technology progress – to reflect the fact that these stories are focused more on improving the supply chain than making rapid progress in technology.
- All savings relate to the 'net' saving available to the developer once relevant costs to the supply chain are taken into account. For example, many of the cost reductions involve investment in capital by the supply chain. The reported savings reflect the fact that this supply chain investment will need to be rewarded.

This provides a cost pathway assuming no change in supply market conditions from 2011 and no changes in the financing of wind farms.

Supply chain

We identified and tested with industry a series of changes in the way in which offshore wind farms are supplied that will impact LCOE. These supply chain levers have the potential to reduce capital and operating costs and / or risks, thereby reducing LCOE and cover:

- **Asset growth and economies of scale:** As capacity increases, cost savings can be achieved through, for example, productivity improvements (eg having more vessels reduces the impact of installation delays as it affords increased flexibility) and logistics (eg 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: in procurement, through 'learning by doing', by standardising processes and protocols reducing the need for more expensive bespoke solutions and by increasing the productivity of exiting assets (including manufacturing facilities) by increasing volume throughout and run lengths.
- **Changes in contract forms/terms:** Moving away from lump sum contracts, tightening terms and conditions and the introduction of more appropriate incentive mechanisms may lead to cost reductions.
- **Means of managing and pricing uncontrollable risk:** Uncontrollable risks include unpredictable weather (sea state and wind), ground conditions at the offshore construction site and consequential losses not covered by contract terms. A better understanding and apportioning of uncontrollable risk can accrue savings by reducing their impact.
- **Increased competition from UK, other European and low cost country players:** Greater competition in each of the main supply markets (eg turbines, foundations, installation etc) will both squeeze margins and increase the drive for lower costs. In some supply markets the entry of players from China, South Korea, India etc may also have a significant impact as their cost bases are significantly lower than their European counterparts due to lower costs of labour and, in some instances, access to lower cost raw materials or competitive finance. We considered the impact of competition from low cost countries on both the supply of complete wind farm products and key components.
- **Vertical collaboration across different tiers in the supply chain:** Currently contracts are mainly awarded on a project by project basis with most developers typically letting 5-8 major contracts. This can lead to a silo approach without adequate recognition and management of the interdependencies between contracts. This often leaves the developer bearing much of the 'interface risk'.

Vertical collaboration includes: Consolidating procurement contracts and so reducing interfaces, contingencies and cost overruns; improving interface management through development and implementation of programme management tools; and involving suppliers (designers, installers and O&M providers) early in the project life (eg prior to procurement) in order to design out risk and avoid iterations that can result in cost overruns.

- **Increased horizontal co-operation:** This involves sharing of best practices and facilities and development of joint intellectual property among the same tier of the supply chain. It may also involve working together to develop standards and sharing between peers (for example sharing repair vessels amongst O&M operators).

Unlike in the technology area, where an innovation will only be taken-up in the market if its overall impact is to reduce LCOE, [21] supply chain levers can also increase LCOE. This is particularly true in the case of competition, where reduced competition may well lead to higher costs and therefore LCOE.

For each lever, we benchmarked the situation in FID 2011 (eg the number of competitors in each of the main supply markets) and critically reviewed with industry:

- how the supply chain lever may alter by FID 2020.
- the impact on LCOE in FID 2020 as a result of the supply chain lever (over and above the technology impact) as a percentage of baseline costs for each of the element of a wind farm (eg turbine, support structure, installation, O&M, etc).
- the likely impact in the earlier years (ie FID 2014/17)
- the nature of the impact – distinguishing between changes in contract prices and reductions in risk.

We have assumed that, owing to the increasing levels of competition in the sector, cost savings made by suppliers are generally passed through to the prices charged to developers. The extent of this pass through varies by industry story.

We supplemented industry input with research into nature of the offshore wind supply chain levers and the impact of the supply chain levers in comparable industries such as offshore oil and gas. We then moderated the results to ensure there was no overlap between supply chain levers and the technology cost reductions. Finally the overall assessment of the impact of supply chain levers on LCOE was validated with industry.

We then applied the supply chain levers to our technology cost pathways.

Finance

In the finance workstream we considered how the costs of funding wind farms and the costs of insurance might change through to FID 2020.

The costs of funding a wind farm were assessed in two steps:

- Define the capital structure for a representative project. A set of assumptions were made to determine the annual volumes of capital required in each 'story' and the quantity of capital available from different sources (eg developer's own balance sheet, bank debt, etc). These assumptions are used in a 'funding model' which has been developed to establish the capital structure of a 'representative' project reaching FID in 2011, 2014, 2017 or 2020, including, for example, the proportion of debt to equity and the quantities of new forms of capital, such as project bonds.
- Calculate the Weighted Average Cost of Capital (WACC) based on the representative capital structures and using additional assumptions regarding the terms of funding from each source of capital (including cost, timing and repayment). A detailed and flexible 'project finance' model was developed to calculate the WACC under different capital structures and risk inputs.

Through engagement with the financial community the potential key drivers of change to the WACC of offshore wind project were explored and then modelled. These included:

- reduction in systemic risk through policy and regulatory changes
- changes in capital structure such as increases in project gearing (ie the ratio of debt to overall funding) as more experience is gathered
- reduction in the margin charged by debt providers as risks reduce and / or are better understood
- reduction in project specific risks through experience and better management
- reduction in the developer's return uplift as risks reduce and / or are better understood and competition increases
- increases that could occur in WACC through capital constraints, particularly of equity, and the need to attract additional funds beyond that provided by natural equity investors such as utilities, established independent developers and major offshore wind suppliers.

We identified the key drivers of offshore wind insurance cost:

- the level of competition and amount of capacity in the market
- the nature of the insurance products available
- the track record of developers' and their contractors
- the level, source and degree of demonstration of technology innovation.

[21] The only exception being some technologies that purely mitigate environment and health and safety risks.

Through engagement with the finance community, we assessed the potential for insurance costs to reduce to FID 2020 for each industry story.

Overall pathways

For each of our 'stories' and generic site types, we combined the technology, supply chain and finance cost reductions with our assessment of baseline costs to define a set of overall cost reduction pathways . These pathways are internally consistent and show how LCOE might evolve under each set of assumptions. We have overlaid this with an assumed mix of sites that might be built between now and FID 2020 (which varies by story), to estimate the overall envelope of LCOE at an industry level through to FID 2020 (See Appendix B). The cost pathways shown in Chapter 4 represent the average LCOE across the assumed mix of sites and technologies in each year.

Where appropriate we also identified qualitatively the potential for LCOE reduction beyond 2020 to give an indication as to the possible trend in the next decade.

Where assumptions have been made in the models, for example on variables such as commodity prices, exchange rates, or operational lifetime, these have been tested through a sensitivity analysis to assess their impact on the results (see Chapter 4).

Health and safety

The requirement of the study is to reduce cost, but not to the detriment of safety. The impact of innovations and improvement in offshore wind technology and supply chain on health and safety was raised during our engagement with industry. The response from industry were collated and reviewed by safety experts to identify whether the changes would have a positive, neutral or negative impact on health and safety. This was done using a series of risk reduction indicators such as:

- stepping up through hierarchical design mitigation strategies (such as illustrated in the CDM Designers Guide referenced below which contains a simple hierarchical list and information on DRM in practice)
- intrinsic safety introduced
- reduction in exposure hours for a particular element of work
- reducing the frequency of offshore trips and / or offshore transfers
- reducing the frequency of any exposure to potentially hazardous activity
- reducing quantity of interfaces requiring positive management
- improving methodology to reduce number of operations.

Where negative impacts were identified, potential mitigation measures were considered and their implications assessed.

Stage 4 - Formulate prerequisites

A key aspect of this study is to explicitly state the conditions or prerequisites that need to be in place to allow cost reductions to occur. To make this tangible, we have related the prerequisites to the specific decisions that need to be made to drive down the LCOE of offshore wind.

We consider the following key decisions:

- a series of decision gates during the development of a wind farm project, culminating in FID
- the decision by a supply chain company to develop a product that could be purchased by a wind farm developer, most notably a new wind turbine or foundation
- the decision by a supply chain company to invest in new assets primarily serving the offshore wind market (eg new installation vessels, automated jacket welding facility, new quays, etc)
- the decision by a provider of capital to fund a wind farm project.

We then:

- briefly characterised the key decision in term of scale and lead time of investment and either typical asset life or pay-back time
- engaged with the industry and the financial community to understand and validate the key prerequisites.

Study organisation

The study was based on five interrelated work streams:

- **The technology work stream**, which was conducted by BVG Associates, determined the baseline costs and assessed the potential for technology costs reduction.
- **The supply chain work stream, which** was conducted by E C Harris and assessed the potential for supply chain cost reductions.
- **The finance work stream**, which was conducted by PwC, assessed the availability and cost of capital, and the potential for reductions in insurance costs.
- RenewableUK and The Crown Estate facilitated an industry expert group, in order to identify and describe possible cost reduction opportunities related to **transmission**.
- PMSS reviewed the **health and safety** implications of the cost reduction pathways.

The work and output of the five work streams were managed and integrated by a project team at The Crown Estate.
The project team drew on the support of the **Project Advisory Panel** who provided guidance on the study process and critical review of the results (see Appendix C for its Terms of Reference). The members of the Panel were:

• Duarte Figueira	**DECC**
• Allan Taylor	**DECC**
• Mark Thomas	**InfrastructureUK**
• Thomas Arensbach	**Gamesa (until March 2012)**
• Ron Cookson	**Technip**
• Gordon Edge	**RenewableUK**
• Michael Rolls	**Siemens**
• Richard Sandford	**RWE**
• Christian Skakkebaek	**DONG Energy**
• Ian Temperton	**Climate Change Capital**

Cost reduction opportunities

Current costs seem to have stabilised

The escalation in offshore wind cost over the last decade has been well documented (see Section 1). However, experience from recent projects gives cause to believe that the cost of offshore wind energy may be stabilising:

- despite increasing water depth, capital costs seem to have levelled off
- more recent wind farms are in sites with higher wind speeds and therefore greater energy production

Despite increasing water depth, capital costs seem to have levelled off

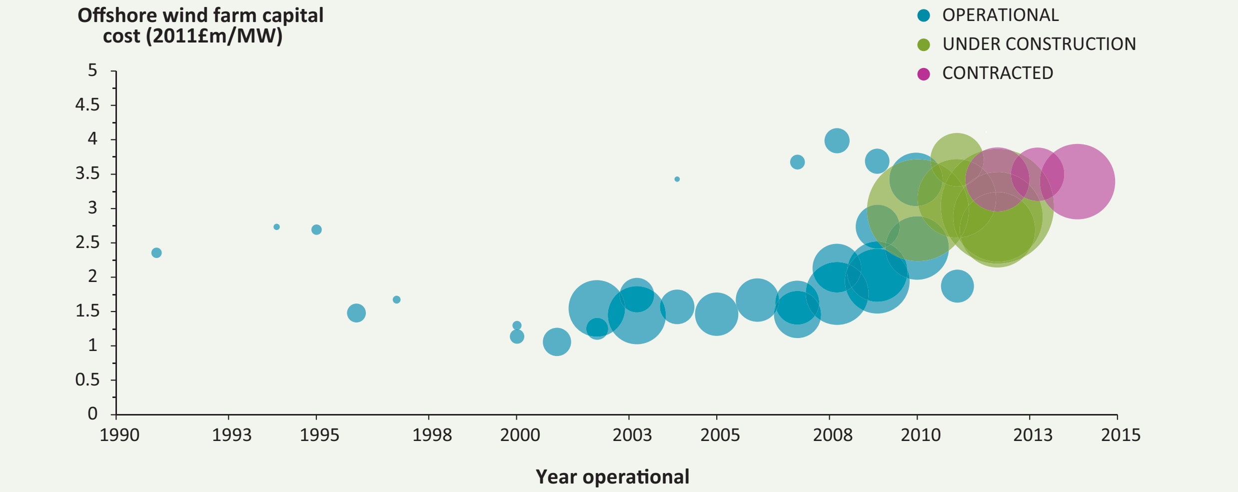
Over the past decade, wind farms have been installed in increasing water depth (see Exhibit 3.1). Commercial wind farms from 2000 to 2005 were in depths of 5-15m. From 2006, water depth increased sharply and wind farms installed in 2012 will be in waters of at least 20m and up to 35m. Increasing water depth increases the costs of foundations and of installation on a like for like basis.

Exhibit 3.1 European offshore wind farm water depth by year

Source: Technology work stream report

Despite this increase in water depth, recently announced wind farm capital cost seem to levelled off between £3m/MW and £3.5m/MW (including transmission capital costs) for sites which are similar to our reference sites A and B (see Exhibit 3.2). This reflects a number of factors including a better understanding of the key risks in offshore wind construction, oversupply in the general wind turbine market and larger projects leading to greater economies of scale.

Exhibit 3.2 European offshore wind farm capital costs by year



Note: Bubble diameter proportion to wind farm capacity The values utilised for the chart are based on published information – typically contractor or developer press releases and / or guidance from the relevant project owner through direct consultation. The values have been adjusted for currency, inflation and scope differences. Adjustment for scope differences has been made in cases where grid connection including offshore substation have been provided by a third-party. In addition, reductions have been made in cases where Warranty, Operational and Maintenance costs have been included in the published value. The values exclude developmental and operational expenditure.

Source: GL - Garrad Hassan

More recent wind farms are in sites with higher wind speeds

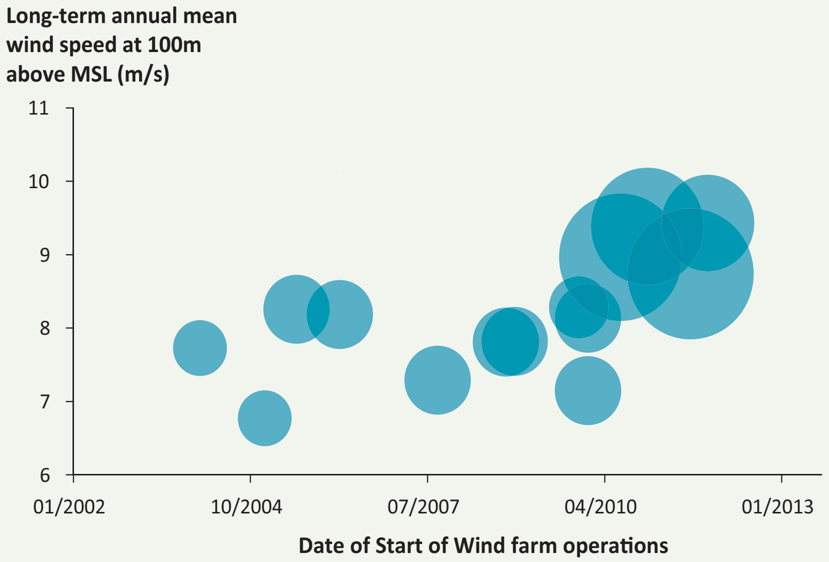
Over the last 3-4 years, wind farms have been installed in sites with increasingly high wind speeds (see Exhibit 3.3). Typically in 2007/8, offshore wind farm sites had annual average wind speeds of between 7 and 8m/s (based on wind atlas data),[22] whilst the four wind farms becoming operational in 2011 are on sites with average wind speeds of 9.5 m/s.

This increase has a considerable impact on the energy generated by wind farms and therefore their LCOE.

For example, the capacity factor of typical current turbines will increase from 28% to 40% when used in sites with wind speeds of 9.5m/s rather than 7.5 m/s, leading to a 40% increase in energy production. Other things being equal, LCOE falls in direct proportion to increases in energy production.

Although no systematic data is collected on the LCOE of wind farms in the UK, the stabilisation of capital costs and the increase in wind speeds for the most recent wind farms give solid grounds for believing the LCOE cost escalation of the past have at least halted, if not reversed.

Exhibit 3.3 UK offshore wind farm site wind speed by year of first operation



Note: Bubble diameter proportion to wind farm capacity.
Average wind speed measured at 100m above Mean Sea Level.

Source: The Crown Estate

[22] Atlas of UK Marine Renewable Energy Resources

Our baseline LCOE estimate is around £140/MWh

Against this background, we estimate baseline offshore wind LCOE of £140/MWh.[23] The key factors underlying this estimate are capital costs, turbine capacity factor and hence Annual Energy Production (AEP), the cost of capital, and operational costs.

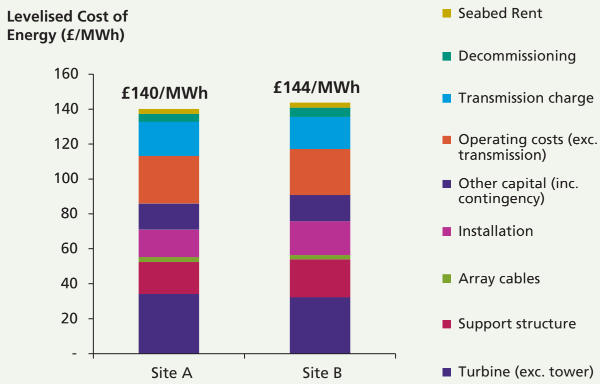
We have estimated FID 2011 capital costs of £2.6m/MW and £2.9m/MW for sites A and B respectively (excluding transmission costs which we consider in the modelling as an annual charge). This is in line with current costs when adjusted for the capital costs of transmission, which represent about £0.5m/MW. Sites A and B are within the range of water depth and distance from shore seen in the most recently announced projects.

We have estimated that the capacity factor of an FID 2011 project as 40% and 42% for sites A and B respectively. This is somewhat above the average capacity factor of 34%[24] for the five commercial UK wind farms for which there is a reasonable body of data. At least three full years of data is needed for analysis owing to the intra-year seasonality of wind speed and the generally low availability of turbines in their first year of operation.[25] Higher capacity factors are expected in FID 2011 because:

- of the higher wind speed of sites A and B (9 and 9.4m/s) compared with between 7.2 and 8.3 m/s for the five commercial UK wind farms for which there is a reasonable body of data.
- our baseline LCOE estimates are based upon the use of turbines with larger rotors for a given rated capacity, which increases the expected capacity factor.

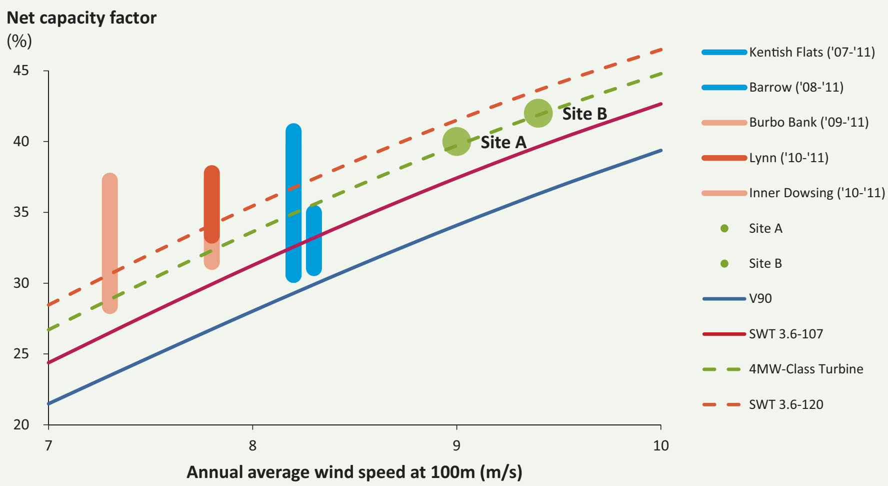
Exhibit 3.4 illustrates both these impacts. The lines show the expected relationship between annual average wind speed and capacity factor based on power curves and typical offshore wind speed distributions. The solid lines show the two most commonly used turbines in the UK (the Vestas V90 and the Siemens SWT3.6-107) and the dotted lines show the recently introduced larger rotor Siemens SWT 3.6-120 and our baseline 4MW-Class Turbine. For any given wind speed the newer, larger rotor turbines have a higher capacity factors. The points are the actual capacity factors for the wind farms using the V90 turbine (Kentish Flats and Barrow) and the SWT 3.6-107 (Burbo Bank, Lynn and Inner Dowsing) plotted against the wind farm average annual wind speed using wind atlas data. This shows that current wind farms are performing better than might be anticipated from wind atlas data. As we have used wind atlas data to determine the wind speeds for sites A and B, this provides confidence that the baseline capacity factors are realistic.

Exhibit 3.5 2011 Levelised Cost of Energy breakdown by component, 4MW-Class Turbine £/MWh



Source: Finance work stream report

Exhibit 3.4 Expected turbine and actual wind farm capacity factor versus annual average wind speed



Note: Actual capacity factors for commercial UK wind farms using the V90 or the SWT3.6-107 turbine. Includes wind farms with more than 3 full years of operation, excludes first full year of operation (ie starting with 2nd full year of operation). Wind farm average actual net capacity factor is plotted against wind speed from the Atlas of UK Marine Renewable Energy Resources.

Operating costs of £164-167k/MW p.a. and a weighted average cost of capital of 10.0% (post-tax nominal), give a baseline LCOE of £140/MWh for Site A and £144/MWh for Site B.

Capital expenditure accounts for just over 60% of LCOE – the majority of which comprises the cost of the turbines, support structure and installation (see Exhibit 3.5).

Operating costs, including transmission charges, are also important, together making up one third of the total. The support structure and installation cost is higher for Site B reflecting the greater water depth.

[23] For site type A. The corresponding figure for site type B is £144/MWh for projects at FID in 2011.

[24] From second full year of operation of each wind farm to December 2011. Covers wind farms using the V90 and SWT3.6-107 turbines rather than earlier models. Wind farms are: Kentish Flats, Barrow Burbo Bank, Lynn and Inner Dowsing.

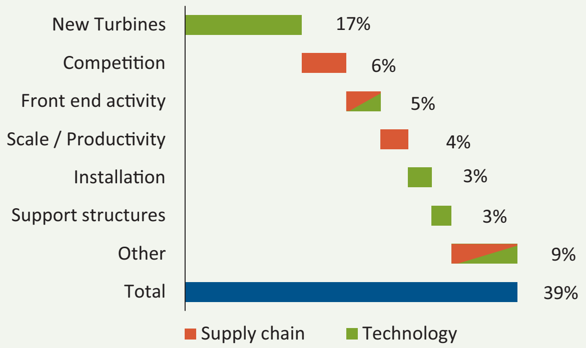
[25] The first full year is not considered due to the 'bathtub' effect. At least 2 further full years of operation is then needed.

There are many, diverse ways in which offshore wind costs can be driven down by technology and the supply chain

Up until now offshore wind farms have largely used products adapted from application in other fields, for example marinised onshore wind turbines and foundations designed using oil and gas industry standards for manned platforms. Similarly the supply chain that serves offshore wind farms is immature and operates on a project-by-project basis. Moving to products specifically designed for offshore wind and industrialising the supply chain provides a large number of opportunities to reduce capital and operating costs and increase power generation. Compared with a wind farm project whose FID is in 2011, FID 2020 projects could reduce the LCOE of offshore wind power by 39% (see Exhibit 3.6).

Exhibit 3.6 Offshore wind power cost reduction opportunities from technology and supply chain

% reduction in levelised cost of energy FID 2011 to FID 2020



Note: FID 2011 refers to a 500MW project whose Final Investment Decision is in 2011. Similarly for FID 2020. The period from FID to completing a wind farm is around three to four years.
The cost reduction opportunities above are based on a comparison of a typical FID 2011 wind farm (3-5MW class turbine) vs. a typical FID 2020 wind farm (5-7MW class turbine).
For this comparison the cost of capital is held constant over time, and all costs are in 2011 money.
Percentages are multiplicative not additive so the total is the product rather than the sum of the cost reduction elements.

The key opportunities for cost reduction are generated by:

- the introduction of **turbines** which are larger, have higher reliability and energy capture and lower operating costs.
- **greater competition** from within the UK, the rest of the EU and from low cost countries in key supply markets (turbines, support structures and installation).
- **greater activity at the front end** of the project including early involvement of suppliers, multi-variable optimisation of wind farm layout, more Front End Engineering and Design (FEED) and more extensive site surveys.
- exploitation of **economies of scale and productivity** improvements including greater standardisation, capturing and building on learning by doing and better procurement.
- optimisation of current **installation** methods.
- mass-produced **support structures** for use in water depths greater than 35 metres.

Other opportunities to reduce cost exist, both from other technology innovations (in particular operations and maintenance), and from the other supply chain levers. However, these generate fewer cost savings or will only become a major cost reduction contributor post 2020.

Introduction of new turbines

Offshore wind turbines will radically change between now and 2020. Existing offshore wind turbines have mostly been marinised versions of the largest available onshore turbines and therefore have been designed primarily to meet onshore market constraints. Offshore many of these constraints are released, eg:

- Visual impact and limits on the size of components that can be transported by road have restricted onshore turbines to a maximum of 3-4MW. Offshore both of these constraints are loosened; taller structures are more acceptable and transport limits are less stringent as large components can be built then transported from dockside locations.
- Onshore noise concerns have limited blade tip speed to 70-80m/s, whereas offshore turbines may have tip speeds of up to 100m/s.

The cost structures of onshore and offshore wind turbines are quite different, and therefore so is the optimum trade-off between size, cost and capacity factor. Onshore wind capital costs are dominated by turbine costs (up to 75% of the total),[26] whereas for offshore wind farms the turbine (including tower for comparative purposes) represents between 40-50% of total capital costs.

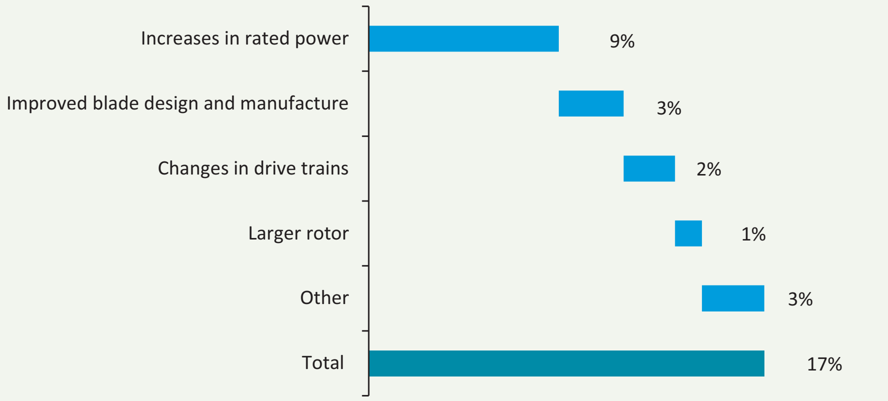
The key expected changes between FID 2011 and FID 2020 are therefore driven by the relaxation of constraints and different economics offshore wind turbines as well as the development of new technologies:

- an increase in rated power of the workhorse turbines 4MW-Class to 6MW-Class (ie from 3-5MW to 5-7MW machines), together with the introduction of 8MW-Class Turbines.
- an increase in the ratio of rotor size to rated power.
- improvements in blade design and manufacture.
- changes in the drive train with improved mechanically geared high speed drive systems and the introduction of new technologies (including mid speed geared, direct and hydraulic drives).

The greatest cost reductions result from the increases in turbine size and changes in blades and drive trains (see Exhibit 3.7).

[26] Source: Intelligent Energy-Europe, 'Wind Energy – The Facts', 2008

Exhibit 3.7 Offshore wind power cost reduction opportunities from changes in turbine



Note: Reflects LCOE reduction opportunities from a FID 2011 4MW-Class Turbine on Site B to a 6MW-Class Turbine FID 2020 on Site B.

Source: Technology work stream report, The Crown Estate

Increases in rated power and rotor size

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 4MW-Class to 6MW-Class or 8MW-Class 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 Exhibit 3.8, where the capital costs of two 4MW-Class Turbines is compared with the capital costs of one 8MW-Class Turbine.

This shows that the decrease in installation and support structure costs leads to an overall reduction in capital costs of about 4%. A similar effect occurs with 6MW-Class Turbines.

This increase in rated power of turbines is also anticipated to reduce operating costs by of the order of 12%. A proportion of operations and maintenance costs (around 3% for the baseline case) are fixed (eg for environmental monitoring and the operations and maintenance base) and do not increase with turbine size.

These cost reductions are combined with an increase in energy production of up to 5% caused by:

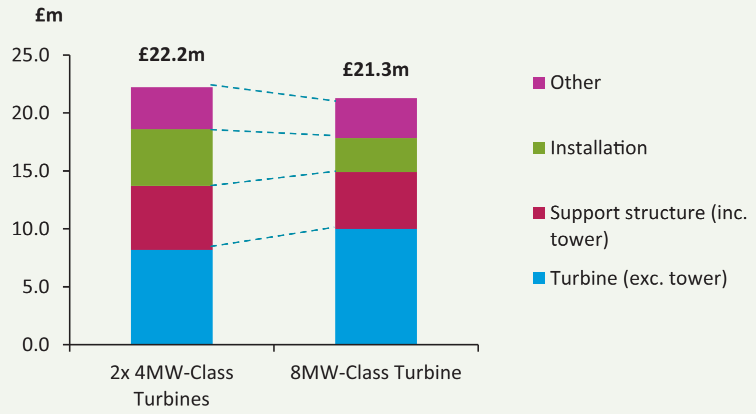
- an increase in hub height wind speed due to the larger rotor size.
- A decrease in aerodynamic losses. Fewer turbines are needed for a given wind farm size and a greater proportion of those turbines can be placed at the boundary of the wind farm hence reducing losses.

An increase in the rated power of turbines reduces capital costs by up to 4-5%, operating costs by up to 10-15% and increases AEP by up to 5% leading to 9% reduction in LCOE[27] per MW.

At the same time as increasing rated power, offshore wind turbines are likely to be fitted with relatively larger rotors, increasing capacity factor and energy production. 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. Therefore the impact of spending more on the rotor (along with knock-on costs on other elements) causes a smaller percentage increase in capital costs offshore than it does onshore.

The key innovation therefore is to produce longer blades at low cost. Input from industry indicates that increasing 6MW-Class 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%.

Exhibit 3.8 Comparison of the capital costs of two 4MW-Class Turbines with one 8MW-Class Turbine, Site B, FID 2011



Source: Technology work stream report, The Crown Estate

[27] The figures relate to the saving available simply due to an increase in rated power. Further savings from other innovations are not included in this figure.

Improved blade design and manufacture

As well as increases in the length of blades, significant improvements are expected in their design and manufacture by FID 2020. This will be achieved by a series of changes including :

- Improved aerodynamics, including new aerofoils and greater use of passive aerodynamic devices such as vortex generators.
- Improved manufacturing, including further automation. Manufacturing costs contribute around 30% of the costs of blades and, based on experience over the last 30 years, can be reduced by a further 25% in the foreseeable future.
- Improvements in blade design standards and process, including greater design optimisation, better material characterisation, improved erosion resistant coatings and improved verification and testing. This builds on the increasing sophistication of design tool software.
- Increased blade tip speed up to 100m/s based on relaxed noise limitations offshore, thereby reducing nacelle loading and therefore capital costs.
- Development of smarter blades including the use of active aerodynamic devices from the aviation industry, increasing blade performance.

Overall, this series of innovation is expected to reduce LCOE by around 3%, allowing for the maturity of the technical innovation and likely market take-up by 2020.

Changes in drive train

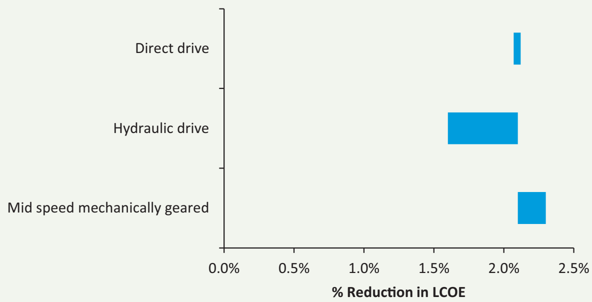
To date offshore wind turbines have used mechanically geared drive trains with high-speed generators to convert the rotational energy from the rotor into electricity. In some cases, the reliability of these drive trains has been poor. The highest profile examples have been the withdrawal of the Vestas V90-3.0MW turbine from the market between early 2007 and May 2008 caused by gearbox problems.

In response to the high costs of maintenance and component replacement, new drive train concepts are in the process of being developed:

- 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.

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. Our analysis shows that each new concept is likely to have a variety of strengths with no clear winner. Overall technical potential of each of these concepts is broadly similar (see Exhibit 3.9), depending on the size of turbine and the site conditions.

Exhibit 3.9 Range of technical cost reduction potential of new drive train concepts



Source: Technology work stream report

Other turbine innovations

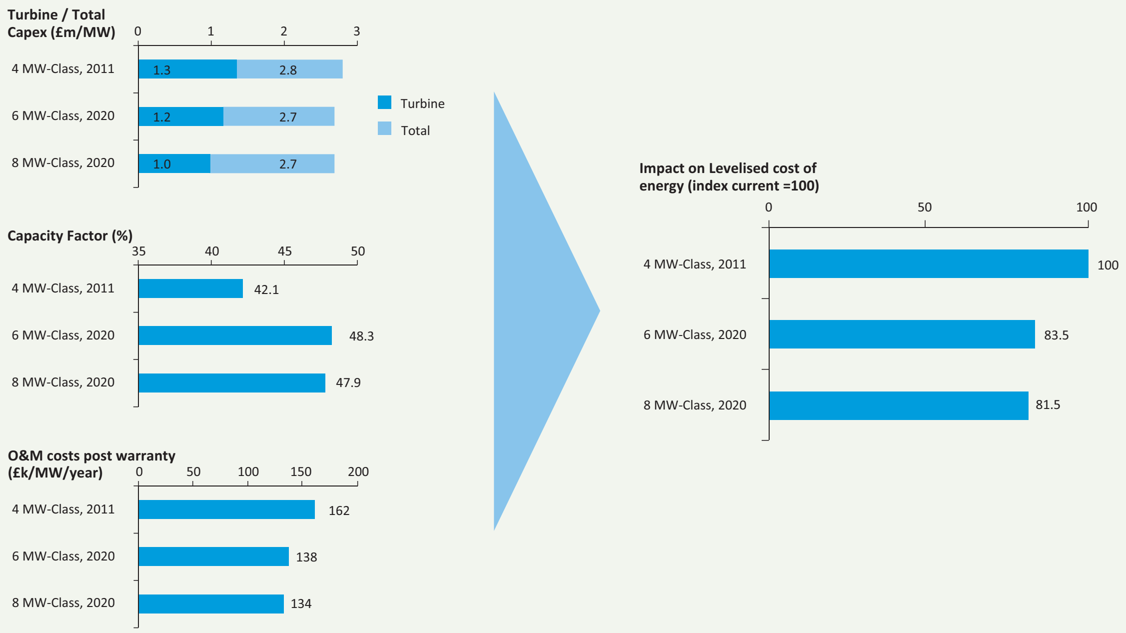
A variety of other innovations related to the turbine have the potential to reduce LCOE by a further 3% by FID 2020 including:

- 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 potential impact on capex, opex and AEP is significant

Overall impact of the introduction of new generation turbines is expected to reduce LCOE by about 17%%. We have illustrated this in Exhibit 3.10 which compares the turbine capital costs, operating costs, capacity factor and LCOE of a 4MW-Class Turbine in FID 2011 with a 6 and 8 MW-Class turbine in FID 2020 both on Site B. This shows that the higher capital costs of new generation turbines will be more that counterbalanced by increased capacity factor and lower operating costs.

Exhibit 3.10 Technical potential impact of turbine technology innovations on LCOE, Site B



Source: Technology work stream report 28

Well advanced plans for new turbines

At least 12 major international equipment manufacturers are actively progressing wind turbines whose output is greater than 4MW, almost all of which are specifically designed for offshore wind applications (see Exhibit 3.11) Prototypes of seven different models are installed, with rated capacity up to 6MW and rotors diameters up to 150m. Plans are in place to prototype 7MW machines with diameters greater than 165m. These will cover all the different drive train technologies.

This quantity of activity provides confidence that some manufacturers will have the new generation of 6MW-Class Turbines available for FID 2014 projects, with more widespread availability for FID 2017 projects.

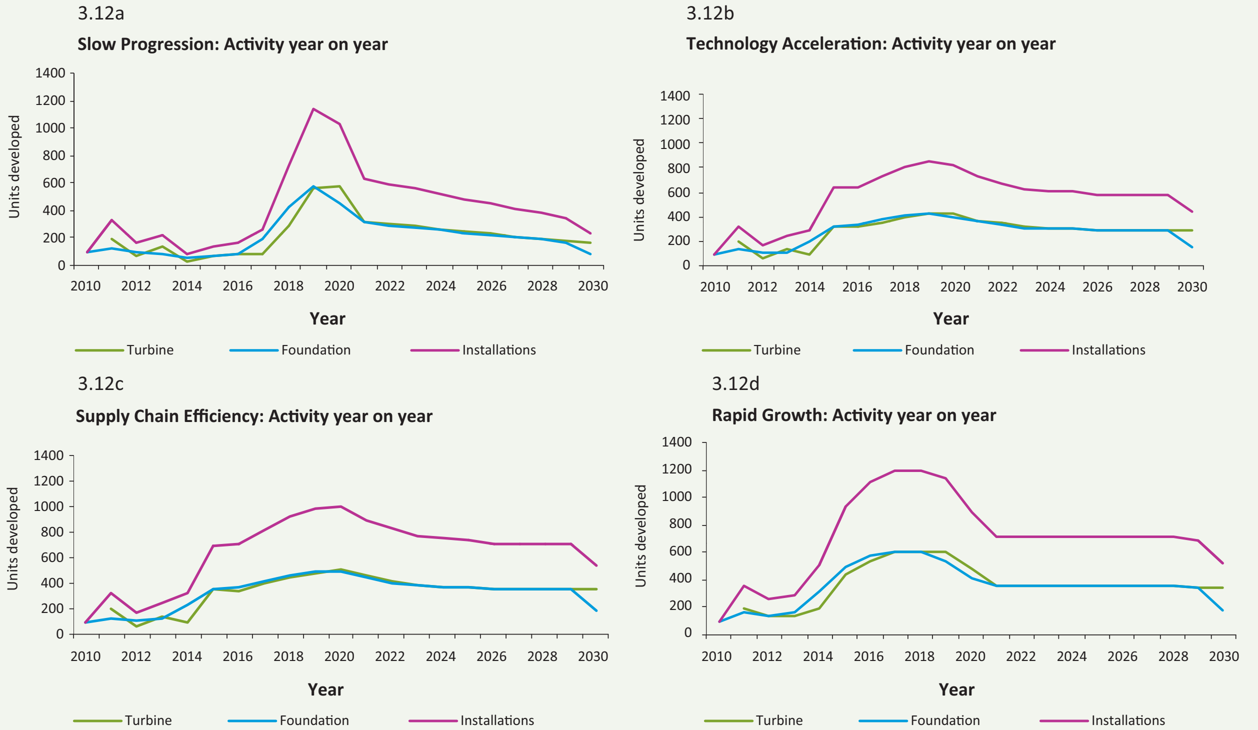
Exhibit 3.11 Status of new turbines (April 2012)

Supplier	Model	Capacity [MW]	Rotor Dia. [m]	Drive Technology	Status	Specific Rated Capacity (W/m2)
Mitsubishi (MPSE)	SEA Angel	7.0	>165	Hydraulic	Onshore and offshore prototypes planned for 2013	TBC
Samsung HI	-	7.0	TBC	Mid speed	Onshore prototype planned for Scotland	TBC
BARD	BARD 6.5	6.5	120	High speed geared	Two onshore prototypes installed in Germany (Jan 2011)	575
REpower	6M	6.2	126	High speed geared	First commercial scale project under construction at Thorton Bank 2012	493
Vestas	V164-7.0	6.0	164	Mid speed geared	Onshore prototype installation planned for 2014	284
Siemens Wind Power	SWT-6.0-154	6.0	154	Direct drive	Onshore prototype of SWT-6.0-120 installed in Denmark (June 2011)	322
Alstom	6 MW Haliade 150	6.0	150	Direct drive	Onshore prototype installed in France March 2012 and production series expected to start in 2014	340
Sinovel	SL6000	6.0	128	High speed geared	Onshore prototype produced in China (May 2011)	466
Goldwind	-	6.0	TBC	Direct drive	Onshore prototype planned for 1H 2012 in China	TBC
AREVA	M5000	5.0	135	Mid speed geared	Areva expects to commence serial manufacture Q2 2014	349
Gamesa	G128-5.0 MW	5.0	128	Mid speed	Onshore prototype of G10X-4.5 MW installed in Spain (June 2009)	389
XMEC Darwind	XV115	5.0	115	Direct drive	Onshore prototypes installed in Netherlands (June 2011) and China (March 2012)	481
GE Energy	GE 4.0-113	4.1	113	Direct drive	Onshore prototype installed in Sweden November 2011	409

Source: The Crown Estate

[28] O&M costs include transmission

Exhibit 3.12 UK offshore wind supply chain activity by year by story



Note: All four charts measure activity in units in an actual year (eg number of turbines, number of installation operations, etc), rather than MW or GW capacity. The average turbine size varies over time and across the stories – with the average turbine size increasing quickest in the Technology Acceleration and Rapid Growth stories to around 6.7MW by FID 2020.

Source: Technology work stream report

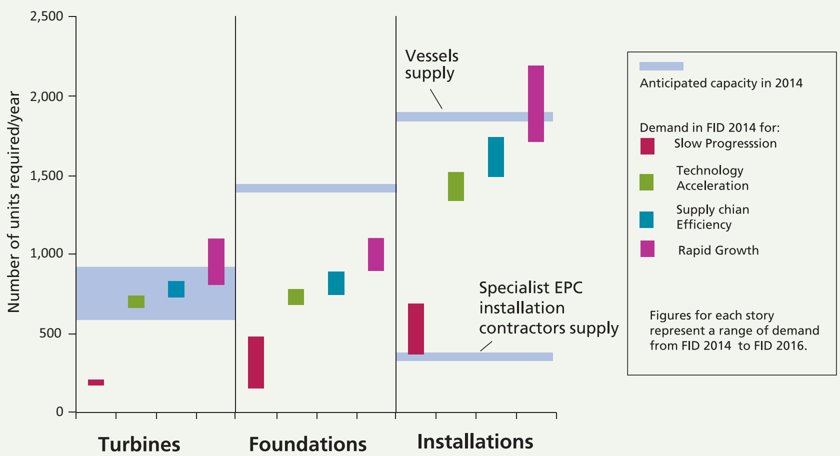
More competitive supply markets will reduce costs

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. We look at each in turn, examining first supply and then demand.

Supply market bottlenecks are likely to be avoided, maintaining competitiveness, provided investment is forthcoming

Based on our four industry stories and assumed build out trajectories, we have assessed the expected demand for turbines, foundations and installation operations.

Exhibit 3.13 European offshore wind supply demand balance by key supply market, for projects reaching FID in 2014



Notes:
Anticipated capacity includes E C Harris's assessment of the impact of new committed investment into the supply chain that will come on-line in 2012-2014. It excludes new UK-based turbine manufacturing capacity which will not come into production before 2015
Demand is for all of Europe in line with the four stories, and is expressed in number of components or operations

Source: Supply chain work stream report

Exhibit 3.12 shows the profile of UK activity by supply market for each of our stories (note: these are activities by actual year rather than the year in which a project reaches FID). This shows a strong peak in activity between 2017 and 2020, particularly in the Slow Progression and Rapid Growth stories. In reality, these are likely to be smoothed out by the wider market, as suppliers will not invest purely to satisfy a short-term UK peak.

In Exhibit 3.13, we compare demand activity against supply in FID 2014 (with the supply picture based on actual 2012 capacity plus announced additions). As the North Sea, Baltic Sea and Channel are accessible to almost all suppliers the scope of this analysis is European. This shows that capacity constraints are unlikely to affect any of the key supply markets in or before FID 2014 in the Slow Progression, Technology Acceleration and Supply Chain Efficiency stories. Only in the

Rapid Growth story are severe supply chain bottlenecks for wind farm installation expected to appear before FID2017. The only exception is specialist installation contractors offering Engineer, Procure, Install and Construct (EPIC) contracts that are in relatively short supply. However developers can overcome this potential bottleneck by multi contracting with individual vessel owners who have the relevant expertise.

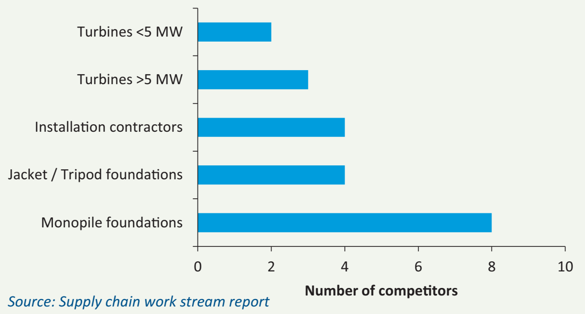
In the past offshore wind has suffered some supply chain bottlenecks as a consequence of high demand from either onshore wind or the oil and gas sector. We have not explicitly considered in our analysis the impact of a resurgent demand for oil and gas offshore services or onshore wind returning to previous growth levels.

More competition will drive down costs

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

In Exhibit 3.14, we highlight the number of players in the turbine, foundation and installation markets at present.

Exhibit 3.14 Current number of competitors by key supply market



Source: Supply chain work stream report

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.

Turbines

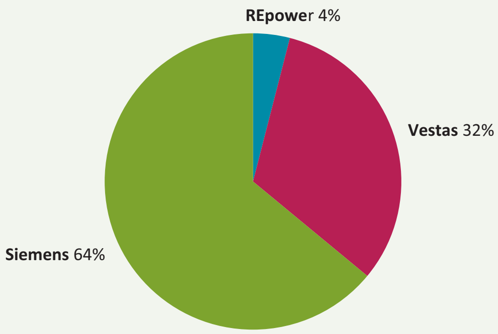
Currently Siemens, which has provided nearly two thirds of all the turbines installed in UK waters (see Exhibit 3.15), dominates the supply of offshore wind turbines, with Vestas and REpower also active in the UK market. Areva has been active in the supply of offshore wind turbines in the rest of the EU, but has yet to supply the UK market.

Ten companies have made announcements indicating an intention to invest in offshore wind manufacturing facilities in the UK and the rest of 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.

Our Technology Acceleration, Supply Chain Efficiency and Rapid Progression stories imply 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. We have, therefore, 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 (see Exhibit 3.16). Many active turbine manufacturers have a high degree of in-house component supply eg 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.

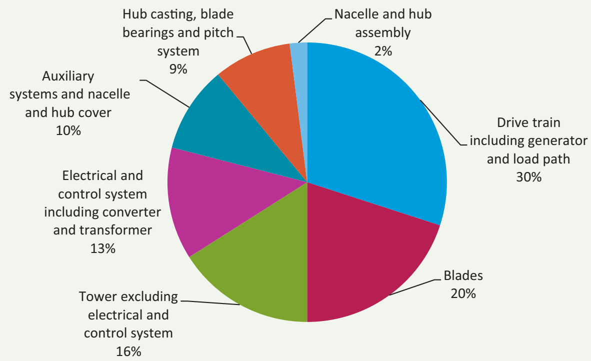
Exhibit 3.15 UK offshore wind turbine market share



Note: based on data for 25 UK wind farms where the turbine manufacturer was stated

Source: Supply chain work stream report

Exhibit 3.16 Offshore wind turbine cost structure



Source: BVG Associates

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. Reportedly, Sinovel have offered a 10% saving compared to Western market leaders.

Overall, feedback from industry indicates that increased competition will reduce turbine prices by up to 15% (excluding warranty) from FID 2011 levels by 2020, lowering LCOE for the whole wind farm by up to 5%.

Support structures

Feedback from industry has generally indicated that space frames will probably be the main support structure, apart from smaller turbines on shallow sites which will continue to use monopiles, and some penetration by (concrete) gravity bases towards the end of the decade. We have used this view as the basis for our modelling. Other well-founded views also exist including the use of monopiles for 6MW-Class Turbines in shallower sites and the much earlier and significantly greater penetration of gravity based foundation. The market will decide the actual mix of foundation types.

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.

The EU demand for offshore wind jackets will be around 800-1,000 units per year from 2017 to 2025 in the Supply Chain Efficiency story, and slightly lower in the Technology Acceleration and Rapid Progression stories. 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. There are considerable logistics difficulties and costs associated with low cost and Far East supply include approximately 35 day shipping duration and potential double handling of preformed large structures. Hence, 'flat pack' or kit form supply is likely to favoured including pre-cut sheet and formed components with either high cost density or good packing density.

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, we expect greater competition to reduce support structure prices by 7% by FID 2020, reducing LCOE for the whole wind farm by around 1%.

Installation

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).

In most cases, the manufacturers themselves provide turbine installation management services. Although new business models may emerge for turbine installation, it seems likely that the supply of turbine installation management services will keep up with the supply of the turbines themselves.

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-table 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. Although the rest of the North Sea offshore engineering market is likely to have high levels of activity related to decommissioning as well as O&M; active participants including Amec, Stadtkraft, KBR, McDermott and Technip may introduce new capacity as the offshore wind foundation installation market grows. Technip for example has established an offshore wind business unit and has invested in sub-sea cable installation capability.

The market for major installation vessels is fairly well balanced. There are currently twelve specialist installation vessels operating in European waters, and a larger number of jack-up barges used for a range of off-shore operations. Delivery of ten further vessels is scheduled for 2012 and 2013. All will have capability to deal with larger monopiles and turbines and waters up to 45m deep. Capacity to deal with larger jacket foundations will also be expanded. EWEA[29] calculated that 12 additional installation vessels will be needed to deliver 40 GW of capacity by 2020 in Europe. On the basis of investment decisions already made, a significant element of this fleet is already on line and may suffer from a short term surplus of supply ahead of growth in installation volumes from

[29] EWEA, Opening Up Offshore, Wind Directions, September 2009

2015 onwards. There are four main vessel providers: A2Sea, MPI Offshore, Seajacks and Seaway Heavy Lifting Based on announced investments, Swire, Fred Olsen, RWE, Workfox and Van Oord will enter the market in 2012/13. The market for vessels is increasingly characterised by alliances and long term relationships between developers and vessel owners. The introduction of additional capacity and new participants during 2012 and 2013 will help to ensure that the market for vessels is competitive and diverse in the medium term

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
- Volker Stevin Marine Contractors
- JD Contractors
- Van Oord
- Technip (who recently purchased SubOcean – formally CNS)
- Subsea7.

Offshore Marine Management and CT Offshore are planning to enter the cable installation market.

By 2020, we expect a well-diversified installation contracting market that will eliminate current undersupply and introduce other new players from oil and gas and other sectors. Greater competitive pressure will lead to cost reductions through the introduction of more efficient processes. For example, large oil and gas installers may be able to optimise practices such as vessel and staff utilisation across offshore work (oil and gas as well as wind). This will reduce installation price by 5% by FID 2020, reducing LCOE for the whole wind farm by around 0.5%.

Overall, increased competition is expected to reduce LCOE by 6% by FID 2020 (including the impacts described above, plus impacts of competition on operations and maintenance costs and array capital costs).

Mass produced support structures

As indicated previously, although a variety of views exist, the basis of our assessment is that space frames will be the most common support structure in the future.

Although there is over 70 years' experience of space frames in the offshore oil and gas industry, the use of space frames in offshore wind has been limited to date.

Currently space frames are designed for each turbine location and manufactured using a batch process with much of the welding done manually. This results in high proportion of tooling and labour costs, commonly two thirds of total costs.

We expect that space frames will be mass-produced in the future leading to considerable cost savings. This will involve automated fabrication and automatic welding and the use of more standardised designs. The standardised designs will tolerate small changes in water depth (so the same foundation design will be used more than once) and use more standard parts such as the tubular sections and other components such as personnel access arrangements.

As a result, production time and cost is expected to reduce by 50%. These innovations are expected to have reached a high level of market penetration by FID 2020, leading to a reduction in LCOE of 2.6%.

Significant steps have already been taken by key players to advance space frame manufacturing. This includes BiFab, which announced in 2010 an investment programme of £14 million to extend its manufacturing facility at Methil, and WeserWind that has invested £90 million in Bremerhaven. Announcements on new facilities should also be expected from existing and new players such as OGN and Heerema.

Greater activity at the front end of the project

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. The drive for more activity at the front end of a project has come from:

- the greater complexity of Round 3 sites, which are larger, often have variable water depth and sea-bed conditions, and grid connection constraints
- a series of lessons learnt from past projects where unexpected cost increases occurred during the installation phase that could have been avoided by more thorough up-front characterisation of seabed and other conditions
- the availability of a wider range of technology that could be implemented on a given site and more advanced understanding to help make choices about the use of this technology.

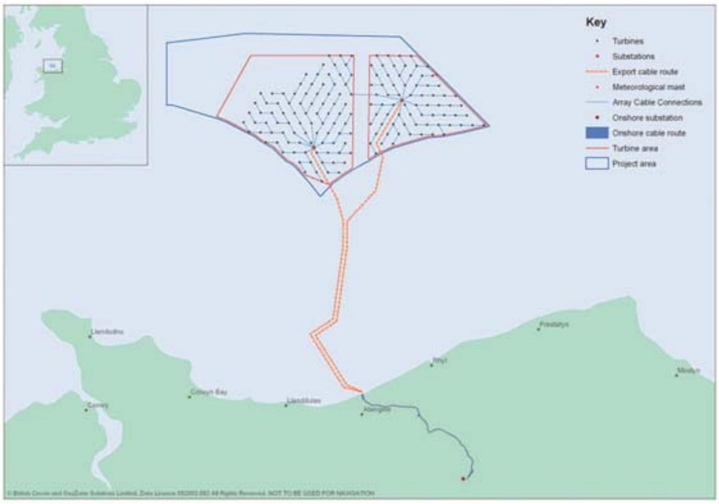
Feedback from industry is that greater investment in wind farm design and optimisation at the development stage will yield considerable cost savings later in the project. The cost reductions will come from both technology and supply change influences. New software tools will drive multi-variable optimisation 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.

Array optimisation

In the relatively benign and uniform conditions of Round 1 and 2, array layout was largely 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 at the cost of higher capital and operational expenditure and less energy production per unit of seabed. Round 3 sites 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.

Exhibit 3.17 Gwynt y Mor wind farm layout



Source: The Crown Estate

Exhibit 3.17 illustrates the nature of these trade-offs at Gwynt y Mor, where the turbines were not installed on part of the site, and, the decision was taken to have two sub-stations and transmission cables.

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.

Overall optimised array layouts could reduce LCOE by up to 2%, however, we anticipate only 40% of this saving will be realised by FID 2020 as progress will be gradual as tools are trialled and then developed to include more variables.

The first steps in the development of optimisation tools are underway. The Carbon Trust's Offshore Wind Accelerator programme has undertaken some initial analysis of parameterised models for wind farm layout. Further early work to develop optimisation tools is underway by a consortium of companies led by DTU Wind Energy as part of a European-funded research project.

Greater use of surveys and optimisation during FEED

The saving from greater use of FEED and greater use of survey data are highly linked, based on a philosophy of higher front-end spend to reduce overall costs.

FEED studies allow developers to choose the basic design concept and the size of the key components. FEED studies 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 (eg to foundations, array cables, electrical architecture, installation method etc). 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.

Often geotechnical and geophysical survey data are available only at turbine locations and with a focus on properties some distance below the sea-bed. This leads to significant uncertainties in cable design and installation. 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 cable 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. On a 500MW wind farm using our baseline 4MW-Class Turbine on Site B, we anticipate an investment of £2m in greater FEED and more survey data will reduce overall capital costs over £30m.
We expect a high penetration of these innovations by 2020, leading to a reduction in LCOE of 1.2%.

Earlier involvement 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
  - More appropriate apportioning of risks
- Reduced over-ordering of steel for support structures through detailed procurement planning

- Reduced operating costs through the early identification and then 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, facilitating maintenance work.

- Better scoping of surveys and improved information flow to component designers.

Earlier involvement of the supply chain is expected to reduce LCOE up to 3.1% by FID 2020 (this is explored further in the Supply Chain workstream report).

Some developers have partnered with suppliers during development indicating that this approach is beginning to gain traction. DONG Energy, for example, has framework agreements with Siemens and Bladt, as well as taking stakes in A2Sea and CT Offshore. SSE Renewables has engaged closely with Siemens, Atkins, Subsea7 and BiFab while Mainstream Renewable Power has Siemens and EMU as development partners.

Optimised installation methods

Installation is a major cost, currently accounting for 18-21% of CAPEX (or 11-13% of LCOE) for projects with FID in 2011. The trend towards larger turbines with higher rated capacities will mean fewer installation operations are required for a given wind farm size. Even with no further innovation, the shift from 4MW class to 6MW class turbines will reduce installation CAPEX per MW by up to 30% (up to 45% if moving from 4MW to 8MW turbines). This saving has been counted as part of the impact of larger turbines, on page XX above .

However, a further reduction of 3-4% in LCOE could be achieved by optimising installation methods and introducing technology innovation in a number of areas.
There is significant opportunity to optimise the current methods of installation by:

- considering installation early in design of projects with suppliers and contractors

- the use of specialist vessels rather than generalist or oil and gas vessels

- an increase in the range of working condition of vessels

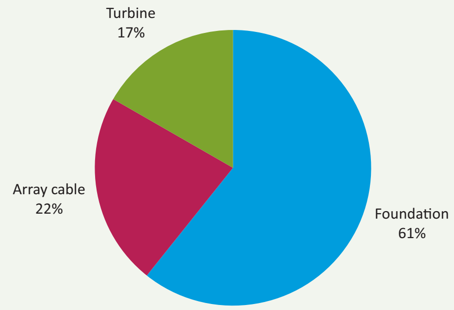
- further optimisation of installation logistics

- using more experienced contractors.

Currently installation is conducted sequentially with support structure (excluding tower) first, then array cables, then the tower and finally the turbine. Support structure installation can occur year round. Array cable and turbine installation occurs March to October. Array cable installation involves personnel transfer to the support structure, which cannot be undertaken in the heavy sea states common in winter. Similarly, the turbine rotor lift is sensitive to high winds. The main opportunities for improvement are in foundation and array cable installation.

In addition there are a number of radically new installation methods currently in development such as 'float out and sink' installation and buoyant concrete gravity base solutions. However these innovations are expected to have limited impact by FID 2020. More detail on these innovations is provided in the Technology work stream report.

Exhibit 3.18 Breakdown of installation capital costs, 4MW-Class Turbine FID 2011, Site B



Source: Technology work stream report

Foundations account for largest part of the installation costs followed by array cables then the turbine (see Exhibit 3.18). This figures shows the breakdown installation costs for a 4MW-Class Turbine FID 2011, Site B with jacket foundations installed using a jack-up vessel.

Three foundation installation technology innovations are expected to have significant impact on costs:

- Improvements to the range of working conditions for support structure installation: The consensus from the study is that increasing the average significant wave height (Hs) working range from 1.4m to 2.5m represents a significant but achievable target, which would reduce weather downtime from around a third for Site Type B with 6MW-Class Turbines to around a fifth and support structure installation costs by 20 per cent. 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 (see Exhibit 3.19).

Exhibit 3.19 Example of the typical characteristics of large foundation installation vessels

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

Source: Technology work stream report

- Greater use of feeder arrangements in the installation of support structures: this can improve the utilisation of the large installation vessels by reducing the amount of time they spend in port and in transit. This has already been demonstrated at the Greater Gabbard wind farm.

- Improvements in the installation process for Jackets: industry indicates that there is scope for optimising the process through the introduction of a bespoke fleet of vessels, each optimised for a specific task, whether pin-piling, support structure installation or grouting. This could shorten the support structure installation process through the use of more efficient vessels, innovations in seabed pile templates and parallel operations, as well as decrease the average day rate for vessels by not using over-specified vessels for less onerous tasks.

Three array cables installation innovations are expected to have significant impact on costs:

- Greater use of specialist array cable installation vessels: Currently, most array cable installation, especially at shallow water sites, is done using barges (which are slow to reposition) or cable installation vessel that are neither wide nor long enough to carry the largest, 7000 tonne cable carousels. Greater use of 100m cable installation vessels will reduce the time taken to load and lay cable.

- Increased range of working conditions: At present, array cable installation involves access to the foundation to pull-in and hang-off the cable through a J-tube connecting the sea bead to the turbine base. Access to the foundation is limited to sea conditions where the significant wave height is at or below 1.4m. Improved access systems (including the use of heave compensated walkways) are expected to increase the upper limit of working conditions to 1.8m. This is anticipated to reduce weather downtime and shorten installation programmes by 8%.

- Introduction of optimised cable pull-in and hang-off: A number of new methods are being developed either eliminating the need for personnel access when the cable is drawn through the J-tube or introducing new turbine connection points. These new methods are expected , on average , to reduce time spent at the foundation interface by 20%, leading to a 6% reduction time in cable installation time.

Together with some more minor changes in turbine installation and allowing for higher day rates for more specialised vessels, optimised installation methods are expected to reduce offshore wind LCOE by around 3-4% by FID 2020.

There are promising signs that new foundations installation vessels are being developed. A2SEA and Teekay are planning to design a DP foundation installation vessel capable of working in water depths of up to 60m and in sea conditions with significant wave heights of up to 3m. Other vessel operators are also expected to make similar announcements in the next couple of years.

Although a number of cable installers have plans for specialised offshore wind cable-laying vessels, none has yet committed to an investment. However, the recent acquisition of cable installer CT Offshore by DONG may well be a precursor to new vessel investments.[30]

Exploitation of economies of scale and productivity improvements

The offshore wind market is still relatively small and dominated by bespoke design and batch production. Strong growth is projected, particularly in the UK.
However, this largely depends on Round 3 projects that have yet to be consented or reach FID. For the supply chain, this means uncertainty around future orders.

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:

- procurement due to volume (rationalising suppliers and obtaining volume discounts)

- ‘learning by doing’ and implementing procedures that allow repetition (doing the same in larger volumes) in a more efficient manner

- standardising processes/protocols thus reducing the need for more expensive bespoke solutions and serial production, standard lengths for array cables

- ‘sweating assets’ or increasing the productivity of existing assets (including manufacturing facilities) by increasing volume throughout.

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

[30] In January 2012 A2SEA acquired a further 29% share interest in the Danish cable installation company CT bringing their total shareholding in the company to 67%. A2SEA is owned by DONG Energy Renewables (principal shareholder) and Siemens Wind Power. During DONG’s ownership, A2SEA have invested in the turbine installation vessel, Sea Installer.

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

Assured pay-back on investment in high capital cost, long lead items

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 will 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. Centrica is known to have part-funded the refitting of an MPI installation vessel to increase its lifting capacity as part of a long-term deal. Based on industry feedback we expect charter savings for vessels and port facilities to reduce installation costs by 4% and about 0.8% respectively. Similar cost reductions (of the order of 4%) may be achieved with long term chartering of cable installation vessels.

Capturing learning through continuity of work
There is often a high level of learning 'on the job' which means that installation rates for projects start slowly and then accelerate before levelling off towards the end. Exhibit 3.20 is based on the actual time taken for turbine installation during a recent UK project showing that the speed of turbine installation increased significantly as the project progressed.

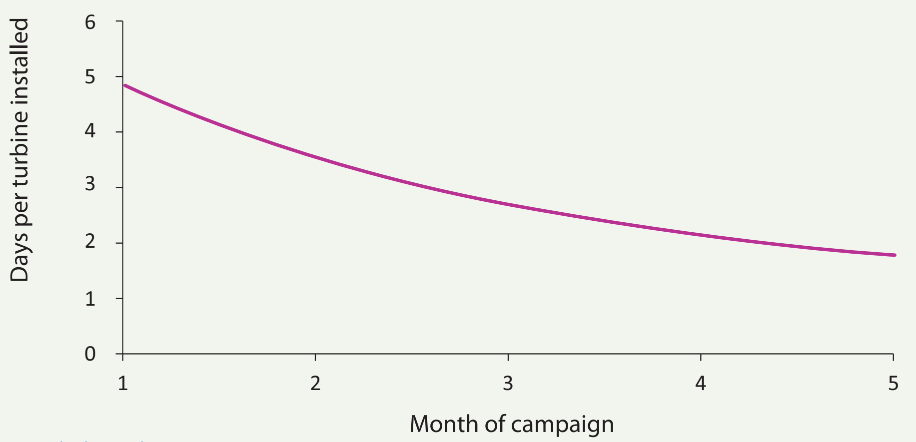
This type of learning must be built upon by increasing the continuity of work either within projects or across a number of projects to ensure collaborative learning brings down average rates to completion.

Standardisation
Greater standardisation of practices, technology and processes throughout the industry will increase the productivity of assets and labour. For example, switching from bespoke, project-specific deck spread design and fitting to common fastening methods for turbines and foundations would speed up installation by 2 to 3 hours per turbine. More standardised vessels would also save handling time at ports. Multi-skilling vessel crews will yield considerable savings particularly in foundation installation where skilled labour could be cut by a half. This would reduce installation costs by about 1% but would require training and acceptance by clients.[31]

Overall, we expect asset growth and economies of scale to reduce installation costs by 10% by FID 2020, which will result in a 1% reduction in LCOE). Given the lead-time for investment, we expect these savings to kick in first in FID 2017. These savings are broadly in line with a recent review of a wide range of infrastructure projects where certainty over workload has driven cost savings.[32]

Examples of volume-base procurement to enable asset growth and economies of scale are beginning to emerge including the extended supply framework arrangements entered into by RWE and REPower, Scottish Power and DONG and Siemens.

Exhibit 3.20 Indicative learning during a turbine installation (single project)



Source: Technology work stream report

Feedback from interviews suggests this trend is typical for all areas of installation, although the learning rate shown here is higher than usual. A vessel operator provided a further example where installation productivity improved by 25% over two seasons by retaining the same vessel and installation crew on a large wind farm project.

[31] The cost of labour in installation represents about 20% of the total costs with 1/3 assumed for foundation installation.
[32] HM Treasury and Infrastructure UK, 'Infrastructure Cost Review: Main Report', 2010.

Support structure

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.
  This would also allow advance bulk purchasing of materials (steel, concrete) and long-term partnering with potential subcontractors. It is also possible to reduce costs through maintaining continuity of workforce schedules: for example by working cyclically it is possible to increase productivity.

- Locating new manufacturing facilities in the UK as opposed to importing from fabrication yards in the rest of Europe would result in about 1% cost savings. These savings are mainly in logistics and transport (as these account for 1-2% of support structure manufacturing costs) and apply to both jackets and gravity bases. Other costs (eg material and labour costs) are similar in the UK and the rest of Europe.

- Standardisation of the industry and practices: this will allow increased productivity of assets and labour. A foundation manufacturer suggested during the workshops that development of a standardised base solution would deliver immediate savings related to design and engineering, together with progressive year on year improvements related to productivity.

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), with first savings seen in FID 2014.

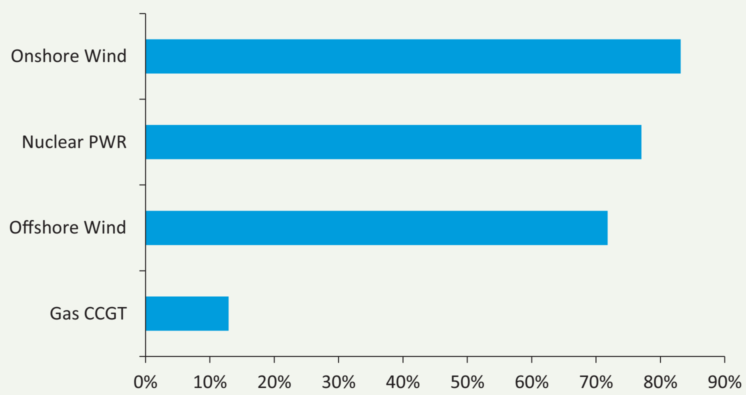
Turbines

Although material, 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. Cost reductions from larger orders of materials/equipment/services (say the equivalent of 100 turbines) can range from 5 to 10%. Investment in new capacity and in particular locating new manufacturing facilities in the UK would also result in about 1% cost savings compared with imports from the rest of Europe. These savings are mainly in logistics and transport (as these account for 1-2% of turbine manufacturing costs). A number of turbine manufacturers have announced their commitment to the UK market and confirmed their willingness to build factories in the UK if there is greater clarity over future volumes.

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), with some benefits seen as early as FID 2014.

Exhibit 3.21 Capital costs as a proportion of total levelised costs



Note: Onshore wind, nuclear PWR and gas CCGT figure are for a project starting in 2013, 10% discount rate

Source: Finance work stream report, and Mott MacDonald, 'UK Electricity Generation Costs Update', June 2010

Financing costs may well reduce slightly

Financing is an important cost element

The initial capital cost of offshore wind (including transmission) currently account for about 70% of the LCOE of offshore wind.[33] Exhibit 3.21 shows that this proportion is very similar to that of nuclear power, but much greater than, for example, Gas CCGT.

As a result of the high proportion of front-up capital costs, financing cost play a significant role in determining LCOE and the quantities of funds required to deploy offshore wind are very high.

Holding all other factors constant, a one percentage point reduction in the cost of capital reduces the baseline LCOE by about 6% or £8/MWh. Future changes in the cost of capital could therefore have a significant impact on LCOE.

Future funding assumptions

Key sources of funding	Current share of UK offshore wind	Key assumptions
UK vertically integrated utilities	50%	• Very limited capacity to raise external funds and no significant growth in operational cash flows before 2015 • Total UK capex held constant until 2015; increasing share allocated to offshore wind over period to 2020
European utilities / IPPs / oil and gas companies	40%	• Continued interest in UK offshore wind provided financial returns remain compelling • Assumed to retain current share of UK projects.
OEMs	10%	• Continue to take minority shares in projects in order to help support sales of technology
Financial investors (pension, insurance and sovereign wealth funds, corporates)	<5%	• Operational projects only. Increasing appetite, particularly post 2017 (replacement of RO-mechanism by feed-in tariff complete) • Some corporate interest (including from Europe and other international

Availability of capital has an important impact prior to 2020

Exhibit 3.22 Total cumulative CAPEX requirements by story (£bn, 2011) [excluding transmission assets]

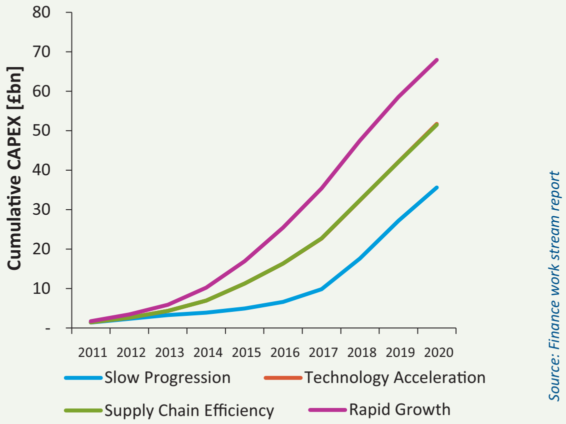


Exhibit 3.22 shows the cumulative funding requirements by story based on the assumed deployment rate. A total of £52 billion is needed by 2020 in the Technology Acceleration and Supply Chain Efficiency stories.[34] This is heavily loaded towards the end of the decade, with £30bn required between 2017 and 2020. The funding requirement rises to £68 billion by 2020 in the Rapid Progress story, with an inflexion point in 2014.

Given the very high demand for funds made by offshore wind deployment, the availability of capital has a crucial impact on the rate of build and the costs of finance.

In the UK to date, most projects have been funded purely by developers' equity through the construction phase; following which some projects have been refinanced, generally 12-18 months post-completion.[35] This is driven by investors' perceptions of risk (see following section). Looking forward, we expect the funding structure of offshore wind farm projects to change only slowly:

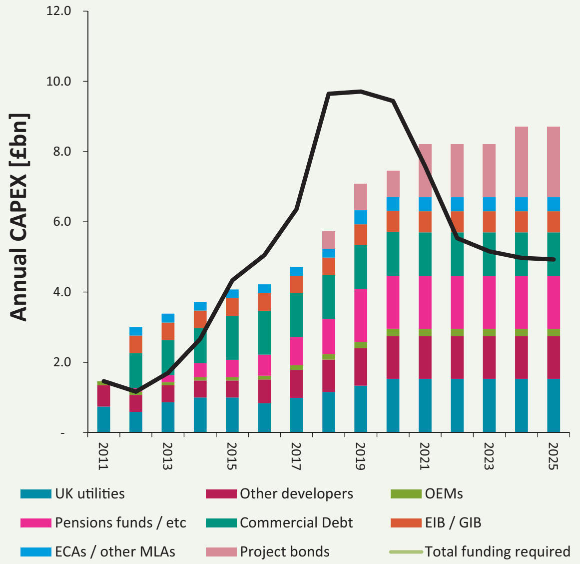
- Up to FID 2017, all construction work will be equity financed. As risk perceptions reduce, in FID 2020 up to 40% of the construction finance could be provided by a mix of EIB / GIB, bank and mezzanine debt.
- We do not believe levels of post construction debt will increase above current levels by FID 2020. In the stories with a relatively higher level of technology risk (Technology Acceleration and Rapid Progression), debt levels will drop to 20-25% in FID 2014 and increase to 30-40% by FID 2020.
- Debt in the form of project bonds will be only available in FID 2020. The offshore wind sector will need to demonstrate to investors that its financial profile matches what they are seeking (eg long term, predictable cash flows) and that its risks (eg technology risk or output variability) are either at an acceptable level or can be mitigated. This demonstration will require significant time and effort. Projects bonds widen the pool of funds that offshore wind farm financiers can draw upon, but do not significantly alter the costs of finance.
- With the availability of debt for offshore wind construction levels unlikely to rise significantly, the critical source of funding will be developer's equity. To date about 50% of the developers' equity has been drawn from UK based vertically integrated utilities, 40% from European utilities and Independent Power Producers (IPPs), and 10% from Turbine manufacturers.
- Our analysis shows, however, that the funding available from the current set of developers is not sufficient to meet the funding needs of any of the industry stories. Based on our developer future funding assumptions (see Future funding assumptions), we estimate a cumulative funding shortfall to 2020 of between £7 billion in the Slow Progression story and £22 billion in the Rapid Progression story.

[33] For baseline 4MW-Class Turbine on site A, FID 2011. Includes transmission costs as part of the initial investment costs.
[34] Excluding funding for offshore transmission
[35] For the purposes of modelling the baseline FID 2011 project, we have assumed 100% equity funding at construction stage, with debt introduced only after about 18 months operation and at a low level of 40% gearing.

Exhibit 3.23 illustrates the funding shortfall in more detail for the Supply Chain Efficiency story. This shows that the key period for the shortfall is between 2015 and 2020 (which will therefore impact on projects at FID in 2014 and 2017, as capital is required over a number of years from FID onwards). From 2020 onwards there is no funding shortfall as the annual funding requirement settles and supply increases. The other stories display a similar pattern with a peak funding requirement in the later part of the decade.

Therefore, it will be necessary to identify additional equity funders willing to take construction risk. This funding will only be available at a return in excess of the 10% baseline WACC. There are a number of ways in which the funding shortfall could be addressed:

Exhibit 3.23 Annual funding requirement compared with available funding, Supply Chain Efficiency Story (£bn, 2011)



Note: Years shown are actual years rather than FID years. The annual requirement for funding has been calculated based on the predicted pattern of expenditure over an assumed 4-year construction period. In other words, a FID 2014 project will require capital to be allocated over the period 2014 to 2018. The corollary of this is that a shortfall in a given year will impact the financing costs for projects at FID for a number of years previous to this.

Source: Finance work stream report

- Existing developers allocating more capital to UK offshore wind
- The entry of new developers such as other European utilities, Asian and American IPPs and corporates
- The introduction of Private Equity (PE) construction phase funding to the UK. PE funding has already occurred in Germany, for example Blackstone's investment in Meerwind.

The required return for this additional funding varies by turbine maturity, site type and story (reflecting the overall demand for additional capital), but is in the range of 18-30%. This reflects a conservative assumption that the additional funding will come from PE investors although it is possible that the opportunity to earn these higher returns could attract capital from other, less expensive sources. There is, of course, a possibility that this funding shortfall is not rectified, particularly in the Rapid Growth story, which would result in delayed projects

The impact of the funding shortfall is significant. In the Supply Chain and Technology Acceleration stories, the use of expensive capital increases the WACC by 0.5%, increasing LCOE by around 2.5% in FID 2017. In the Rapid Growth story, the WACC and LCOE increase are 1.5% and 8% respectively. By FID 2020, however, the balance between the demand and supply of capital improves, and the cost of capital improves accordingly.

As project risk is better understood, managed and mitigated, costs of capital will come down

Based on input from industry stakeholders, we have identified the key project risks that are specific to offshore wind and that will affect expected returns as:

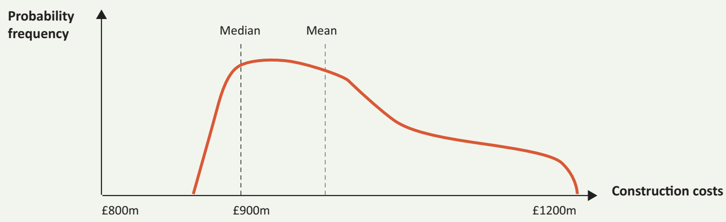
- Installation costs – the potential for out-turn costs to be higher (or lower) than expected
- Operations and maintenance costs – particularly once the wind farm is out of warranty.

The risks to investors are that they may be required to provide additional capital, or the project's completion and energy generation may be delayed - both of which will reduce the overall return on investment.

For both installation costs and operations and maintenance costs, the risk of cost overrun is much greater than the potential for cost saving. This is illustrated in Exhibit 3.24 using installation costs as an example that shows that the downside risk is much larger than the upside. The asymmetry in this distribution creates uncertainty for the developer, which they factor in to their required rate of return (as an increase); and it also has an impact on required debt margins. Through the Finance work stream model, it has been possible to quantify the impact of these project risks on the required equity and debt returns by estimating the relationship between the expected installation cost (or 'P50') and the P90 installation cost – where the P90 cost represents a value that has only a 10% chance of being exceeded. The smaller the multiple between the P90 and the P50 values, the narrower the probability distribution, the lower the level of risk, and therefore the lower the required returns.

We have assessed the impact of the technology and supply chain innovations described throughout this report on the installation and operations and maintenance risks, by assessing how the ratio of P90 to contract price (taken as the median of the probability distribution) will develop over time and across stories.

Exhibit 3.24 Illustrative distribution of installation risks for an offshore wind farm



Source: Finance work stream report

For projects reaching FID in 2011, we estimate the P90 installation factor as 2x the contract price – in other words for the baseline contract price of £611,000 (for 4MW, site B), the P90 value would be £1.22 million. Our assessment is that the installation cost risk is likely to reduce over time as new technology is introduced, and due to supply chain learning and improvement. The largest reductions are expected to occur in the Supply Chain Efficiency story, where the installation risk factor drops to 1.5x by 2020 for 4MW-Class Turbines and 6MW-Class Turbines on site types A and B (see Exhibit 3.25). In this story, the greatest progress is made in developing standardised installation methods and more transparent, less complex contracting structures.

The introduction of a new turbine (6 or 8 MW-Class) in any of the four stories will push the P90 value back to 2x the contract price in the year of its first deployment, as financiers will perceive this to be 'first of a kind' technology.

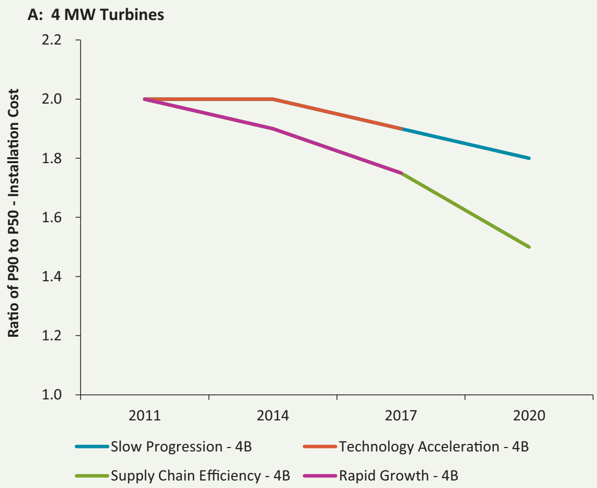
Site types C and D will have higher risk profiles owing to more difficult access, the relative inexperience of dealing with these site types, and the potential requirement for new technology to meet installation and operations and maintenance related activities. Consequently, we expect reductions in the installation risk factor to occur more slowly than for sites A and B. This higher perceived project risk for sites C and D has been factored in to the assessment of the cost of capital for these sites, and therefore the LCOE.

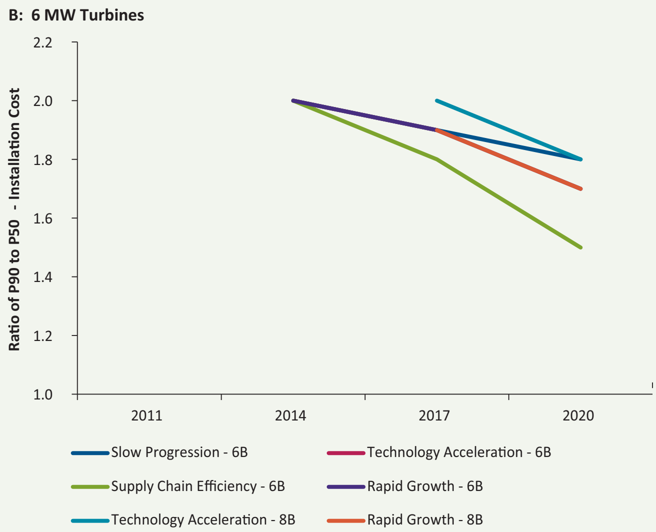
Operations and maintenance risk is broken into two discrete periods: warranty period and post-warranty. The post-warranty period, which we assume covers years 6-20 of a project operational lifetime, carries the greater risk. Once out of warranty, wind farm operators are at risk of having to pay significant amounts for servicing or replacing components that are generally covered under the warranty package.

The post-warranty period operations and maintenance P90 risk factors are illustrated below (for a site type B). We start by assuming a 1.3x multiple between the P90 O&M cost and the contract price; but then the level of risk will reduce as the sector matures over the period to 2020. The timing and extent of change varies by story but is expected to reduce most under the Supply Chain Efficiency story (to a 1.2x multiple by 2020). In this story, most progress is made in the development and relative maturity of the supporting supply chain infrastructure (eg vessel availability, cable supplies) and there is a narrow focus on 4 MW and 6 MW-Class Turbines over the period. New turbine technology (i.e. 6 MW class and 8 MW class machines) will increase the operations and maintenance risk until it has built up sufficient operating hours to demonstrate that it performs in line with expectations.

An example of the overall impact of reduced installation and operations and maintenance risk is to reduce the WACC by 0.4 percentage points, and reduce LCOE by 2% by FID 2020 (for a 6MW-class turbine on site type B in the Supply Chain Efficiency story). The corresponding values for a 4MW-class turbine in 2020, are a 0.7 percentage points reduction in WACC, and 3% reduction in LCOE.

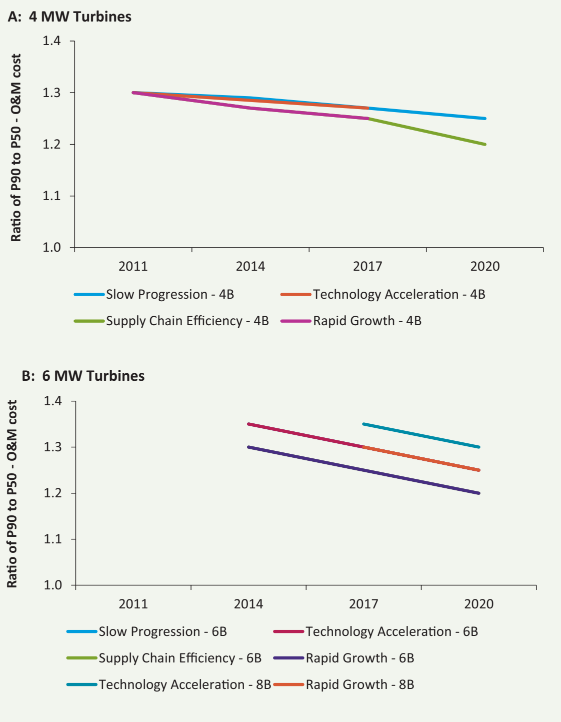
Exhibit 3.25 Installation P90 risk factor, Site B





Source: Finance work stream report

Exhibit 3.26 Post-warranty operations and maintenance P90 risk factor, site B



Source: Finance work stream report

Policy changes will reduce the costs of finance

As part of the proposals contained in the UK government's 2011 Electricity Market Reform White Paper, the Renewables Obligation is expected to be replaced by a feed-in tariff mechanism that would pay generators of low carbon electricity a fixed price per unit of output. The rationale behind this proposal is that it will reduce the overall risk of investing in projects by removing some of the price uncertainty under the Renewable Obligation framework. Any such reduction in systematic risk should be reflected in a lower cost of equity and hence a lower WACC. The reduction in risk will also help attract new classes of investor, such as pension funds, particularly to operational assets, thereby allowing developers to recycle their equity for other projects.

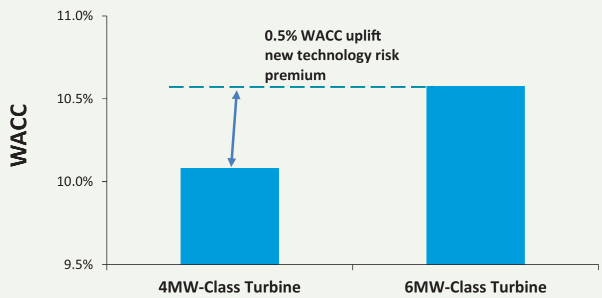
On the other hand, a feed-in tariff will remove the potential for equity holders to benefit from any upside from rising power prices, a benefit they currently derive under the Renewables Obligation framework. Some market participants have suggested that removing this upside reduces the overall attractiveness of investing in offshore wind. Therefore any reduction in price risk could be partially offset by the addition of an equity premium. On balance, we expect that the introduction of a feed-in tariff mechanism will reduce the cost of equity by 0.5 percentage points based on a reduction in the asset beta from 0.6 to 0.5.[36] Although the feed-in tariff will be available from FID 2014 onwards, it will take time before the market fully incorporates the full reduction in risk into the cost of capital; as a result the change in the asset beta is applied only to projects reaching FID from 2017 onwards.

New technologies will increase the costs of finance

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 including the track record of the technology developer, the strength and credibility of performance guarantees and the degree of testing of the technology.

Exhibit 3.27 compares the WACC of a 4MW-Class Turbine reaching FID in 2014, with a newly introduced 6MW-Class-Turbine both on site B. This shows that the introduction of a new turbine is expected to increase WACC by 0.5 percentage points.The LCOE impact of the WACC uplift is about £4/MWh. This uplift will erode with time and by FID 2020 is expected to be 0.2% percentage points or equivalent to around £1.5/MWh.

Exhibit 3.27 Weighted average cost of capital by turbine class, site B, FID 2014, Slow Progression story



Note: Post-tax nominal

Source: Finance work stream report

Overall costs of finance will drop by around one percentage point

Exhibit 3.28 illustrates the effect of the above changes on the WACC of the workhorse turbine, starting with a 4MW-Class Turbine in FID 2011 and ending with a 6MW-Class Turbine in FID 2020 (site B, Supply Chain Efficiency story).

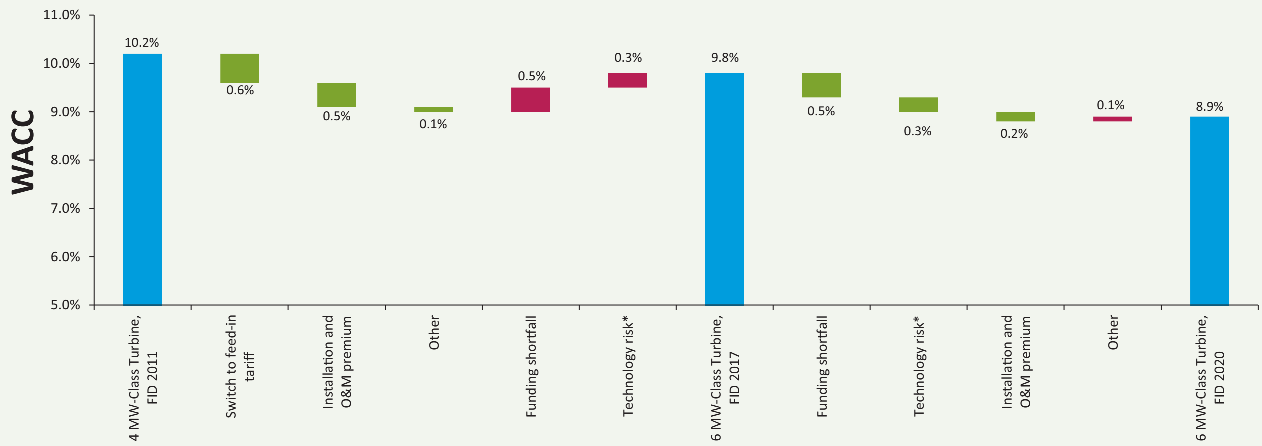
The WACC of the workhorse turbine only shows a small decrease from 10.2% in FID 2011 to 9.8% in FID 2017. The reduction in WACC from the policy change to a feed-in-tariff and lower installation and operations and maintenance risk is counterbalanced by the increases in WACC due to the increase in returns required to rectify the funding shortfall and an increase in technology related risk.

A more substantial reduction in WACC is expected between FID 2017 and FID 2020 because of the elimination of the funding shortfall and reduced technology and installation and operations and maintenance risk as the 6MW-Class Turbine matures further.

[36] See section 4, finance work stream report

The impact of this reduction in the cost of finance is to reduce LCOE by about £10/MWh by 2020. A similar pattern is seen across the other stories and sites, although site C and D have a higher starting point in terms of WACC.

Exhibit 3.28 Changes in Weighted average cost of capital, Supply Chain Efficiency story, site B



Source: Finance work stream report

Note: * Impact on cost of equity through the Developer Premium

Although not a core part of this study, we believe there are opportunities to reduce transmission costs

Electricity transmission infrastructure typically accounts for around 15-20% of the capital costs of developing an offshore wind farm (equivalent to 10-15% of the LCOE). To date, transmission infrastructure has been developed by wind farm developers as part of integrated projects. Given the licensing requirements in the Electricity Act 1989 however, following commissioning, these assets must then be transferred to a third party (OFTO) via a competitive tender process run by Ofgem. Given the range of current policy initiatives – including in terms of network coordination, transmission charging and interconnectors – there is a uncertainty about the future policy framework for offshore transmission. For these reasons, transmission was not included as a core part of this study. Nevertheless, despite this challenging backdrop, work undertaken by RenewableUK has identified that there are opportunities to reduce the cost of transmission over the short to medium term.

The workshop approach for considering transmission cost reduction opportunities took both a 'bottom up' and 'top down' perspective. Under the bottom up approach, 11 priority cost reduction opportunities were identified and it is clear that that the potential for cost reductions derives from a wide range of sources, such as:

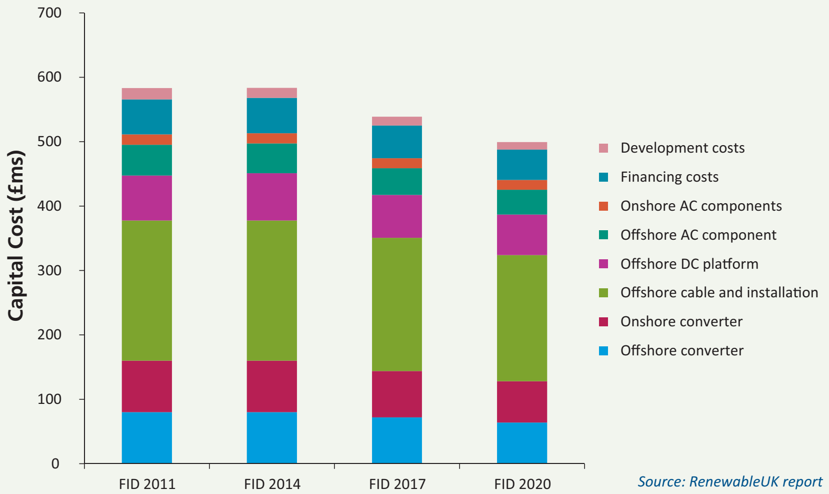
- reduced capital costs;
- reduced risk (thereby reducing cost of capital);
- shorter development and construction periods (thereby reducing financing costs);
- lower O&M costs; and
- reducing plant depreciation costs (by extending asset lives).

The outcome of this process yielded a range of potential capital costs reductions of between 27-63%. It is highly unlikely that this cumulative total would be achievable. It is important to note, however, that each opportunity was reviewed on its own merits and no explicit consideration was given to whether any of the opportunities were mutually exclusive or co-dependent. This will be an important future step.

The top down approach considered potential cost reduction from the viewpoint of a likely trajectory of transmission costs to 2020 for two hypothetical wind farm projects (one near shore AC connected project and one far shore HVDC connected project). This was a separate exercise from the bottom up approach and provides an alternative perspective on cost reduction potential.

For each project, key assumptions were made about the network design based on the example configurations provided in the 2011 ODIS.[37] Baseline costs for 2011 were then assumed for the main assets of these network designs, where possible using information in the public domain.[38] The workshop approach was to consider a trajectory of costs at intervals to 2020, based on participants' expectations of future developments. The RenewableUK report identifies a cost reduction range of between 5.5-11.5% for the near shore project and around 14% for the far shore project.
Exhibit 3.29 illustrates the potential cost trajectory for the far shore HVDC project.

Exhibit 3.29: Potential cost trajectory for hypothetical far shore project (2011 prices)



Source: RenewableUK report

Key reasons identified for the potential cost reduction trends included:

- greater standardisation, for example with respect to platform design,
- technology improvements,
- improved installation techniques, for example for cabling,
- more suppliers in the market, and
- improved risk management processes

The process followed to uncover cost reduction opportunities in transmission was much more limited than for other parts of the value chain and so the results must be considered as illustrative and qualitative only at this stage. It is also recognised that there is also work ongoing on some of the issues identified, for example in terms of encouraging network coordination and further development of the OFTO regime.

Nevertheless, the opportunities and indicative cost reductions identified are important 'signposts' as to where detailed follow up should be focused in order to understand the likelihood of realising the opportunity.

[37] Appendix 1 of National Grid (2011) Offshore Development Information Statement
[38] Capital costs largely from National Grid (2011) ODIS; financing and development costs based on OFTO transactions completed to date.te

Scope for further cost reduction exist beyond 2020

The focus of this study is on offshore wind farm projects reaching FID in 2020. However, we have identified a number of ways in which offshore wind costs could continue to fall beyond 2020.

Unexploited technology potential

Many of the technology innovations identified in the Technology work stream report will not be fully exploited by projects reaching FID in 2020. Of the top 12 innovations (ranked by potential impact) for a 6MW-Class Turbine, 11 have more than half of their potential unused by FID 2020 (see Exhibit 3.30). Therefore, there is considerable scope for cost reduction beyond 2020 simply by fully utilising innovations that are currently being developed and introduced or can be foreseen now.

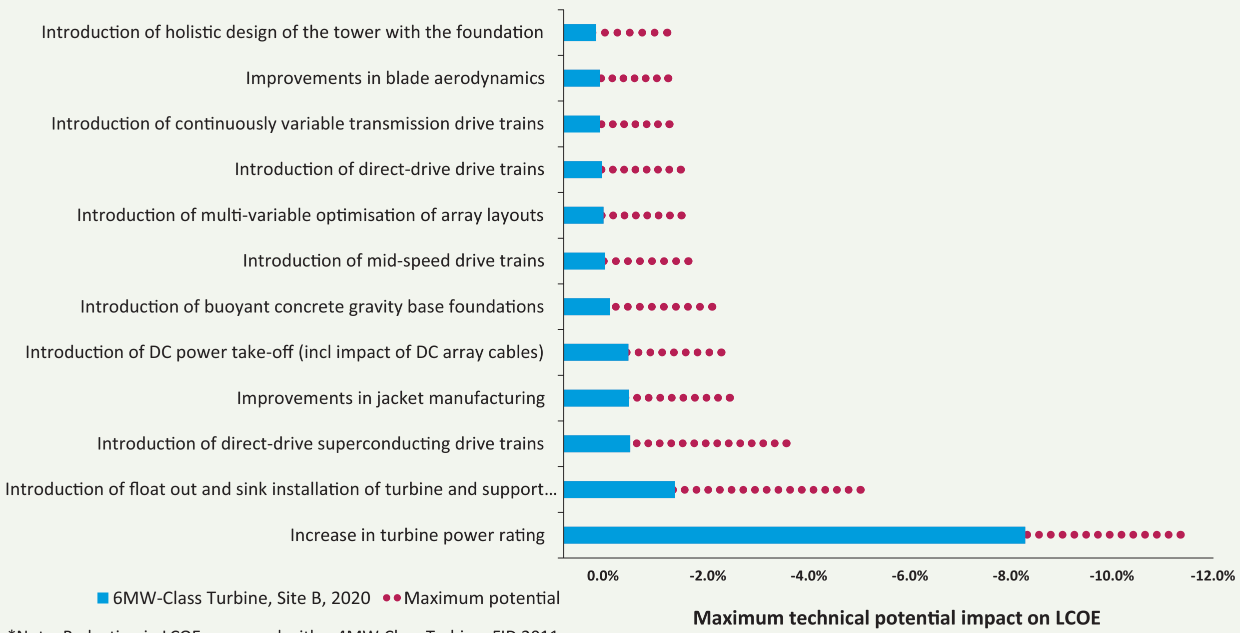
Radically new technology

We have only examined technologies whose impact can be foreseen with some degree of accuracy. A number of radically new technologies are in the course of being developed. They have the potential to further reduce the LCOE of offshore, possibly very sharply. Should any one of these be successfully developed, then the impact is likely to begun to be felt in the next decade.

Unexploited supply chain opportunities

Feedback from industry indicated that a significant cost reduction prize was attainable through supply chain improvement of operations and maintenance costs. This will only become available to the industry once turbines are out of warranty (usually five years) and a supply base has built up. The view of industry is that insufficient experience will have been acquired by 2020 to allow these savings to be bankable by this time. However we expect these savings to be realised and bankable for projects in the course of the next decade.

Exhibit 3.30 Potential and anticipated FID 2020 LCOE impact* of top 12 innovations for 6MW-Class Turbine, Site B)



*Note: Reduction in LCOE compared with a 4MW-Class Turbine, FID 2011. Only considers relevant innovations.

Source: Technology work stream report


OR-A5

4 Cost Reduction Pathways

This section sets out the key results of the study in the form of 'pathways' for cost reduction to 2020. As outlined in Chapter 2, a 'pathway' combines assumptions on the evolution of the offshore wind market to 2020 with the characteristics of a number of generic site types. Exhibit 4.1 provides an overview of the assumptions made on the evolution of the industry – or the 'stories' considered:

Our analysis has considered the extent to which the cost reductions outlined in Chapter 3 can be realised under each of the stories. To be clear, the figures presented in this chapter do not represent a forecast, but an illustration of the cost reduction possible under each set of assumptions.

£100/MWh is challenging but achievable by 2020

Exhibit 4.2 provides trajectories for the Levelised Cost of Energy for each of the industry stories. The figures represent the average project reaching Final Investment Decision (FID) in each year. It has been necessary to make assumptions concerning the mix of sites under construction and coming into operation at each point in time (ie the transition towards more challenging Round 3 sites and sites in Scottish Territorial Waters), and the mix of technologies being deployed (see Appendix 2 for assumptions).

Exhibit 4.3 provides a high level breakdown of the overall cost reduction to 2020 across the key research areas considered: technology (including transmission), supply chain, and finance.

Exhibit 4.1: Summary of Industry 'Stories'[39]

Finance & Supply Chain (vertical axis: Incremental improvement → High innovation)

3. 'Supply Chain Efficiency'

- 36GW in Europe by 2020 (17GW in UK)
- Incremental technology evolution (e.g. steady progress to 5-7MW turbines)
- Greater competition, investment, project collaboration and better risk management
- Deeper financial markets, lower risk/lower cost of capital

4. 'Rapid Growth'

- 43GW in Europe by 2020 (23GW in UK)
- High levels of technology evolution across all wind farm elements (e.g. turbines progress rapidly to 5-7MW+)
- Greater competition, investment, project collaboration and better risk management
- Challenging volume of finance required

1. 'Slow Progression'

- 31GW in Europe by 2020 (12GW in UK)
- Incremental technology evolution, progress limited by market size
- Limited competition/economies of scale
- Modest developments in financing solutions, reduced in risk/cost of capital

2. 'Technology Acceleration'

- 36GW in Europe by 2020 (17GW in UK)
- High levels of technology evolution across all wind farm elements (e.g. turbines progress rapidly to 5-7MW+)
- Fragmented supply chain with some improvement in collaboration
- Limited improvement in cost of capital due to ongoing changes in technology

Technology (horizontal axis: Incremental improvement → High innovation)

[39] Note: all GW capacity figures relate to operational capacity by 2020

There are several possible pathways to cost reduction

Our analysis shows that in three of the four industry stories we have explored, the levelised cost of offshore wind projects could be £100/MWh or less by FID 2020 (measured in real 2011 prices):

- **Story 2 – Technology Acceleration:** this scenario assumes a high degree of technological progress, coupled with a sizeable market, with 17GW operational capacity in the UK by 2020. Under these assumptions, our analysis shows the LCOE could reach £100/MWh by FID 2020, mainly through technology-related cost savings. Under these conditions it is more difficult to realise supply chain and finance savings due to the ongoing changes in technology.

- **Story 3 – Supply Chain Efficiency:** in this scenario, the focus of the industry is on improving the competitiveness and efficiency of the supply chain, with more modest incremental improvements in technology. This set of assumptions reaches a slightly lower LCOE of £96/MWh by FID 2020; through a mix of technology, supply chain and finance savings.

- **Story 4 – Rapid Growth:** this scenario assumes a larger market (23GW UK operational capacity by 2020), plus significant progress both in technology and the supply chain. Under this ambitious set of assumptions it is possible to achieve an LCOE of around £89/MWh by FID 2020, through a mixture of technology and supply chain savings. Finance-related savings would be limited under these conditions owing to the challenging volume of finance required (hence the need to resort to more expensive forms of capital), and the increased risk-pricing associated with using new technology.

- **Story 1 – Slow Progression:** this scenario assumes incremental advances in technology and supply chain development, and smaller market growth in the UK, providing only 12GW operating capacity by 2020. Under this set of assumptions it is only possible to reach an LCOE of around £115/MWh in 2020.

As described in Chapter 1, the Renewable Roadmap published by DECC sets a goal for the Levelised Cost of Energy from offshore wind to reach £100/MWh for projects becoming operational in 2020. As the period from FID to full operations is typically 3-4 years, the equivalent milestone for this target within the pathways framework is actually around FID 2017. Our analysis shows that the £100/MWh target is not met by FID 2017 under any of the stories explored, but would instead be met by around 2018-19 (in story 4) or 2020 (in Stories 2 and 3).

Exhibit 4.2: Levelised Cost of Energy (LCOE) under the four industry 'Stories'

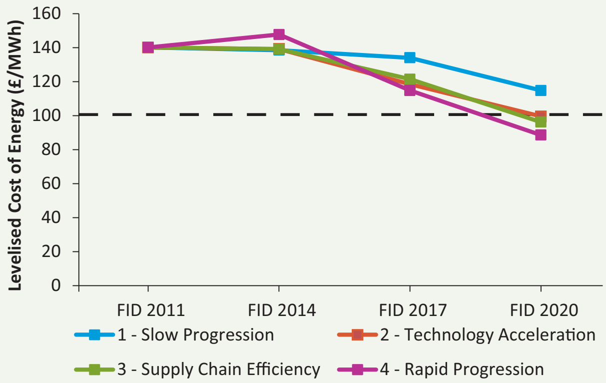
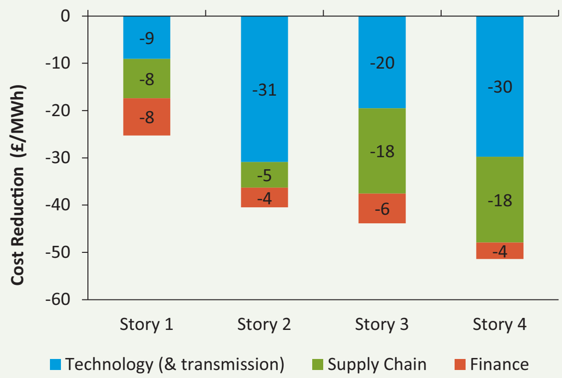


Exhibit 4.3: Breakdown of cost reductions to 2020 (versus 2011 baseline)



Story 2: Technology Acceleration

Key assumptions

This story explores what would happen if the industry goes down a technology-driven route. The feedback from participants through this project was that though rapid technology progress may lead to cost reduction in itself, it may also limit savings and progress in terms of the supply chain and finance. This is due to a concern that the supply chain would remain fragmented (with limited economies of scale or standardisation), and it would take longer for financiers to become accustomed with the risk profile of each new technology as it is introduced. Key assumptions of this story are as follows:

Exhibit 4.4: Story 2 Key Assumptions

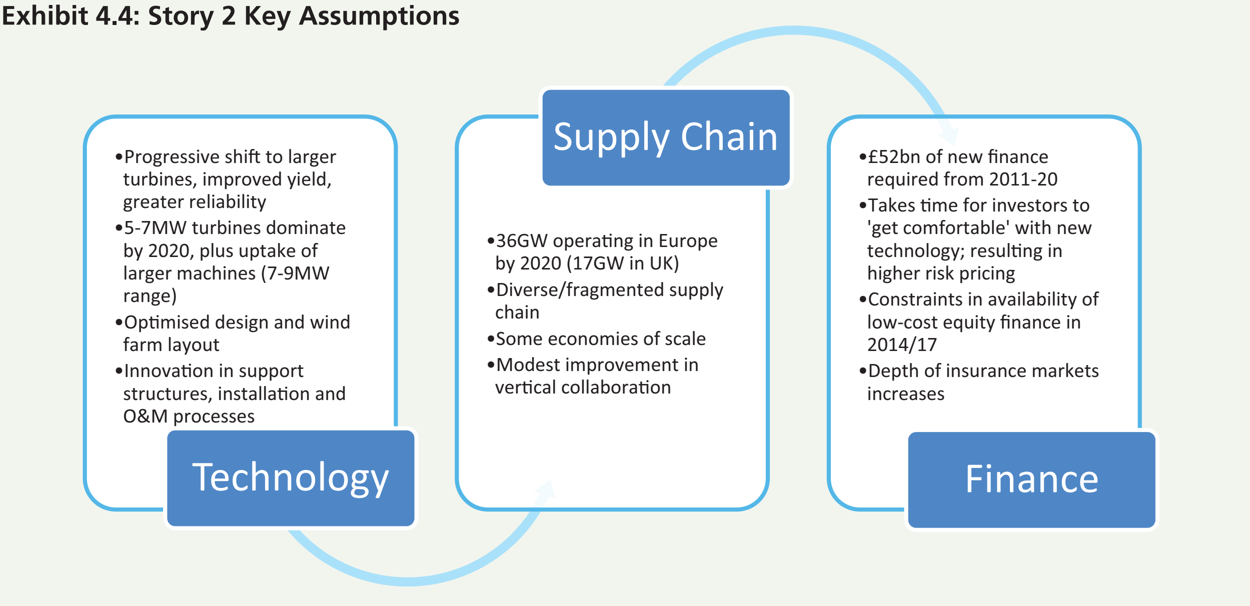


Exhibit 4.5: Story 2 Capacity Trajectory

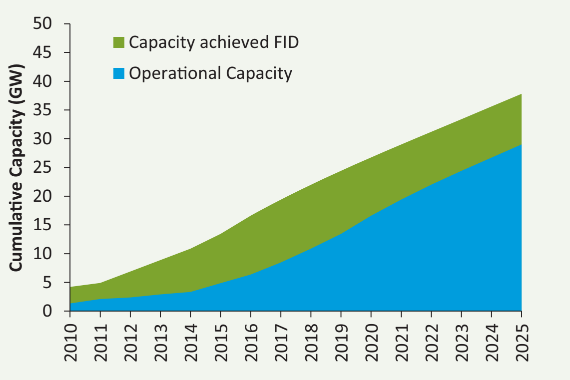


Exhibit 4.6: Story 2 Turbine Mix

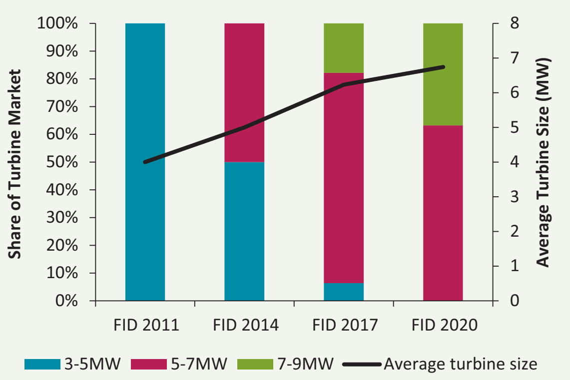


Exhibit 4.7: Story 2 Cost Trajectory

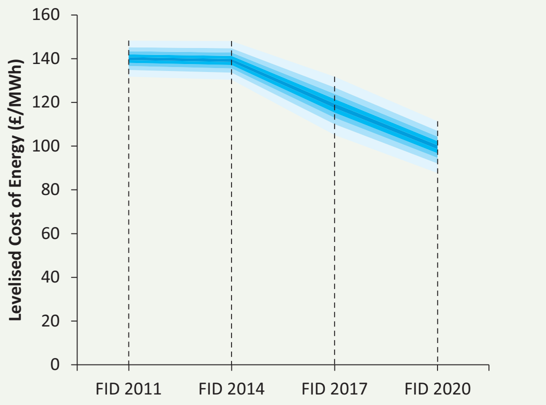
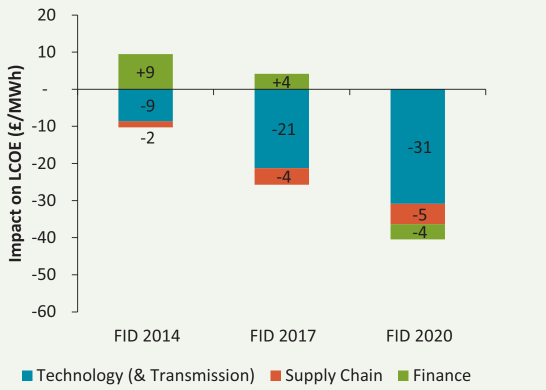


Exhibit 4.8: Story 2 Breakdown of Savings



Results: New technology offers significant potential for cost reduction

Exhibit 4.7 shows the trajectory for the levelised cost of energy under Story 2: Technology Acceleration. This shows a range of costs around a central trajectory. The central trajectory represents the 'average' project at FID in a given year; with the range representing the fact that at any time there will actually be a number of projects using a range of different technologies and across a range of site conditions.[40] Exhibit 4.8 shows the breakdown of cost savings over time in this story across Technology (including transmission), Supply Chain, and Finance.

In all stories, the baseline cost for a project at FID in 2011 is £140/MWh (+/- £8/MWh). Under the Technology Acceleration Story, the central view is that costs will reduce to £100/MWh by FID 2020 (+/- £12/MWh) – a reduction of 29% relative to the baseline. The primary reasons for this improvement are as follows:

- The primary source of cost reduction by 2020 is in **technology** improvements – which amount to a £31/MWh (22%) saving by 2020. This is primarily due to a rapid shift to next generation offshore turbines which are larger, have bigger rotors and more reliable drive trains, and are designed specifically for the marine environment.
  This scenario assumes that 6MW class turbines dominate by 2020, together with a significant market share of larger machines in the 8MW class. As explored in Chapter 3, turbine innovations may result in a higher turbine CAPEX per MW, but make a significant contribution to reducing LCOE through improved reliability and energy capture, and reduced O&M costs per MW. There would also be a significant contribution from other technological advances such as improvements in support structures, installation methods, and O&M strategies.

- However, there would be limited improvement in the **supply chain** in this scenario due to a lack of supply chain maturity. Due to the high levels of technology innovation and the wide range of products and services in the market, the supply chain would remain fragmented and fail to achieve significant economies of scale or competition. There may be a modest saving (£5/MWh, or around 4% off the baseline LCOE), attributable to supply chain factors, such as improvements in vertical collaboration – better management of interfaces within the supply chain.

- Similarly, the saving related to **finance** would also be limited – at £4/MWh or 3% of baseline costs by 2020.
  In this scenario, the ongoing changes in technology would mean that developers and financiers would continue to perceive projects as using 'first of a kind ' technology, and therefore attach a relatively high risk premium when calculating their cost of capital. The risk profile for newer turbines would also deter some forms of investors such as pension funds, institutional equity or insurance equity. There may be some downward pressure on the cost of capital due to industry learning and risk reduction over time. However this would be offset by an upward pressure on the cost of capital due to the challenging volume of capital required (particularly in FID 2014), which would mean that developers would have to resort to more expensive forms of capital.

- The charts show that there would be virtually no progress in LCOE between 2011 and 2014, with the savings only emerging after FID 2014. This is due to the fact that in FID 2014, the possible savings related to technology and supply chain would be offset by an increased cost of capital as a result of the financing challenges outlined above. Also, some potential Technology savings may not be passed through to customers as reduced prices due to insufficient competition at this stage. However, by FID 2020 the finance 'penalty' would be remove, as the demand/supply balance of finance is projected to improve (with greater capacity and reduced demand); and greater levels of competition would mean that technology and supply chain savings are passed through to customers to a greater extent.

[40] The shaded range has been calculated on the basis of variance form the 'average' wind farm, and is an approximate indication of the P5 to P95 range of outcomes (ie there is a 90% probability that the LCOE would lie in this range on the basis of the information available and modelled outcomes).

Story 3: Supply Chain Efficiency

Key assumptions

This story explores what would happen if the industry focuses on maximising improvements and efficiencies in the supply chain – such as realising economies of scale, attracting new entrants to the market to create competition, and increasing collaboration. In this scenario, it would still be possible to make some improvement in technology (albeit not as rapidly as in Story 2); and there is significant scope for improvement in the finance and insurance markets, as financiers and developers get comfortable with the technology and risk is reduced.

Exhibit 4.9: Story 3 Key Assumptions

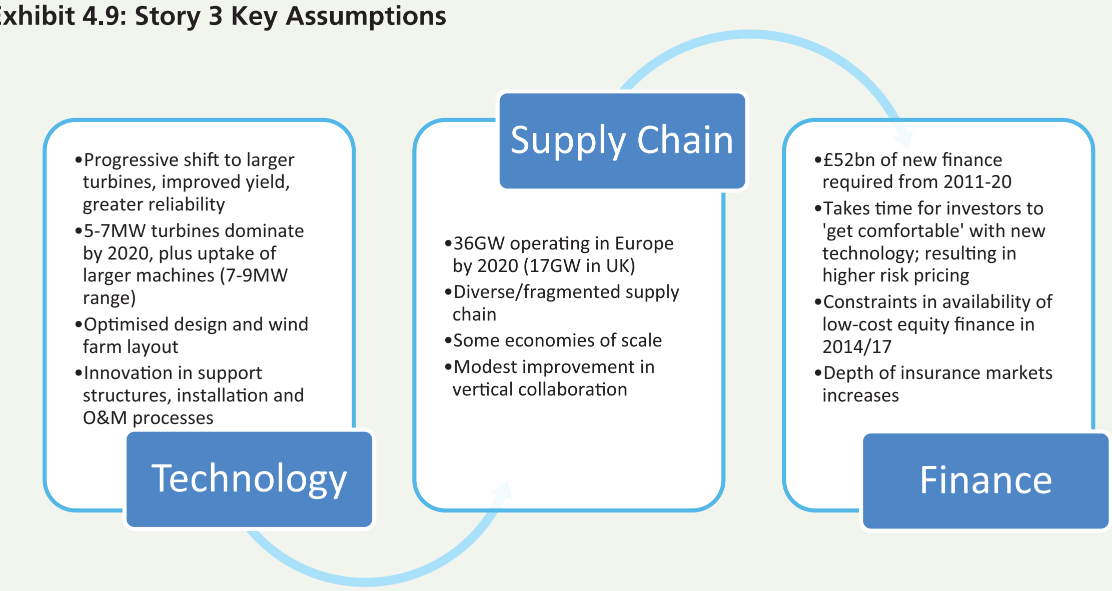


Exhibit 4.10: Story 3 Capacity Trajectory

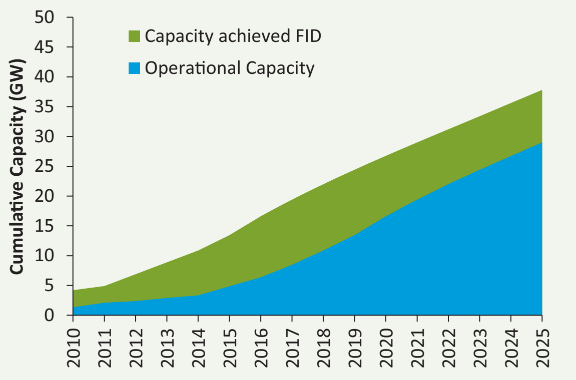


Exhibit 4.11: Story 3 Turbine Mix

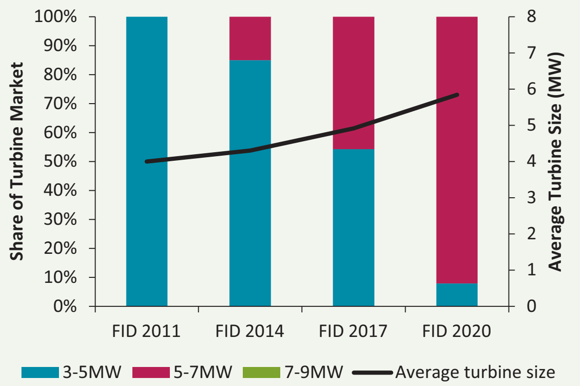


Exhibit 4.12: Story 3 Cost Trajectory

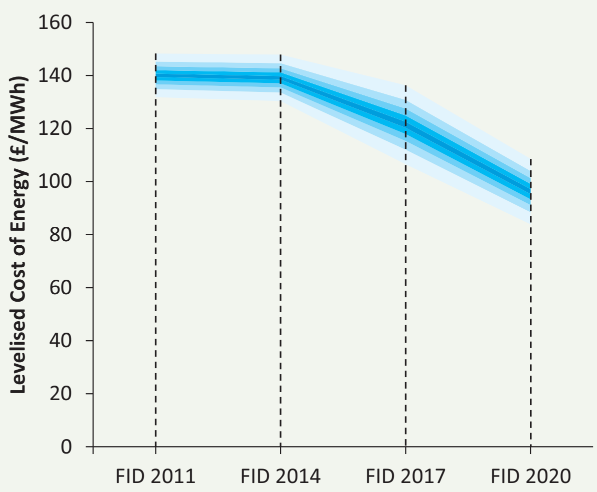
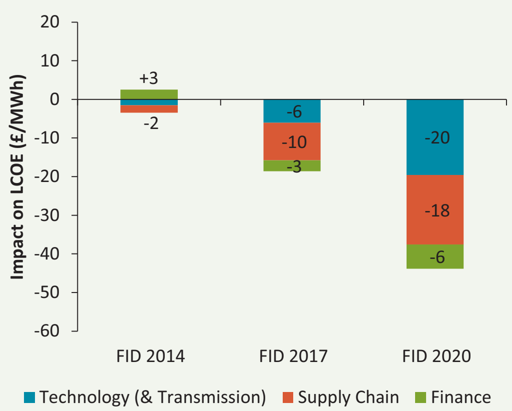


Exhibit 4.13: Story 3 Breakdown of Savings



Results: Significant cost reduction from supply chain improvements is also possible

Under the Supply Chain Efficiency Story, the central view is that costs will reduce to £96/MWh by FID 2020 (+/- £12/MWh) – a reduction of 31% relative to the baseline. The primary reasons for this improvement are as follows:

- **Supply Chain** factors result in a £18/MWh (13%) saving by 2020, due to a range of factors. The primary driver is an increase in competition in the sector due to new entrants in the UK, the rest of the EU, and low cost jurisdictions; which will result in lower margins and prices. The second most significant driver is the better management of interface risks through increased collaboration across the various actors within the supply chain (including developers). Thirdly, it will be possible for the supply chain to realise economies of scale and greater productivity through investment in new manufacturing capacity and standardisation.

- **Technology improvements,** though not as rapid or extensive as in Story 2, still result in a £20/MWh (14%) saving by 2020. In this story, it is assumed that next generation turbines in the 5-7MW class dominate the market in 2020; which makes a significant contribution to reducing LCOE through improved reliability and energy capture, and reduced O&M costs. There would also be a significant contribution from other technological advances such as improvements in support structures, installation methods, and O&M strategies; albeit not to the same extent as in Story 2.

- **Finance** would also make a contribution of £6/MWh (or 4%) by 2020. In this scenario, the finance and insurance communities become more familiar with technology as it is demonstrated and deployed at scale, and the perceived risk decreases. This results in a reduction in risk premia, combined with the entrance of new sources of finance (such as greater levels of debt finance, institutional investors, pension funds, and bonds).

- Though there is a significant benefit by 2020, the improvement to FID 2014 is negligible. This is due to the fact that many of the identified supply chain savings will not materialise until at least FID 2017. As with Story 2, there is also a small cost penalty in FID 2014 associated with the challenging scale of finance required, and the need to resort to more expensive forms of finance; although this is assumed to be mitigated by FID 2020.

Story 4: Rapid Growth

Key assumptions

This story explores the cost reduction potential under a somewhat larger market than Stories 2 and 3 – assuming that by 2020 there would be 23 GW operational capacity in the UK, plus a further 10GW+ that has reached FID and is awaiting or is under construction. In this context, it is assumed that it is possible for the sector to focus on delivering both new technology and supply chain improvements; in order to bring about greater reductions in the cost of offshore wind energy. It should be noted that this story was seen by some project participants as challenging due to a combination of supply chain and finance constraints, and unlikely to occur without significant effort and commitment from government and industry.

Exhibit 4.14: Story 4 Key Assumptions

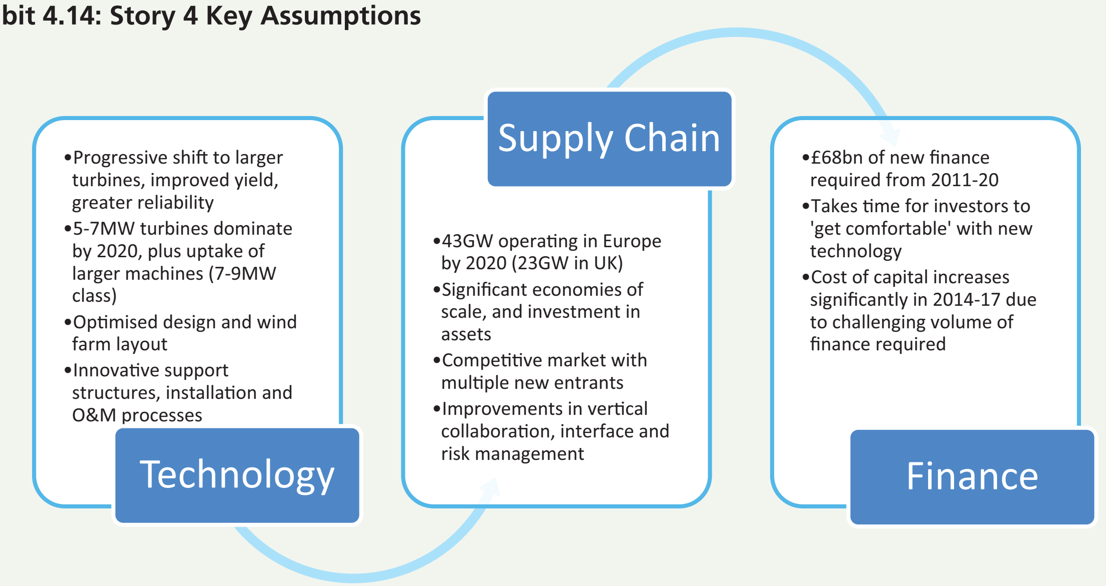


Exhibit 4.15: Story 4 Capacity Trajectory

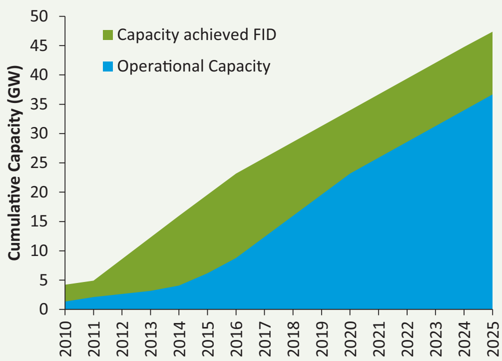


Exhibit 4.16: Story 4 Turbine Mix

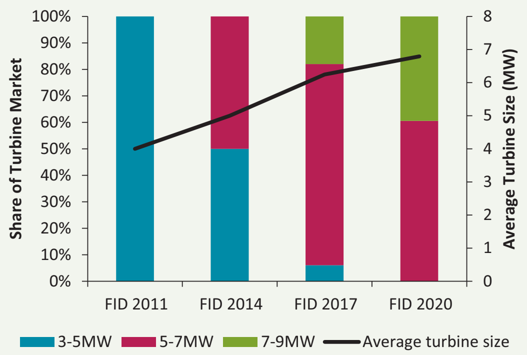


Exhibit 4.17: Story 4 Cost Trajectory

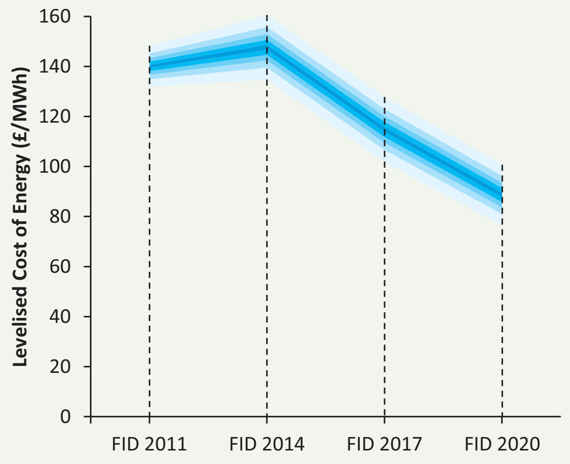
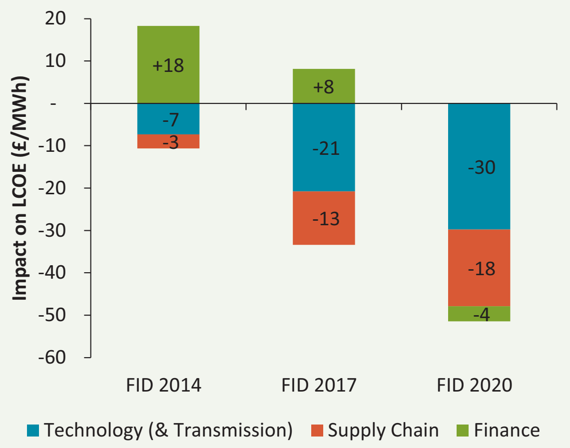


Exhibit 4.18: Story 4 Breakdown of Savings



Results: A large market may offer even greater potential for cost reduction, but also presents significant challenges

Under the Rapid Growth Story, the central view is that costs will reduce to £89/MWh by FID 2020 (+/- £12/MWh) – a reduction of 37% relative to the baseline. The primary reasons for this improvement are as follows:

- **Technology improvements** – the bulk of cost savings in this story are due to the rapid development and uptake of new technology, contributing to a £30/MWh (21%) saving in LCOE by 2020. As in Story 2, this is due to a rapid shift to larger turbines – with improved reliability and energy capture, and reduced O&M costs (offset to an extent by higher CAPEX). There would also be a significant contribution from other technological advances such as improvements in substructures, installation methods, and O&M methods.

- **Supply Chain** factors result in a saving of £18/MWh (13%) by 2020. It is assumed that the larger market enables supply chain improvements to be made despite the range of technological solutions on offer. As with Story 3, the primary drivers of cost saving are competition, vertical collaboration, and economies of scale. However, some project participants felt that in delivering this volume of projects, there would be a risk of capacity constraints in some markets – this is explored further in the Supply Chain workstream report.

- Another major challenge in this story is that of **Finance**. In 2020, there is a small cost reduction attributable to Finance of £4/MWh (or 3%). However, earlier in the pathway in FID 2014 and 2017, there is a significant uplift in LCOE attributable to an increase in the cost of capital. Overall in this story it has been calculated that around £68 billion of new capital needs to be allocated over the period 2011-2020. Our modelling shows that a significant shortfall in available finance in 2014 and 2017 will mean that if the assumed volume of projects is to be funded, there will be a need to resort to expensive forms of finance such as private equity and mezzanine debt. For a project reaching FID in 2014, this would mean that any saving from technology and supply chain is more than offset by an increased cost of finance.

Overall, the story shows that under the assumed set of conditions it is possible for LCOE to drop to £115/MWh by FID 2017, and £89/MWh by 2020. However, in general it is seen as a high-risk and challenging scenario, and would require significant intervention and commitment from government and industry in order to be realised.

Story 1: Slow Progression

Key assumptions

This story can be seen as steady state or a 'do minimum' scenario. It assumes a somewhat smaller market than the other stories, although still delivers 12 GW of operational capacity in the UK by 2020. It is assumed that there is incremental development and uptake of new technology, and limited improvement of the supply chain. Overall as a result, this story offers a reduced potential for cost reduction, and fails to achieve the £100/MWh benchmark by 2020.

Exhibit 4.19: Story 1 Key Assumptions

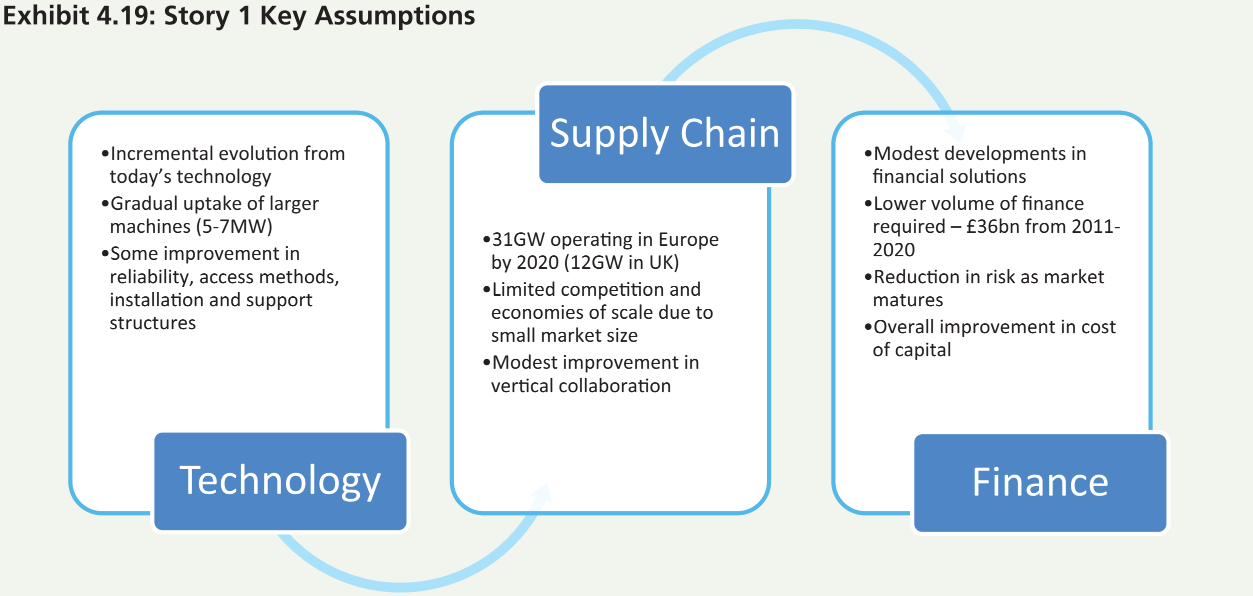


Exhibit 4.20: Story 1 Capacity Trajectory

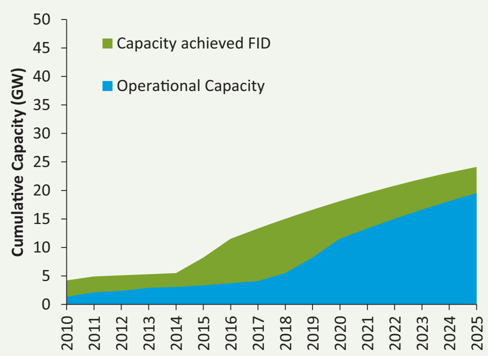


Exhibit 4.21: Story 1 Turbine Mix

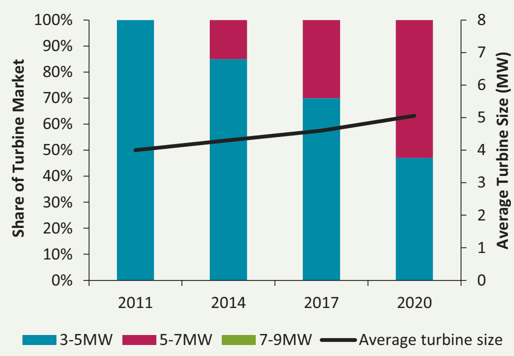


Exhibit 4.22: Story 1 Cost Trajectory

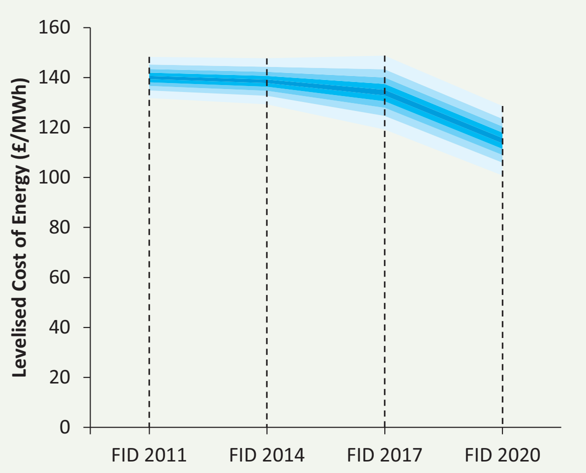
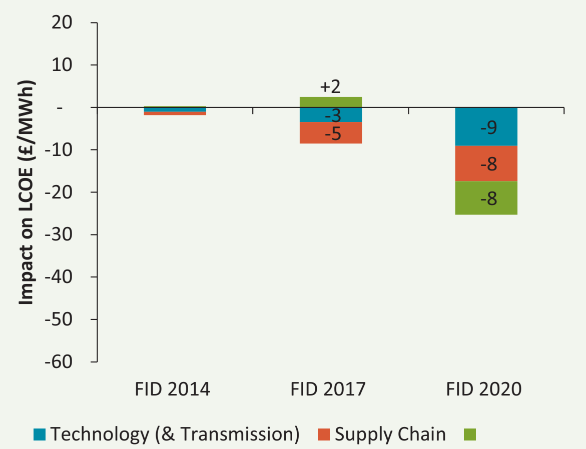


Exhibit 4.23: Story 1 Breakdown of Savings



Results: Continuing with Business as Usual will not get us to £100/MWh

Under the Slow Progression Story, the central view is that costs will reduce to £115/MWh by FID 2020 (+/- £14/MWh) – a reduction of 18% relative to the baseline. Under this story there is a much smaller aggregate saving, which is driven by the following factors:

- **Technology improvements** – it is assumed that there is incremental improvement from today's technology, but at a much slower rate than in the other stories. It is assumed that 5-7MW turbines enter the market in FID 2014, but uptake is slow, with penetration of only around 50% by 2020. It is assumed that there would also be some limited progress in respect of foundations, installation and O&M. This slow rate of progress contributes to a modest saving of £9/MWh (or 6%) by 2020.
- Similarly, it is assumed that improvement in the **Supply Chain** is limited and incremental, because the size of the market is insufficient to attract investment to the UK, to realise economies of scale or competition. In this scenario, the UK becomes a marginal market with facilities being located elsewhere. The supply chain is less keen to challenge the status quo, and does not address issues around contracting, or improve collaboration. As a result, the overall saving from supply chain factors is limited to £8/MWh (or 6%) by 2020.
- In terms of **Finance** – this story requires the lowest volume of new finance, at £36 billion over the period 2011-2020, which can more easily be met than in other stories. As a result of this, there is less upward pressure on the cost of capital; and there is some downward pressure on the cost of capital because of risk reduction and industry learning. Overall, finance makes a modest contribution to cost reduction of £8/MWh (or 6%) by 2020.
- In this story, there is limited cost reduction potential prior to FID 2017, as the limited scale and stop-start nature of the market deters investment in technology or supply chain. Some cost reduction could be achieved in the later part of the decade as the deployment rate increases.

Overall, this story demonstrates that with a limited market size and limited intervention and commitment from government and industry, there would be missed opportunities and limited potential for cost reduction. Moreover, there is a risk that if cost reductions do not materialise, there could be a lack of confidence and commitment to offshore wind; which would make it difficult to achieve even the 12GW operational by 2020 assumed in this story.

All sites offer similar levels of cost reduction potential

A key feature of this study is that it has explored cost reduction opportunities both by industry 'story' and for a number of distinct site types. As outlined in Section 2, four generic site types have been specified in terms of water depth, distance to shore, and wind speed:

- Site A – 25m water depth, 40km from shore, 9 m/s average wind speed – similar to Round 2 site
- Site B – 35m water depth, 40km from shore, 9.4 m/s average wind speed – similar to Round 3/STW site
- Site C – 45m water depth, 40km from shore, 9.7 m/s average wind speed – similar to Round 3/STW site
- Site D – 35m water depth, 125km from shore, 10 m/s average wind speed – similar to Round 3/STW site

They are generic sites rather than representing specific projects or zones – but the spread of site characteristics broadly reflects the current programme of sites in UK waters. Our analysis takes into account the overall programme of UK offshore wind sites, and when each of the generic site types is likely to start being built out. For example, in FID 2011 only Site As are available – whilst Site Bs and Cs (akin to later Round 2, Round 3, and Scottish Territorial Water sites) will start to be built out from FID 2014.

The following chart provides a summary showing the range and average of LCOE figures generated for each site, across all stories and turbine types.

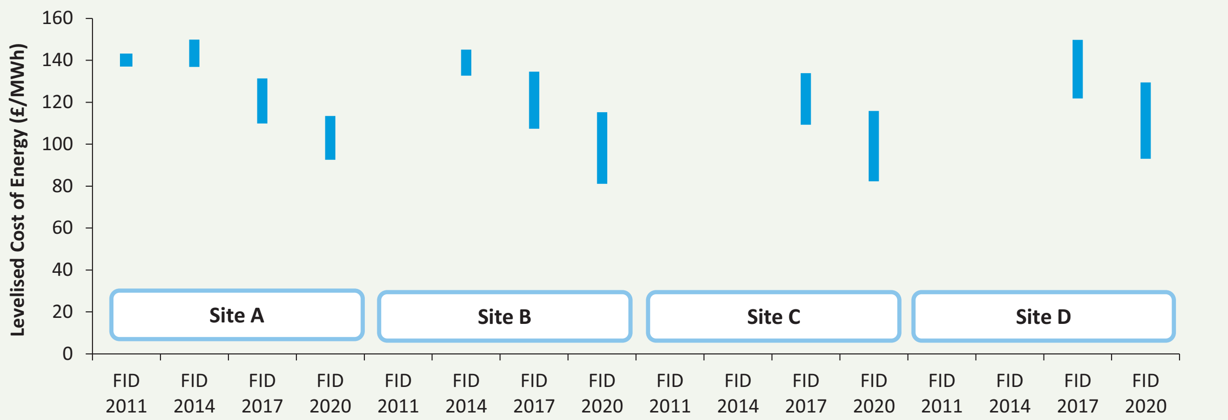
Overall the analysis shows that there is no significant variation between the sites in terms of the Levelised Cost of Energy. Generally, as we move to sites in deeper water or further from shore (ie from Site A to Sites B, C and D), our model shows that CAPEX and OPEX increases. However this is offset by a corresponding increase in wind resource, which translates into a higher load factor and higher energy output.

In other words, though Round 3 and STW sites may appear to be more challenging and have higher CAPEX than current Round 1 and 2 sites, they are roughly equivalent in terms of LCOE – even after adjusting for the additional risk associated with these sites (which has been factored into the cost of capital model).

This finding is contrary to several previous studies which have predicted that there will be a cost penalty for Round 3 and STW sites as they are generally in more challenging conditions. The increase may be true in terms of CAPEX and OPEX, but as shown by our model these more challenging sites are broadly equivalent in terms of LCOE owing to the higher energy output. One of the reasons why previous studies may have overestimated the LCOE of Round 3 and STW sites is by failing to factor in the increase in wind speed, capacity factor, and energy yield associated with these sites, which may be realised through current and future technology.

In addition, it is worth noting that the costs of all sites have been modelled based on a standard 500MW project size. In reality, there are a number of Round 3 zones which are considerably larger than this, which have the opportunity to realise economies of scale at a zonal level - for example by adopting a campaign approach to installation, or utilising larger export cables. This could further reduce the LCOE for sites C and D to below the figures presented.

Exhibit 4.24: LCOE Range for each site



Moving to the next generation of turbines is an important part of cost reduction

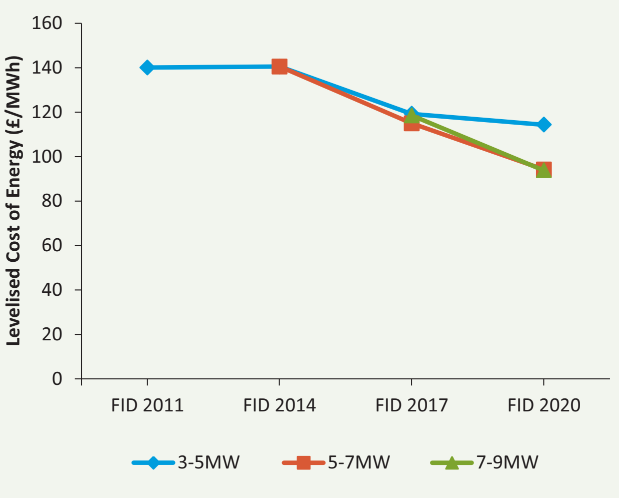
As well as modelling the Levelised Cost of Energy for each of the combinations of story and site type, this study has also considered the impact of turbine size on LCOE. The following chart provides a high level summary of the trajectory of LCOE by turbine size – split into distinct turbine families or classes. The lines show the average LCOE value across all stories and sites for each turbine class, taking account all innovations across technology, supply chain and finance.

As can be seen, the overall trend is that LCOE will reduce over time across all turbine sizes. From the baseline figure of £140/MWh, the cost of a 3-5MW turbine is likely to reduce to around £114/MWh by 2020. Our modelling suggests that a 5-7MW turbine introduced in FID 2014 will have an LCOE which is broadly equivalent to smaller models at around £140/MWh. However, the pace of change after 2014 will be greater for larger machines, with the 5-7MW machine reaching an 'average' LCOE of around £94/MWh by FID 2020. Conversely, our modelling suggests that there will be less improvement in the 3-5MW class beyond FID 2017, and it will cease to be cost-competitive with larger machines.

As and when larger turbines (7MW+) enter the market in FID 2017 or FID 2020, the LCOE of these machines will closely match that of the 5-7MW class (which are likely to dominate the market by this time).

It should be noted that this is based on industry's current view of future technology, which may evolve over time as the detailed costings of larger machines are established and certainty over future costs increases.

Exhibit 4.25: Levelised Cost of Energy by turbine class (average LCOE value across all sites and stories)

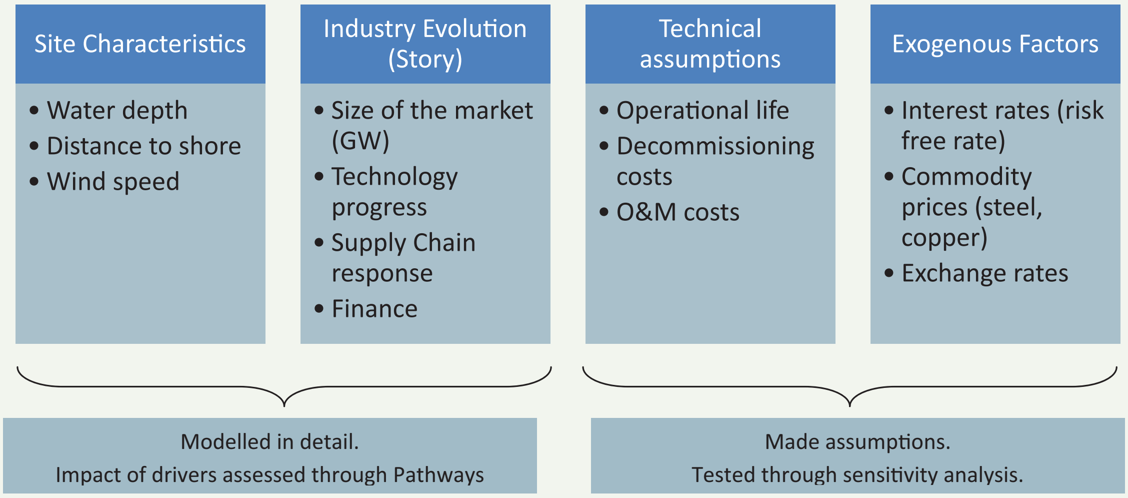


Offshore wind costs are sensitive to external factors and technical assumptions

There are many factors which can influence the cost of energy of a wind farm project – from technical or supply chain factors, to site characteristics, to macro-economic factors such as interest rates, commodity prices and exchange rates.
Within this study it has been necessary to make some choices about which aspects to model in detail, while making simplifying assumptions in other areas. Where assumptions have been made, they have been tested through sensitivity analysis – ie by examining the impact on LCOE of changing a single input variable.

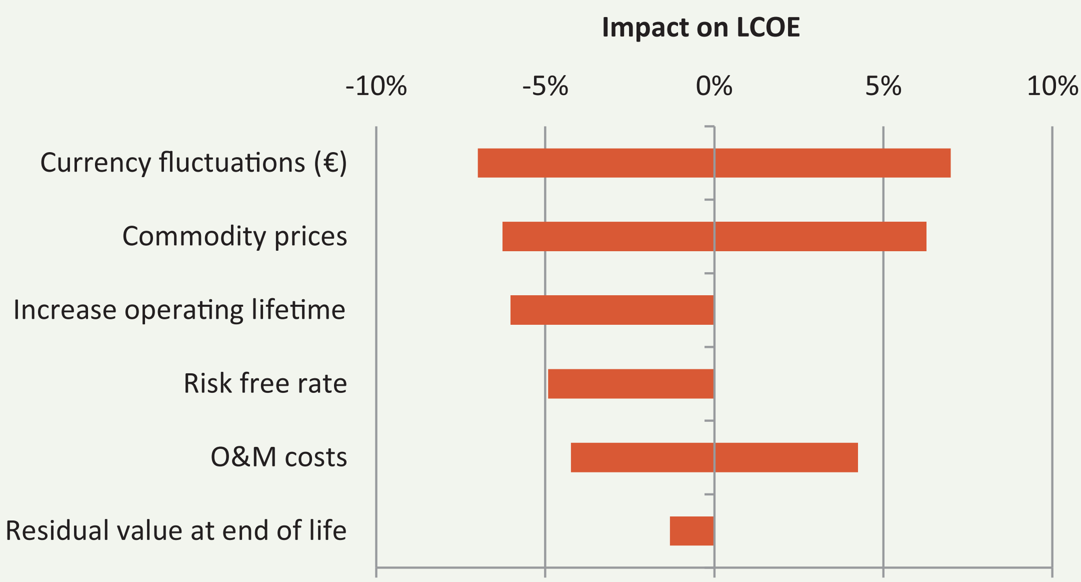
The following chart provides an overview of our approach to analysing cost drivers – the first two categories have been modelled in detail, whilst for the latter two categories global assumptions have been made which have been tested as sensitivities.

Exhibit 4.26: Cost Driver Analysis Approach[41]



The following chart provides the results from the sensitivity modelling,[42] which are explored further below as well as in the workstream reports:

Exhibit 4.27: Sensitivity Modelling Results (based on project at FID in 2020)[43]



[41] O&M costs and Decommissioning costs are calculated for each data point (ie site, story, turbine, year combination); whereas the operational lifetime, commodity prices, exchange rates and interest rates are fixed across all datapoints. See Appendix 2 for more details of our assumptions.
[42] Analysis based on a wind farm at FID in 2020 using 6MW turbines, on site B, in the Supply Chain Efficiency story
[43] It should be noted that the impact of each of these sensitivities changes over time. For example, since the turbine increases as a proportion of CAPEX and LCOE between FID 2011 and FID 2020, the impact of the steel price sensitivity also increases over time. The results presented related to a typical project at FID in 2020.

The key sensitivities, in order of relative impact are as follows:

- **Currency fluctuations** – this is a key sensitivity due to the significant proportion of the value of an offshore wind farm which is imported into the UK. The depreciation of the Pound against the Euro was one of the contributory factors to the increase in wind farm CAPEX in recent years. If we assume that a project in 2020 has just over 50% UK content, then a +/- 15% swing in the Sterling exchange rate could result in around a +/- 7% swing in LCOE. The impact would be felt particularly in terms of CAPEX, rather than OPEX, as the UK content of Operations and Maintenance activities has tended to be higher than that of wind farm products and installation services.

- **Commodity prices** – the price of commodities such as steel and copper can be extremely volatile, and price increases in recent years contributed to recent cost increases for offshore wind. Steel and copper are key materials used in the offshore wind supply chain, making up approximately 6% and 5% of total LCOE respectively (for a 6MW wind farm in 2020). Large quantities of steel are used in monopile and jacket support structures, as well as turbines; copper is used in cabling, and to a lesser extent in the turbine nacelle. Based on the wide range of copper and steel prices seen in recent years, we have tested wide sensitivity ranges of +/- 65% for copper and +/- 50% for steel. Our analysis shows that both sensitivities result in a +/- 3% impact on LCOE; or a total impact of +/- 6% for both factors combined.

- **Operating lifetime** – one simplifying assumption in our model has been to fix the operational life of the wind farm at the current expected value of 20 years, rather than allowing this to vary over time. However, feedback from project participants suggested that the lifetime of wind farms could be increased, and this could be a driver of cost reduction. This has been tested as a sensitivity by assessing the changes in CAPEX, OPEX and energy generation if the operating lifetime is increased to 25 years. Two strategies for achieving lifetime extension are to either: invest more upfront (estimated as a 4% increase in CAPEX); or to undertake more intensive operations and maintenance activity towards the end of the life of the plant (around a 6% increase in O&M). Industry appears to be keener on the later approach, which we estimate would result in a 6% reduction in LCOE; as the increased cost is more than offset by the increased energy output in the additional 5 years of generation.

- **Interest rate (risk free rate)** – interest rates have a clear impact on the cost of capital; which in turn is one of the key drivers of the levelised cost of energy. The 'risk free rate' is used in the calculation of the cost of capital and, as shown in the finance workstream analysis, is currently around 1% lower than the historic average rate. The finance workstream has taken a prudent approach and used the long-term, rather than current rate; however if this 1% difference is factored in to the LCOE model, then this results in a further reduction in LCOE of 5%.

- **O&M costs** – there is considerable uncertainty surrounding O&M costs, particularly in the post-warranty period, due to the limited number of projects that have been in operation for five or more years to date. Our analysis has taken a somewhat prudent approach in respect of baseline O&M costs (but consistent with the approach typically taken by developers), hence there is a potential upside for O&M costs to be lower than anticipated. Equally, factors such as fuel costs and material costs could have a material impact on O&M costs in the future. As a result of this, we have tested a +/-25% variation in O&M costs from our central case; which results in a +/- 4% change in LCOE.

- **Residual value / decommissioning costs** – our model generally applies a cost relating to the decommissioning of the wind farm assets at the end of their operating life. However, there may a residual value attached to these assets which could be sold or reused in the event of a repowering exercise. In this sensitivity, it is assumed that this residual value equates to the decommissioning cost. The impact of this is to reduce LCOE by just over 1% – the saving is limited as the benefit is so far into the future and hence heavily discounted.

Overall, the sensitivity analysis shows that there are a range of external factors (commodity prices, exchange rates, interest rates, O&M costs) which could have a material impact on future costs, and either add to or counter the cost reductions described in the pathways. There are some potential sources of LCOE reduction (lifetime extension and residual value at decommissioning) which it has not been possible to factor into our main analysis, but offer additional opportunities beyond those described in the pathways.

Further potential beyond 2020

This study provides detailed pathways for cost reduction to 2020. In addition to this, Chapter 3 and the associated workstream reports describe a range of cost reduction opportunities which can only be realised post 2020, such as a deepening of technology-driven savings; radical step-change technological solutions; and a deepening of supply chain savings in particular for operations and maintenance.

Prerequisites

Cost reduction will occur as the result of a series of key decisions

To take advantage of the cost reduction opportunities, individual companies and Government must make and effectively implement a series of decisions on industrial and financial investments, new ways of working, and policy.

The relationships between the most significant LCOE reduction opportunities to 2020 and the key decisions required to unlock them are illustrated in Exhibit 5.1.

optimised installation methods, generate more competition and avoid potential bottlenecks, and reduce a key risk.

- A series of cost reduction opportunities depend on developers and key suppliers deciding to enter into longer term relationships. These opportunities involve better specification of projects before FID, capturing learning through greater continuity of work and spreading investment payback over a longer period of time.

Exhibit 5.1 Key cost reduction decisions

Key decisions		High impact offshore wind LCOE reduction opportunities to 2020								
		New larger turbines	Competition	Mass produced space frames	Front end activity	Scale and productivity	Optimised Installation methods	Installation / O&M risk reduction	Funding shortfall	Introduction of FiTs
Industrial investment	Introduction of new turbines	X	X			X				
	Investment in automated space frame fabrication		X	X		X				
	Investment in new installation vessels and methods and capability		X				X	X		
Ways of working	Developers and key suppliers decide to enter into long term relationships				X	X				
	Launch joint industry project on standardisation / best practice					X		X		
Financial investments	Investors allocate (more) capital to offshore wind								X	
Policy	Support mechanism									X

Source: The Crown Estate

These key decisions cut across wind farm developers, their supply chain and the finance community. Overarching all these specific decisions, is the decision by a developer to take forward an offshore wind farm project. Clearly this requires both an appropriate balance of risk and reward and the commitment to make substantial investments and commitments pre-consent and pre-FID.

In summary, these key cost reduction decisions are:

- The introduction of new 6MW-Class Turbines and 4MW-Class Turbines. These decisions by the turbine manufacturers will both capture technology opportunities (higher rating, larger rotors, advanced blades, etc) and generate a higher level of competition. If the introduction is supported by manufacturing located in the UK, further logistics saving will be made (as well as reducing foreign exchange risk).
- Investment by fabrication yards in automated space frame fabrication facilities. These decisions will unlock the technology based savings, generate more competition and logistics savings from UK manufacture.
- Investment by vessels operators in new, specialist foundation and cable installation vessels and by installation contractors in greater capacity (mainly skilled manpower) and improved processes. These decisions will capture a large number of technology savings around

The key drivers will be the developers and the Tier 1 suppliers who will then cascade these relationships as necessary down the supply chain.

- Some cost reduction opportunities require an industry-wide decision. Capturing the cost and risk reduction benefits of standardisation and best practice sharing will need concerted backing from all the key developers and suppliers.
- In all of the industry stories additional funding is needed, as that available from the current set of developers is not sufficient. Therefore either existing investors must allocate more capital to UK offshore wind or new investors (equity or debt) must decide to enter the UK offshore wind financing market. These decisions will help address the funding shortfall, eliminating the need for more expensive equity and debt, thereby reducing the costs of capital and avoiding potential funding constraints.
- Finally, the policy change to a feed in tariff support mechanism is intended to reduce revenue risk and hence the cost of capital. This decision has been taken in principle through the Electricity Market Reform proposals, but in order to feed through to cost reductions, the EMR needs to be implemented in a timely and manner, as discussed further below.

The list of key decisions is relatively constant across the different cost pathways, but the balance of investment alters in each of the pathways. For example, in the Technology Acceleration story, the quicker introduction of new turbines incorporating a greater number of innovations is emphasised, whereas in the Supply Chain Efficiency story decisions on joint working and new methods are more important.

Prerequisites must be in place to enable cost reduction decisions to be taken

For almost all the key cost reduction decisions, a number of prerequisites need to be in place. Without these prerequisites, it is unlikely that any company will take the decisions necessary to reduce offshore wind costs.

The nature of the prerequisites depends on the type of decisions being made. We have combined these into three groups taken by private sector companies:

- Industrial investments.
- Ways of working.
- Financial investments.

Prerequisites for industrial investments revolve around market, availability of manufacturing sites, and technology support

The industrial investment decisions include the introduction of 6MW-Class and 8MW-Class turbines, automated space frame fabrication facilities, and new installation vessels and capabilities. All of these decisions involve very significant capital expenditures ranging from £50m to £400m (see Exhibit 5.2). Particularly for fabrication yards these are large compared to the size of the typical players in these industries and so the exposure and hence risk related to these investment is high. These are also long cycle investments. For example, the total lifecycle of a turbine is at least 13 years (6 years of development and at least 7 years of sales life), or about ten years from FID for a production facility.

The market for offshore wind power is mandated by Government rather than customer demand. As the investment decisions needed for cost reduction are long cycle and involve high levels of capital expenditure, the extent to which companies can rely on the existence of a market for their goods and services in 10+years time is critical. There are at least four resulting prerequisites:

- **A predictable flow of projects emerging from the consenting process.** This requires that the clear timetable for planning determination (as proposed under the NID and Planning Act) is met reliably. This allows the supply chain companies to gain confidence that the wind farm projects necessary to justify industrial investments will reach final investment decision and generate a steady stream of orders. Delays in the project flow will delay orders and hence stop industrial investments.
- **A robust policy framework mandating steady and growing demand for offshore wind** with reasonable certainty over a 10-15 year period. This will generate market confidence for offshore wind farms against which turbine manufacturers and the rest of the supply chain can invest. It is crucial to avoid lulls in demand. These are toxic for almost all cost reductions; increasing perceptions of risk, decreasing the appetite to invest and destroying the opportunity for learning. Turbine manufacture, fabrication yards, vessel operators and marine contractor all operate within a European if not global market. However, the UK is expected to make up around half of European demand and so has a crucial role in establishing a steady growing market.

Exhibit 5.2 Characteristics of key industrial investment decisions

Decision	Typical investor (turnover)	Investment lead time	Typical investment size
Introduction of new turbines	International engineering companies (£1-50bn/year)	• 6 years from concept design to full commercial launch • 3 years from FID of manufacturing facilities to full commercial launch	£150-400m /turbine (inc. RD&D and production facilities)
Investment in automated space frame fabrication	Fabrication yards (£100-300m/year)	• Up to 3years for a jacket (from FID to operations)	£50-160m/facility
Investment in new installation vessels and methods and capability	Vessel operators (£30-60m/year)	• 3-4 years from FID to operations for new build • 2-3 years for conversions	£200m/ vessel
	Installation contractors (~£1bn/year)	Up to 2 years	Up to £5m

Source: Finance workstream report, Technology workstream report, Supply chain workstream report, The Crown Estate

- **Developers pass through of market demand.** Fabrication yards and installers need to make technology specific investment decisions. Therefore, developers need to signal the nature of their technology choices and then to make supply commitments at the earliest possible opportunity to provide a strong market backdrop to allow investment.

- **Planning envelope flexibility.** The planning process must allow developers to adjust technology choices after consent within reasonable limits. This will speed up the introduction of new turbines and optimised installation methods. Limited flexibility will lock in old technology and delay the realisation of cost reductions.

Offshore wind turbine manufacturers have demanding requirements for their factories. For example, a nacelle assembly facility needs in excess of 20ha of land adjacent to strengthened deep water (8m at LAT) quayside with 24 hour access. Therefore in addition to market demand, the timely **availability of consented sites for coastal manufacturing and assembly**[44] is also a prerequisite. Turbine manufacturers and fabrication yards will need to build new coastal facilities for their 6MW-Class Turbine and support structures. Finding and consenting suitable sites is a potential bottleneck – for example, there are only 1-2 possible East coast sites with the potential to meet the demand for quayside lay down / marshalling. These sites could be in the rest of Europe, however, this would diminish the cost reduction potential and lessen the economic benefit to the UK.

Finally, there are prerequisites related to technology development. A key step in the commercialisation of new turbines is test and demonstration. This is particularly critical given the step change expected with the introduction of 6MW-Class Turbines and the increasing demands on reliability made on further from shore sites. Testing and demonstration requires verification facilities and both onshore and offshore demonstration sites. A prerequisite is therefore the **availability of demonstration sites and verification facilities.** Furthermore, analysis by the UK and Scottish Governments[45] has identified continuing **Government support for Research, Development and Demonstration** (RD&D) as a prerequisite for both cost reduction and generation of UK benefit.

Underpinning all these prerequisites is the availability of people with the right skills. Although not a key focus of this study, other analyses have shown that the sector will require an inflow of over 40,000 people with engineering, manufacturing and construction skills at the professional and technical level.[46]

Greater collaboration is a key prerequisite for new ways of working

Decisions by developers to enter into longer term relationships with key suppliers and for the industry to work collectively to standardise and establish best practice will generate considerable cost savings. In addition to market certainty and human capital prerequisites discussed above, developers and the supply chain must embrace collaborative working as opposed to adversarial working. This prerequisite has a number of aspects:

- **Attitude:** The industry player must be open to ideas from outside their organisation, challenge existing preconceptions on how to design, build and operate offshore wind farms and be prepared to accept standard rather than in-house solutions.

- **Incentive structures:** Developers must put in place contractual or other mechanisms to share risks and incentivise the supply chain to bring forward cost reductions, stop considering projects as one-off and take advantage of the scale across the UK and the rest of the EU to manage a portfolio of projects.

Extensive industry, Government and finance community engagement is a prerequisite for financial investment in offshore wind alongside a robust policy framework

To avoid a funding shortfall, new investors in either equity or project bonds need to be attracted to the sector. In addition, the increased use of debt needs to be facilitated.

New equity or project bond investors will invest in UK offshore wind only if:

- The potential financial returns are sufficiently attractive relative to other opportunities both in the UK and beyond.

- Risks around the regulatory framework, construction and operations are understood and can be managed.

If effectively implemented, the policy framework changes proposed in the Electricity Market Reform White Paper are helpful in that FiTs will reduce revenue risk and prices will be set by the market rather than by Government and so should achieve investors required returns.

In addition to the policy framework a further prerequisite is **engagement between developers / supply chain and new investors** to ensure that they understand the key installation and O&M risks and how these are being addressed through new technology, and methods of working. There is a particular need for a high level of engagement with pension and insurance funds that may provide project bonds. The lead time for them to become comfortable with the risk is considerable and developers need to understand their requirements. Government has a role in ensuring that these funds are not inadvertently discouraged from making investments in long term infrastructure assets such as offshore wind due to regulatory changes (such as Solvency II), pension regulation, and revisions to accountancy rules (eg IAS 19).

Introducing debt into wind farm projects when operational will release funds that can be recycled into further projects,

[44] Including considerable quayside lay down and marshalling areas. For example the purpose-built offshore wind farm port in Belfast harbour will have a 450-metre quay and 50-acres of building space.
[45] For example see: Low Carbon Innovation Coordination Group, 'Technology Innovation Needs Assessment (TINA) Offshore Wind Power Summary Report', February 2012.
[46] RenewableUK, 'Working for a Green Britain', 2011. Includes both direct and indirect employees.

reducing the funding shortfall. To date one of the challenges has been the impact of project debt on the credit rating of project sponsors which equity fund the construction and early operational phases. A number of potential solutions are being worked on but none have been proven. The industry would benefit from co-ordinated engagement with the ratings agencies on potential financing structures: for example indicative structures could be reviewed by the ratings agencies and the feedback shared with market participants.

Independent power producers represent a potentially important source of capital, as they arguably face fewer issuers with the credit rating agencies and are more able to raise non-recourse debt finance (as evidenced in the European market). In many of these financings, the EIB and other Multi-Lateral Agencies (MLAs) have played a significant role and it is likely that support from the GIB would be required.

The prerequisites with the most wide ranging impact are the policy framework, consenting process, and developer pass through of demand

Exhibit 5.3 summaries the link between the key decisions needed to realise high impact LCOE reduction opportunities to 2020 and the prerequisites that must be in place for those decisions to be taken.

The prerequisites that make possible the widest range cost reduction opportunities revolve around market certainty – the policy framework, the flow of consented projects, and ensuring the supply chain gets market signals from developers. Without market certainty, developers and the supply chain will not make the investments needed to reduce costs, be they industrial investments or investments in time and effort to introduce new ways of working or investments in human capital.

The prerequisites around finance (engagement with new investors and credit rating agencies and MLA support) are both focused and critical, as expensive capital or even worse a capital constraint would severely limit industry progress and cost reduction.

Offshore transmission prerequisites

In common with the rest of this study, we have not studied the prerequisites for offshore transmission cost reductions in such detail. However, the results of our more high-level work indicates a small number of broad themes which are largely consistent with the rest of our analysis:

- Stable and predictable policy framework – this will enable investment and development in full view of risks and opportunities.
- Appropriate risk/reward balance – will be required to incentivise behaviours of all market participants, and allocate risk where it is best managed.
- Industry collaboration – notwithstanding the competitive nature of the generation market in the UK, there are clear opportunities for enhanced collaboration in key areas such as transmission system design and construction best practice. Industry structures need to be aligned to enable such an approach and behaviours need to be appropriately incentivised.
- Standardised approach – as the market matures it will be essential that common standards are adopted for key transmission assets to fully enable interoperability across different transmission systems (nationally and internationally) and to harness benefits throughout the supply chain.

Exhibit 5.3 Offshore wind prerequisites vs. key decisions

Prerequisites	Key Decisions to realise high impact LCOE reduction opportunities to 2020					
	Industrial investment			Ways of working		Financial investments
	Introduction of new turbines	Investment in automated space frame fabrication	Investment in new installation vessels and methods and capability	Developers decide to enter into long term relationships with key suppliers	Launch joint industry project on standardisation / best practice	Investors allocate (more) capital to offshore wind
A robust policy framework mandating demand for offshore wind	x	x	x	x	x	x
A predictable flow of projects emerging from the consenting process	x	x	x	x	x	
Developers pass through of market demand		x	x	x	x	
Planning envelop flexibility	x		x			
Government RD&D support	x	x	x			
Availability of demonstration sites and verification facilities	x	x	x			
Availability of consented sites for coastal manufacturing and assembly	x	x				
Collaborative working				x	x	
Engagement with new investors						x
Engagement with credit agencies						x
MLA support						x

Source: Finance workstream report, Technology workstream report, Supply chain workstream report, The Crown Estate

The list of prerequisites in Exhibit 3.5 represents a minimum set to make possible the cost reductions we have identified. We do not claim that it is exhaustive. Our assessments clearly show that these prerequisites need to be in place; but others may also be required.

Urgent issues need to be addressed to ensure that the prerequisites are in place for projects reaching FID in 2014

Not all the prerequisites are in place to allow the radical cost reduction which is required to make offshore wind a credible long term electricity supply option.

All the prerequisites are important, but some are urgent in order to be in place for projects reaching their Final Investment Decision in 2014.

These projects are crucial as they will lead the way for major changes to offshore wind farms that will drive down costs including:

- The introduction of 6MW-Class Turbines.
- The establishment of mass produced support structures.
- The use of HVDC connections for far from shore sites.

Successful implementation of these projects will build confidence in the market and lead to a process of learning-by-doing.

Timing is very tight for projects reaching FID in 2014. They will have to submit their consent application this year (2012) and will have to receive key project consents in 2013. In order to meet this timeline, developers will have to make substantial commitments for long lead time items prior to gaining consent, often in the range of hundreds of millions of pounds (eg for grid user commitments and turbine and offshore sub-station reservation fees).

Within this context, exhibit 5.4 highlights those prerequisites which must be fully in place for FID 2014 projects but which are not now.

Market demand must be reinforced in order to create confidence in the market

Through the engagement process for this project, developers and supply chain companies have consistently raised concerns relating to the current regulatory framework – in particular economic support mechanisms, consenting, and the offshore transmission regime. These concerns and uncertainties make it more difficult for developers to finance projects, and for the supply chain to assess the future demand for their products and services; all of which holds back potential cost reduction.

Key concerns related to **economic support mechanisms** are as follows:

- Within the lifetime of this project, DECC and the Devolved Administrations have undertaken consultations on future bandings for the **Renewables Obligation** (RO) that will apply to future renewable energy projects that qualify under the scheme out to March 2017. Whilst the new bandings have now been clarified, there remains some uncertainty surrounding the future price of ROCs, both before and after the introduction of the feed-in tariff.
- The replacement of the RO scheme by a **Feed-in Tariff (FiT) mechanism**, as set out in the **Electricity Market Reform** (EMR) proposals and the Energy Bill. The Feed in Tariff will apply to all offshore wind projects that come on-line from 1st April 2017 and will ensure the generator is paid a fixed amount (£/MWh) for each unit of output. Although it is now known that National Grid Plc will be the administrator of the FiT system, key questions need to be addressed in relation to the role of the administrator, the counterparty for FiT contracts, the overall allocation available for offshore wind, the FiT allocation process, and the strike price.
- The **timetable for the implementation of the EMR** and the Feed in Tariff is extremely tight, and many future projects will soon need to know the support they will receive under the feed-in tariff mechanism in order to progress to Final Investment Decision. For example, a project coming on-line just after the RO end date of March 2017 could need to secure its FiT contract in 2013/14. DECC has announced FID enabling measures for any projects caught in the transitional period which would otherwise be delayed.

Exhibit 5.4 Offshore wind prerequisites – FID 2014 gaps

Pre-requisite	Status	Gap
A robust policy framework mandating demand for offshore wind	Uncertainty on EMR / FiTs Levy Control Framework set to 2015	More clarity required on EMR mechanism and transitional arrangements
A predictable flow of projects emerging from the consenting process	New process in place	Unclear funding limits after 2015
Developers pass through of market demand	Some framework contracts and back integration	Process not yet proven
Availability of consented sites for coastal manufacturing and assembly	Siemens, Samsung and Gamesa have announced plans for the UK, plus Areva and Alstom in France.	Most fabrication yards and installers report limited pass through
Collaborative working	Some vertical collaboration through alliancing and long term contracts.	Majority of industry have neither the attitude nor the incentive structures for collaborative working.
Human capital	Currently difficulties associated with obtaining pepie with the correct skills.	Skill development programmes need to be uprated? Build offshore experience more rapidly?

Source: Finance workstream report, Technology workstream report, Supply chain workstream report, The Crown Estate

- In view of the increased focus on energy affordability, a key consideration for all offshore wind players is the level of public funding that the UK government will make available (ie through consumers paying a premium on energy bills) to renewable energy over the next decade, and what happens if that level is exceeded. At present, money available to fund renewable energy is capped under the **Levy Control Framework**. The current framework runs for the term of this government (ie until May 2015) and is likely to be reset for the expected period of the next government (May 2015 – May 2020). However, at present investors have no guidance as to the likely level of the cap, and whether it will be sufficient to cover offshore wind deployment (under any of the industry stories) as well as other renewable energy technologies and schemes like Warm Front.

In addition potential issues remain on **consenting**. The newly established consenting process needs to be proven. In particular it is critical that the next wave of major projects that have recently entered the consenting process (such as Galloper and Triton Knoll) or will apply this year gain their consents in 2013.

Offshore wind farm demand must be passed through from developers to the supply chain. There are some indications of this beginning to occur, for example:

- Framework agreements have been put in place between RWE and RePower on turbines and DONG Energy and Bladt for monopiles.
- Some developers have back integrated into turbine installation vessels, such as Centrica (through a long term charter), RWE and DONG Energy.

The feedback from the supply chain, in particular foundation suppliers and installers, is strongly that more needs to be done to ensure a flow of supply chain investment in time for FID 2014 projects.

Finally, in order to achieve the key cost reductions on transmission, there is a requirement for a **stable and predictable offshore transmission policy framework**.

The policy landscape for the transmission sector has been volatile over recent times. Whilst this is inevitable in order to bring the fundamental changes needed in the sector, the sheer volume of initiatives – none of which can be considered in isolation – appears to be a contributing factor to overall industry uncertainty. For example, Ofgem's recent review of transmission charging and connection security requirements (both under the auspices of 'Project TransmiT') could have led to fundamental changes to the commercial framework for developers. Recent decisions on connection security and the direction of travel for charging suggest that change will be less radical than could have been, but this was unclear until relatively recently. These developments provide welcome stability. However, uncertainty remains on the horizon in these key areas, particularly how these arrangements will evolve to adequately cater for a coordinated onshore/offshore grid, where the risk/reward profile may need to differ going forward in order to sufficiently incentivise behaviours across the sector. Other regulatory initiatives that have been progressed along similar timeframes include the ongoing development of the enduring OFTO regime, the emergence of a new regulatory model for interconnectors, and to the encouragement of better onshore/offshore network coordination. These sit alongside wider developments such as EMR and establishing new consenting processes.

As decisions in each of these areas have been or are taken (and the requisite delivery mechanisms deployed) the landscape has and will continue to become clearer thus enabling developers to pursue projects against a stable backdrop. However, there is still uncertainty in key policy areas: the enduring OFTO regime is still being developed and there is a lack of clarity on how different types of transmission asset (eg that involve combinations of onshore reinforcements, offshore generation and connections and interconnection) would be treated.

Urgent issues must be addressed around manufacturing and assembly sites and collaborative working

In order to supply and construct FID 2014 projects, turbine manufactures will need to have consented coastal sites for turbine manufacture and developers will need access to large areas of high specification quayside lay down and marshalling areas. This prerequisite is apparently not fully in place.

At present Siemens, Samsung and Gamesa have announced plans to establish turbine manufacturing facilities in the UK. None however, have a consented site for 6MW-Class Turbine manufacturing. Only one developer, DONG Energy has a consented site for assembly / lay down (Belfast).

Turbine manufacture could be done at any suitable site on the North Sea (eg Germany, Denmark, etc). This is particularly important in the Technology Acceleration story, in which 50% of turbines at FID 2014, are of the new 6MW-Class.

Similarly assembly could be done on continental sites for North Sea wind farms (although this is more difficult for projects in the Irish Sea or Bristol Channel.

A number of continental options exist for both turbine manufacture and assembly including St Nazaire, Cherbourg, Eemshvaven and Ostende should enough UK sites not be available, but with a potential loss of UK economic benefit.

In order to deliver FID 2014 projects, collaborative working will be needed to meet very tight timelines. This is particularly true of Sites B, C and D, which will all require new forms of foundations and HVDC connections to shore. Although the initial steps have been taken, industry reports that neither the attitudes nor the incentive structures needed are yet in place.

Concerns exist around the availability of people with the right experience and skills. Engineering Institutions, employers, educators and training providers need to clearly identify the nature and timing of the emerging skills gap.
Effective education, training and on-the-job mentoring schemes properly aligned and connected will then maximise the use of new UK talent and satisfy the supply of jobs being created by this new industry.

Longer term prerequisite issues are important if less urgent

Beyond the cost reduction prerequisites that need to be in place for FID 2014 projects, further issues have to be addressed for FID 2017 and FID 2020 projects.
These are outlined in exhibit 5.5.

periods have led consenting bodies to try and reduce the number of options they examine. This also appears to lead to an apparent lack of opportunity to make minor changes during the determination process and clarity is urgently required on what degree of flexibility exists for projects to amend design post consent. The recent planning applications (eg for the Galloper extension) are likely to be a litmus test of the efficacy of the new process for developers and statutory authorities alike.

- **Government RD&D support:** The UK currently has an extensive programme of technology support including the recently announced Offshore Renewable Energy Catapult and the POWERS programme in Scotland. A framework for assessing low carbon innovation needs has been agreed and used to identify offshore wind priority innovations.

Exhibit 5.5 Offshore wind prerequisites – gaps for FID 2017 and FID 2020 projects

Pre-requisite	Status	Gap
Collaborative working	Horizontal cooperation fora exist	Unclear if these deliver best value
Availability of demonstration sites and verification facilities	Onshore and offshore demo sites being put in place	At European level, shortage expected in both onshore and offshore locations
Planning envelope flexibility	Rochdale envelope in place	To be proven
Government RD&D support	Variety of funded programmes in place around an agreed framework (TINA / POWERS / Catapult)	Extent and impact of any potential funding gap is unclear.
Engagement with new investors	Some new investor being drawn in	Potential for funding shortfall still exits
Engagement with credit agencies	Potential solutions to issue around debt and credit rating proposed, none implemented	Need agreement on bankable structures
Multi Lateral Agency support	GIB established with limited capital	GIB needs to clarify the nature of funding and guarantees it will provide

Source: Finance workstream report, Technology workstream report, Supply chain workstream report, The Crown Estate

The critical, though longer term, issues for non-financial prerequisites include:

- **Collaborative working:** In addition to the vertical collaboration covered above, horizontal co-operation is needed across the offshore wind industry. Although some fora exist (eg within RenewableUK, The Carbon Trust, G9, the OWDF, and the newly formed Norstec) feedback from stakeholders suggests that these need to be subject to ongoing review to ensure they are delivering the best value.

- **Demonstration sites:** Recent analysis has shown there is a shortage of both onshore and offshore demonstration facilities, with a shortage in Europe of 5-10 onshore locations and up to 20 offshore locations by 2015.[47]
The identified shortage of prototype and demonstration facilities has the potential to cause significant delay or, in the worst case, cancellation of new product programmes, reducing the scope for cost reduction.

- **Planning envelope flexibility:** The ability of developers to maintain a variety of design options (eg the size of turbine or type of foundation) exists at present via the 'Rochdale Envelope' approach. Shorter statutory determination

Supporting all the prioritised offshore wind innovations would require a significant increase in public sector funding to UK projects in future funding periods.[48]
The degree to which the UK can benefit from RD&D elsewhere and the impact of any potential funding gap is at present cost unclear. All our industry stories rely most on new technology to drive down costs. However in the Technology Acceleration and Rapid Progression stories the pace of technological development is probably highest, therefore, requiring the greatest RD&D support.

The financial prerequisites revolve around making new equity and debt investors, including potential purchasers of project bonds, comfortable with the risks involved with offshore wind. This becomes critical for FID 2014 projects when the funding shortfall may begin to appear. In addition to the prerequisites already identified, agreement is needed on bankable structures so debt can be added to projects without an adverse impact on credit ratings of sponsor / developers and the Green Investment Bank must identify the nature and extent of its support, which is likely to be critical to draw in independent power producers

Although these issues relate to FID 2017 or 2020 projects, action may well need to be taken now due to long lead times.

[47] GL Garrad Hassan, 'Gap Analysis of Test and Demonstration Facilities for Offshore Wind Technology', August 2011
[48] Low Carbon Innovation Coordination Group, 'Technology Innovation Needs Assessment (TINA) Offshore Wind Power Summary Report', February 2012

Health and Safety

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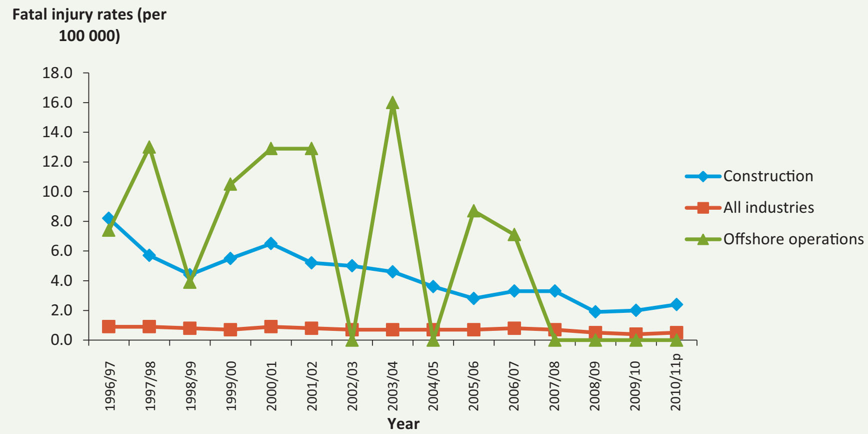
Offshore is a hazardous environment. Health and safety is therefore a key concern especially as offshore wind farms move to deeper water and further from shore sites which could exacerbate hazard levels. Exhibit 6.1 indicates the impact of the risks, with offshore operations in general showing a high level of fatalities in the period to 2006/7 compared with the construction industry and all industries, but with much better performance in the last 4 years.

Exhibit 6.1 Safety performance of offshore operations compared with construction and all industries, 1996/7 to 2010/11



Note: Offshore operations include both oil and gas and offshore wind, but exclude air transport activities and cover all workers. Construction and all industries cover employees only.

Source: Health and Safety Executive

Nothing should impact health and safety negatively

During our study we have noted that a number of industry players have articulated a vision of a high level of health and safety within offshore wind:

- 'Everything will be safe'
- 'HSE is critical'
- 'Nothing should impact health & safety negatively'

There are a number of key organisations, such as The Crown Estate, RenewableUK and the Marine and Coastguard Agency etc, that are taking proactive steps to ensure that this largely self-regulated industry maintains the highest standards. As an example of leading from the top, nine of Europe's largest renewable energy developers have combined to form a forum that places health and safety at the forefront of all its offshore wind activity and developments – the G9 Offshore Wind Health and Safety Association. The G9 intend to work together to:

- Ensure that health and safety is recognised as a core value within the European offshore wind industry,
- Promote and maintain the highest possible standards of health and safety through the life cycle of offshore wind projects,
- Identify key health and safety risks within the European offshore wind industry and identify best practice solutions to mitigate those risks to an acceptable level.

Many cost reduction trends should inherently improve health and safety

The key cost reduction opportunities will, in general, also improve health and safety, subject to appropriate evaluation of HSE impacts along the way.

A key feature of the new 6MW-class and 8MW class turbines is anticipated to be increased reliability. Clearly increased reliability, together with efficient remote operational capability, will reduce the overall time needed to maintain offshore wind turbines and therefore reduce the exposure time of personnel. The increase in the size of turbines will also reduce the number of turbine installations needed for a given size of wind farm and so will contribute, potentially, to reduced exposure to safety hazards. New turbines are also expected to include improved condition monitoring which will improve the ratio of planned to unplanned service –planned service is generally considered a safer environment.

A continuous and predictable pipeline of projects from developers and greater standardisation will augment the ability of the industry as a whole to learn lessons and introduce safer work processes. This will be enhanced by greater collaboration both vertically up and down the supply chain and horizontally among peers in the supply chain.

Many accidents in offshore wind have been caused by equipment – namely working vessels, jack-ups and cranes – working close to their operational limits. New investment is expected to either improve health and safety performance or negate the impact of harsher conditions, for example:

- New installation vessels will be specifically designed for offshore wind service.
- Infrastructure investment, for examples in quays, will also improve safety of the working environment.
- Introduction of automated production processes will reduce manual interventions and reduce risks.

New installation methods (float out and sink and buoyant concrete gravity bases) will reduce the need for heavy lift operations offshore and so also offer the potential for safer working.

There is therefore no inherent incompatibility between health and safety and cost reduction; indeed we expect them to work contemporaneously in all cases.

High risk operations and safety by design need to be addressed

Our analysis has shown a number of health and safety related issues need to be addressed.

- **Helicopter:** There is the potential for some operators to use helicopter access as part of their O&M approach. Helicopters are a high risk operation even in mature applications such as offshore oil and gas. Depending on the extent of use, this may become an area of concern. It is worthy of note that oil & gas H&S performance statistics do not include air travel.

- **Divers:** Diving is a high risk operation and is currently used during installation to intervene in vessel repair, cable installation and repair, inspections of structures, protection systems, recovery of dropped object and the like. To improve health and safety performance, use of diving must be reduced or eliminated. This will involve both technology (eg use of specially adapted ROVs – 'the right tools!') and careful design (to reduce or eliminate root causes)

- **Safety by design:** This is a key area where we must focus longer and harder, including quantifying reliability cases for key components. The Crown Estate – Offshore Wind Cost Reduction Pathway Development – PMSS health & safety guidance note – dated 2 September 2011 gives detailed consideration of the health and safety indicators and relevant reference documentation.

- **Worker health & welfare:** As more projects are built and maintained further from shore new challenges will emerge, particularly around the behavioural aspect of safety management and welfare considerations. Whether working remotely from a fixed platform, or aboard one of the new mothership concepts, attention will need to be paid to patterns of working and rest and the need to keep health and safety top of mind in all situations. Clearly, valuable lessons from the oil and gas industry can be adopted in many cases and modified where the wind industry has different requirements and hazard levels.

- **24/7 working:** We need clear evaluation of the Implication of, and increase in 24/7 working – the influence on accommodation, fatigue, working time directives, staffing levels and quantity of competent resource requirements in the industry to facilitate this.

Taking the lead

The three primary areas of health and safety performance, safe equipment, safe procedures and safe behaviour need to be tackled holistically within the industry.

The concern often voiced is that too narrow a focus on driving down capital and operational costs could impact negatively on health and safety performance. As we have concluded, most of the areas where we would expect that levelised costs could be reduced have an inherently beneficial impact on risk and hazard exposure and reduction, in all phases of the life cycle of an offshore wind farm asset. However, some of the necessary changes to technology, working methods and equipment will bring both opportunity and threat and it will be important that at all levels of the supply chain, clear leadership on safety matters will be required, to ensure the holistic approach to health and safety is followed and not simply a one-dimensional response.

Much can also be learned from similar industries that have been implementing their own cost reduction initiatives and at the same time improving health and safety performance and culture. Both the onshore construction industry and the offshore oil and gas industry have developed effective programmes that deal with both of these issues in a mutually beneficial way and the offshore wind sector needs to take these lessons and apply them in an appropriate way.
The goal should be a cost-effective industry with an exemplary health and safety record that sets a new standard for performance in this environment.

Conclusions

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There is a very considerable prize to be won by reducing the LCOE of offshore wind to levels competitive with other forms of [low carbon] generation. This will unlock up to £68 billion in wind farm investment by the mid 2020s as well as many large investments within the supply chain, for example in wind turbine and component manufacture, port infrastructure, operations and maintenance bases, etc. Lowering the LCOE of offshore wind will also reduce the burden on consumer energy bills.[49]

This will result in a more secure energy supply, the generation of jobs and unique expertise, and a material contribution to tackling carbon emissions. It will also serve to position the UK as the clear leader in offshore renewable energy generation, providing the UK with valuable export opportunities.

We have identified a number of pathways that result in costs of £100/MWh or lower for projects reaching FID in 2020: Rapid Growth, Technology Acceleration and Supply Chain Efficiency. The fact that there is no single 'silver bullet', either in terms of technologies or changes in the supply chain, gives confidence that the pathways we describe are robust, providing multiple routes by which this figure could be achieved. This variety of approaches increases confidence that this target could be reached, enables key players to progress their solutions within an 'envelope' of possibilities, and provides an important element of redundancy if some promising initiatives do not succeed.

Our Rapid Growth story is deliberately a way of testing the boundaries of what is possible and shows that, if everything goes well, reaching an offshore wind LCOE below £90/MWh is conceivable for projects reaching FID in 2020. Our Technology Acceleration and Supply Chain Efficiency stories show that costs of £100/MWh in 2020 can be achieved either through an emphasis on new technologies , new construction methods and a high level of R&D; or a focus on economies of scale, standardisation and more competition. These highlight a natural tension between developers of new technologies and methods on the one hand and financiers and wind farm developers on the other. The search for the optimum balance will be a constant concern for the whole industry and is likely to emerge from the decisions of individual players. All three of these pathways are fundamentally underpinned by a steadily growing market for offshore wind.

The Slow Progression scenario illustrates, among other things, the potential impact of a less conducive market. The LCOE remains stubbornly high through most of the decade until FID 2020. Feedback is that Slow Progression is by no means a worst-case scenario.

Our pathways are not projections or LCOE forecasts. Significant increases in input costs could move us away from the pathways we describe although many of these (such as steel prices and exchange rates) will also impact other forms of low carbon and traditional forms of generation. In the future the main 'wild card' or external event that could jeopardise the cost reduction pathways is a rapid increase in demand for offshore vessels and skilled personnel from the oil and gas sector. There is a natural hedge to this 'wild card' as it is most likely to occur in combination with surging oil and gas prices, which in turn will make offshore wind more competitive with fossil fuel based electricity generation.

All four stories require the raising of significant amounts of capital probably from a wider variety of sources.
The pre-requisites we have identified address cost reduction and the potential for a funding shortfall. Through timely and coordinated action to put in place the pre-requisites, the offshore wind sector could enter a virtuous spiral of risk reduction and transparent asset performance leading to lower required returns and greater appetite for investment.

Many of the 120 companies and organisations involved in this study have key decisions to make which will contribute to cost reduction. These decisions are highly complex and tightly integrated. Successful cost reduction will, therefore, require partnership between Government (including central Government, the Devolved Administrations, planning and consenting authorities and regulators), developers, Tier 1 and 2 suppliers and the finance community (which itself is broad and varied).

Government's role is largely to deliver the pre-requisites for the development of a steadily increasing market that will support investment. This means putting in place a robust framework for mandating offshore wind demand and ensuring the new consenting processes works in practice, hence delivering a predictable flow of projects and consented coastal manufacturing and other sites. These pre-requisites are not fully in place and urgent action is required. Longer term the Government has a role in ensuring the consenting process delivers the flexibility that is currently envisaged, supporting RD&D, and engaging with and removing obstacles to new investors investing in offshore wind (including better clarification on the role of the GIB).

Many actions fall squarely with industry and a large proportion of these are essentially 'no regret' activities. Industry is in the driving seat directly to implement cost reductions such as the introduction of larger, more reliable turbines. However, industry also has a very important role to establish the prerequisites for cost reduction. Developers must pass through market signals and certainty to their key suppliers in order for them to invest. Industry as a whole also needs to become much more comfortable with working collaboratively, challenging attitudes, and agreeing appropriate incentive structures. Industry also has a key role in supporting or establishing further demonstration and other testing facilities (potentially with some Government support) and engaging with the finance community to help them get more comfortable with the balance of risk and reward available in offshore wind.

[49] For a quantification of the benefit to the UK of reducing the costs of offshore power wind see: Low Carbon Innovation Coordination Group, 'Technology Innovation Needs Assessment (TINA) Offshore Wind Power Summary Report', February 2012.

With a large number of programmes of work undertaken by various agencies and organisations it is essential that they are pulled together in a coherent, structured and measured way as:

- Many different decisions and work programmes are closely intertwined.
- Confidence will grow as tangible success is achieved and well communicated.
- Changes will inevitably occur which will require a considered and collective response from the sector as a whole.

The DECC/Industry Cost Reduction Taskforce will address how this might be achieved and under what governance. In presenting this detailed evidence to the Taskforce, The Crown Estate reaffirms its commitment to assist industry and Government in setting and reaching targets designed to maximise the value of offshore wind to the benefit of the UK.

Glossary

AEP	Annual Energy Production
BSUOS	Balancing Services Use of System
CCGT	Combined Cycle Gas Turbines
CfDs	Contracts for Differences
EMR	Energy Market Reform
FEED	Front End Engineering and Design
FID	Final Investment Decision
FiT	Feed-in Tariff
H&S	Health & Safety
GIB	Green Investment Bank
IIPs	Independent Power Producers
LCOE	Levelised Cost of Energy
LCF	Levy Control Framework
MLA	Multi-Lateral Agency
OFTO	Offshore Transmission Owner
PE	Private Equity
RUK	RenewableUK
STW	Scottish Territorial Waters
TNUoS	Transmission Network Use of System
WACC	Weighted Average Cost of Capital


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Appendix A - Recent Analyses of Offshore Wind Costs

- Mott MacDonald for DECC, UK Electricity Generation Costs Update, 2010
- Parsons Brinckerhoff for DECC, Electricity Generation Cost Model Update 2011, 2011
- Ernst and Young for DECC, Cost of and financial support for offshore wind, 2009
- Garrad Hassan for BWEA, UK Offshore Wind: Charting the Right Course, 2009, *http://www.bwea.com/pdf/publications/ChartingtheRightCourse.pdf*
- Garrad Hassan for WINDSPEED, Inventory of location specific wind energy cost, 2011, *http://www.windspeed.eu/publications.php?id=19 (WP2 Report D2.2)*
- UKERC, Great Expectations – The costs of offshore wind in UK waters, 2010, *http://www.ukerc.ac.uk/support/tiki-read_article.php?articleId=613*
- PricewaterhouseCoopers, Turning Windpower promise into performance, 2011, *http://www.pwc.com/gx/en/utilities/publications/pwc-offshore-windpower-survey.jhtml*
- Garrard Hassan for the Danish Ministry of Climate and Energy, Background Report 2: Analysis of competitive conditions within the offshore wind sector, 2011, *http://www.ens.dk/daDK/UndergrundOgForsyning/VedvarendeEnergi/Vindkraft/Havvindmoeller/Fremtidens%20havmoelleparker/Documents/Deloitte%20Background%20report%202%20%20Analysis%20of%20competitive%20conditions%20within%20the%20offshore%20wind%20sector.pdf*
- Mott MacDonald for The Committee on Climate Change, Costs of low-carbon generation technologies, 2011
- Carbon Trust, Offshore wind: big challenge, big opportunity, 2009, *http://www.carbontrust.co.uk/publications/pages/publicationdetail.aspx?id=CTC743*
- Arup for DECC, Review of the generation costs and deployment potential of renewable electricity technologies in the UK, 2011, *http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/policy/renew_obs/1834-review-costs-potential-renewable-tech.pdf*


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Appendix B - Key Assumptions

This Appendix details assumptions made within the project which are not covered in the individual workstream reports.

Global assumptions

- Modelling in real (2011) prices
- Commodity prices fixed at average 2011 levels
- Exchange rates fixed at average 2011 levels
- Energy prices fixed at average 2011 levels
- Energy Policy – it is assumed that EMR progresses on schedule as set out in the White Paper (July 2011), with Feed-in Tariff Contract for Difference (CfDs) as the sole support mechanism from April 2017; and ROC re-banding is implemented as stated in the consultation document (October 2011).

Baseline wind farm cost element assumptions

- **Size:** 500MW wind farm
- **Operational life:** design certified for operational life of 20 years
- **Array cabling:** 33kV on fully flexible strings (in base case) ie provision to isolate an individual turbine and for the isolated turbines on the string make live a connection to another string
- **Ground conditions:** characterised by geotech pre-FID, with 20 per cent of foundation locations deemed more difficult (eg soft, rocky, gradient)
- **Energy yield:** an expected (P50) value has been calculated for each datapoint (i.e. each combination of site, year, turbine, story), and used as the base case for the model. This represents the average yield across all years of operation (taking the variability of wind speed across years and degradation into account).P10/P90 values for energy yield have also been estimated, at +/- 11% around the P50 value (in the base case).
- **Baseline turbines reaching FID in 2011** (to which innovations are applied for subsequent years): 3 bladed upwind, 3 stage gearbox, part conversion, DFIG 1500 rpm 690V output, 88 m/s tip speed. The turbine cost excludes the tower as this is counted under the support structure.
    - 4 MW, 120 m diameter, specific rating of 354 W/m2
    - 6 MW, 147 m diameter, specific rating of 354 W/m2
    - 8 MW, 169 m diameter, specific rating of 354 W/m2
- **Support structure:** includes the jacket plus the tower
- **installation:**
    - Sequential installation of jacket, array cable, then pre-assembled tower and turbine together
    - Jack-up collecting components from installation port.
    - Distance to installation port assumed equal to distance to nearest O&M port.
    - Array cables installed via J-tubes, one cable vessel and ROV
- **Decommissioning:** Reverse assembly process to installation taking 1 year. Piles and cables cut off at a depth below seabed which is unlikely to lead to uncovering. Environmental monitoring conducted at end. Residual value and the cost of scrapping have been ignored.
- **Operations and Maintenance:** Access by work boats and mother ship / accommodation platform for site D. Jack-ups used for major component replacement.
- **Transmission:** this has been factored into the model as an annual TNUoS (Transmission Network Use of System) charge rather than as CAPEX. Charges have been derived for the sites in accordance with a National Grid Guidance note: TNUoS charges for Offshore Generators, which can be found at:
  http://www.nationalgrid.com/NR/rdonlyres/869AF29F-0CBE-4189-97D5-562CBD01AD86/44194/GuidetooffshoreTNUoStariffs.pdf
  Capital costs for the assets were largely taken from National Grid's 2011 Offshore Development Information Statement at:
  http://www.nationalgrid.com/uk/Electricity/OffshoreTransmission/ODIS/.
  The model also factors in BSUoS charges (Balancing Services Use of System), which have been calculated as set out in the following note:
  http://www.nationalgrid.com/uk/Electricity/Balancing/bsuos/

Contracting and finance assumptions (base case, FID 2011)

- In the baseline, it is assumed that the development and construction costs of the wind farm are funded entirely by the project developer, which is consistent with UK experience to date for the sector. It is assumed however that once the wind farm is operational, project finance can be secured to a maximum level of 40 per cent, payable over a period of 14 years and priced at 325bps.
- Multi-contract approach to contracting for construction.

Site assumptions

Our analysis is based on four generic site types, as defined below, which cover the range of sites likely to be developed to 2020.

Site Type	Average Water Depth (MSL) (m)	Distance to nearest construction and operations port (km)	Average wind speed at 100m above MSL (m/s)
A	25	40	9
B	35	40	9.4
C	45	40	9.7
D	35	125	10

Story assumptions

Build profile

Each story has a corresponding assumption on build out profile for the UK and for the rest of the EU. There are three build out profiles in total (as the same profile is used for both the Technology Acceleration story and Supply Chain Efficiency story).
The starting point for the development of the profiles for the was the Offshore Development Information Statement (ODIS) produced by National Grid in September 2011. A number of minor amendments have been made to the ODIS figures to smooth the overall trajectory, however the 2020 numbers remain the same.

Operational Capacity (GW)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Slow Progression (ODIS 'Slow Progression' scenario)	**1.3**	**2.1**	**2.4**	**2.9**	**3.1**	**3.3**	**3.7**	**4.1**	**5.5**	**8.2**	**11.5**
Technology Acceleration & Supply Chain Efficiency (ODIS 'Gone Green' scenario)	**1.3**	**2.1**	**2.4**	**2.9**	**3.3**	**4.9**	**6.4**	**8.5**	**10.9**	**13.4**	**16.6**
Rapid Growth (ODIS 'Sustainable Growth' scenario)	**1.3**	**2.1**	**2.6**	**3.2**	**4.1**	**6.2**	**8.8**	**12.4**	**16.0**	**19.6**	**23.2**

Based on our current knowledge of the projects that have reached FID to date, The Crown Estate also produced a corresponding set of figures for the capacity at or post Final Investment Decision (FID), which includes that which has gone on to be constructed or operational. This is used as a key input into the finance workstream funding model.

Capacity achieved FID (GW)											
Slow Progression	**4.2**	**4.9**	**5.1**	**5.3**	**5.5**	**8.2**	**11.5**	**13.3**	**15.0**	**16.6**	**18.1**
Technology Acceleration & Supply Chain Efficiency	**4.2**	**4.9**	**6.9**	**8.9**	**10.9**	**13.4**	**16.6**	**19.4**	**22.0**	**24.4**	**26.7**
Rapid Growth	**4.2**	**4.9**	**8.6**	**12.3**	**16.0**	**19.6**	**23.2**	**25.9**	**28.6**	**31.3**	**34.0**

In addition, an assumption has been made that 19GW of capacity is operational in the rest of the EU by 2020. This is story independent – ie the same assumption has been made for all four stories. The 19GW figure has been informed by the EWEA Pure Power report (2011), the EU National Renewable Energy Action Plans, and further analysis by The Crown Estate.

Mix of sites

LCOE values have been calculated for a range of generic site types, as defined above. In order to calculate an average, or 'blended' LCOE value for each year, it is necessary to make an assumption about the mix of sites deployed in that year, shown as follows. The assumed mix varies by Story, depending on the overall level of deployment. These assumptions have been made by The Crown Estate for the purposes of this study, based on our current understanding of development programmes (where projects have been allocated to the site type closest to their actual characteristics), fit to the aggregate level of deployment in each story.

Story	Site	FID 2011	FID 2014	FID 2017	FID 2020
Slow Progression	A	100%	31%	7%	13%
	B	0%	69%	33%	10%
	C	0%	0%	42%	50%
	D	0%	0%	18%	27%
Technology Acceleration	A	100%	30%	3%	11%
	B	0%	70%	18%	5%
	C	0%	0%	44%	44%
	D	0%	0%	35%	40%
Supply Chain Efficiency	A	100%	30%	3%	11%
	B	0%	70%	18%	5%
	C	0%	0%	44%	44%
	D	0%	0%	35%	40%
Rapid Growth	A	100%	7%	10%	0%
	B	0%	32%	10%	3%
	C	0%	47%	39%	40%
	D	0%	14%	41%	57%

Mix of turbine sizes

In addition to making assumptions on the mix of sites in each year, it has also been necessary to make some headline assumptions as to the mix of 'products' or turbine types deployed. An assumption on the mix of turbines is made for each Story-Site-Year combination. It should be noted that each turbine 'class' represents a range of turbine sizes – i.e. 4MW class = 3-5MW, 6MW class = 5-7MW, 8MW class = 7-9MW.

		FID 2011	FID 2014		FID 2017			FID 2020		
Story	Site	4	4	6	4	6	8	4	6	8
1 – Slow Progression	A	100%	85%	15%	70%	30%	n/a	70%	30%	n/a
	B	100%	85%	15%	70%	30%	n/a	70%	30%	n/a
	C	n/a	n/a	n/a	70%	30%	n/a	40%	60%	n/a
	D	n/a	n/a	n/a	70%	30%	n/a	40%	60%	n/a
2 – Technology Acceleration	A	100%	50%	50%	30%	60%	10%	n/a	80%	20%
	B	100%	50%	50%	30%	60%	10%	n/a	80%	20%
	C	n/a	n/a	n/a	n/a	80%	20%	n/a	60%	40%
	D	n/a	n/a	n/a	n/a	80%	20%	n/a	60%	40%
3 – Supply Chain Efficiency	A	100%	85%	15%	70%	30%	n/a	50%	50%	n/a
	B	100%	85%	15%	70%	30%	n/a	50%	50%	n/a
	C	n/a	n/a	n/a	50%	50%	n/a	n/a	100%	n/a
	D	n/a	n/a	n/a	50%	50%	n/a	n/a	100%	n/a
4 – Rapid Growth	A	100%	50%	50%	30%	60%	10%	n/a	80%	20%
	B	100%	50%	50%	30%	60%	10%	n/a	80%	20%
	C	n/a	50%	50%	n/a	80%	20%	n/a	60%	40%
	D	n/a	50%	50%	n/a	80%	20%	n/a	60%	40%

Source: The Crown Estate

Appendix C - Project Panel Terms of Reference

Purpose

The Offshore Wind Cost Reduction Pathways project is a study led by The Crown Estate to assist industry and government in developing a common view as to the cost reductions that can be achieved in delivering new generation capacity, and the detailed assumptions of what is required to achieve them.
In order to assist and support the project team in the engagement and analysis of potential pathways it is proposed that a Project Advisory Panel is constituted with representation from both Government and Industry.
Its principle remit will be to:

- Provide guidance in the manner of engagement and types of output that will be meaningful to all parties
- Provide a sounding board within the project for industry participants engaged in the process
- Help to energise and broker cross-sector working during the project
- Assist The Crown Estate in working with the DECC Cost Reduction Taskforce to ensure the work of each project is complementary and enables effective integration of these programmes of work
- Provide specific input on particular issues within the individual members' (and their parent organisations') sphere of influence and knowledge
- Share progress of the project with the wider communities that they represent, where required
- Identify areas in which more work or effort is required and the most appropriate method of addressing those concerns
- Generally assist The Crown Estate in managing the risk to project delivery

Membership

The proposed membership is as follows:

- Duarte Figueira **DECC**
- Allan Taylor **DECC**
- Mark Thomas **InfrastructureUK**
- Thomas Arensbach **Gamesa (until March 2012)**
- Ron Cookson **Technip**
- Gordon Edge **RenewableUK**
- Michael Rolls **Siemens**
- Richard Sandford **RWE**
- Christian Skakkebaek **DONG Energy**
- Ian Temperton **Climate Change Capital**

The Crown Estate members: Adrian Fox, Duncan Clark (n.b. Richard Howard from January 2012)

One corresponding member – Andrew Jamieson (Scottish Power): Chair DECC Cost reduction Taskforce

Alternates will be nominated by each of the members above, to ensure full representation at each meeting, should the main member be unable to attend.

If a member or their alternate is absent for two meetings then a replacement person may be invited to represent that segment for future meetings.

The possibility of additional corresponding members will be reviewed on application and agreed at the next available meeting.

Functions

The first meeting of this Panel has reviewed the draft Terms of Reference and accepts this as its working mandate.

Each member will, in addition to the general remit described under 'Purpose' have the following specific responsibilities.

The Crown Estate will:

- prepare all necessary documentation for each meeting in sufficient time to allow members to be able to respond to the information and issues raised,
- organise relevant presentations from the workstream consultants and report progress and any impediments to the panel at each meeting.

DECC (ORED) will:

- liaise as necessary with Devolved Administrations and other government departments to distribute project progress and information and provide a conduit for information to be made available to the project team from those bodies.

The Developers will:

- report progress of the project to any meeting of the OWDF (or its sub-groups) that takes place within the time frame of the study if that is appropriate within the agenda items of the meeting.

RenewableUK will:

- work to engage with their extensive member and working group networks to cover a wide range of supply chain contributions to the study.
- work to involve wider stakeholders, such as the steel industry, which could influence the reduction in cost,
- Provide a forum for disseminating any out puts of the process through their programme of conferences and workshops
- Through its affiliation with Scottish Renewables provide them with periodic updates and provide a route for their potential contributions to the project.

Meeting arrangements

Frequency: Meetings will be held every four weeks.

Location: Meetings will normally be held at The Crown Estate's offices. Video and teleconferencing facilities will be made available where possible.

Correspondence: Any information provided by members will be stored on an appropriate data management system related to this project only. Members will be notified when new information is published by email.

Chair: The chairperson will initially be appointed from The Crown Estate for the duration of the study.

Administration: Minutes will be prepared and circulated by The Crown Estate.

Reporting

- These Terms of Reference for the Panel may be reviewed at any time during its tenure by special request at any formal meeting.
- The panel will provide suitable updates on the project progress to the Industry Cost Reduction Task Force.

This CD contains:

- BVG Associates, Offshore wind cost reduction pathways – Technology work stream, April 2012
- E C Harris, Offshore wind cost reduction pathways – Supply Chain work stream, April 2012
- PMSS, Offshore Wind Cost Reduction Pathways – Health & Safety Review, April 2012
- PricewaterhouseCoopers, Offshore wind cost reduction pathways project – Finance work stream, April 2012
- RenewableUK, Potential for offshore transmission cost reductions, February, 2012

The Crown Estate is a diverse property business valued at more than £7 billion. We have been trusted to manage a wide range of properties across the UK including commercial developments, retail properties and rural holdings. Our portfolio includes agricultural land, parkland and forestry.
It also comprises around half of the UK’s foreshore, and almost all of the seabed around the UK out to the 12 nautical mile territorial limit.
We are above all a commercial organisation, tasked by Parliament with enhancing the value of the portfolio we manage and generating a profit for the benefit of the nation. In the last year we concluded over £1 billion of property transactions, including sales and acquisitions, and also some of the most ambitious redevelopment schemes in the heart of London. We manage one of the nation's largest rural estates.

To help drive the UK's emerging offshore renewable energy industry we are investing over £100 million alongside some of the world's largest energy companies.

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