OFFSHORE WIND: DELIVERING MORE FOR LESS

AN INDEPENDENT ANALYSIS COMMISSIONED BY STATKRAFT UK

JULY 2015

BVG Associates

BVG Associates is a technical consultancy with expertise in wind and marine energy technologies. The team probably has the best independent knowledge of the supply chain and market for wind turbines in the UK. BVG Associates has more than 150 person years experience in the wind industry, many of these being "hands on" with wind turbine manufacturers, leading RD&D, purchasing and production departments. BVG Associates has consistently delivered to customers in many areas of the wind energy sector, including:

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

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EXECUTIVE SUMMARY

Successive governments have established the UK as the world leader in offshore wind. Levels of deployment in the last few years have set the industry on a path of steep cost reduction and provided a platform for an industry that will be sustainable without special consumer support.

The analysis set out in this document demonstrates that real, tangible advances in technology, the supply chain, and policy have combined to drive down the cost of energy for projects about to go into construction in 2015. This downward pressure is expected to continue, with offshore wind projects going into construction in 5 years that are competitive with new CCGT plant. The repowering of the oldest projects with the most modern turbines could, from the late 2020s, see the advent of offshore wind plant that is cheaper than CCGT, even under the Government's lowest gas price forecast.

This is a radical step towards 'subsidy' free offshore wind and will enable the UK to continue to decarbonise through the 2020s, cost-effectively.

Being cost competitive with CCGT is only one benefit from this UK success story. Offshore wind has also driven significant inward investment and jobs and growth and has the potential to deliver much greater benefits in the long term and contribute to rebalancing the UK economy. Most of this activity will be focused in the Northern Powerhouse and in coastal areas with traditionally high levels of unemployment.

Growth to a market of 24GW in 2030 will provide a significant opportunity for the UK supply chain. UK companies can be expected to secure more than £36 billion cumulatively between 2015 and 2030 and this will drive a strong, productive UK manufacturing and construction supply chain supporting more than 18,000 directly employed in long term roles. Repowering the UK fleet of projects will at least double the total size and duration of the market, by putting at least two generations of assets on each site, each being operated for 25 years. This will create a strong draw for inward investment, increase the likelihood of high UK content and will sustain and grow the levels of employment for 50 years or more.

A strong UK supply chain will be positioned to seize an export opportunity worth £210 billion up to the end of 2030. UK companies are already providing products, services and knowledge to offshore wind markets in Europe, Asia and the USA, replicating the success of North Sea oil and gas. The anticipated growth in the global market could bring an additional 8,000 jobs by 2030. It will enable UK companies to secure an additional £16 billion in exports between the start of 2015 and the end of 2030.

There is a clear path for offshore wind to be competitive with gas fired generation early next decade. The repowering of the UK fleet from the late 2020s is expected to drive costs below those of electricity from gas generation. Repowering will also at least double the industrial opportunity at home and act as a strong draw on inward investment to the UK. A thriving UK supply chain will be ideally positioned to secure export opportunities into a growing global market and contribute to rebalancing the UK economy.

COSTS HAVE FALLEN AND REAL, PRACTICAL STEPS WILL DRIVE THEM DOWN FURTHER

The cost of energy from offshore wind is coming down and more quickly than predicted. This cost reduction will continue through the 2020s and beyond, despite wind farms being built in increasingly challenging conditions. This progress is based on real, practical steps with measurable impact, as discussed in this section, below.

In the next section, we go on to show how these steps have already affected the cost of energy from offshore wind. We also show how these steps will continue this downward trend, by looking at cost of energy at a number of snapshots in time.

TECHNOLOGY INNOVATION

The offshore wind industry is driving down the cost of energy through the development and improvement of products and processes across a number of areas.

The last five years has seen strong progress in improving the operation of the last generation of smaller wind turbines. This has been possible because of growing levels of offshore operating experience and increasing data. Whilst this has driven costs down, the potential savings are ultimately limited.

The introduction of a new generation of larger wind turbines, earlier than anticipated, has had a more radical impact on the cost of energy. With rated capacities of up to 8MW, these turbines offer significant reductions in cost of energy in a number of areas: fewer turbines means fewer foundations, less inter array cable, and lower installation and operational costs. In addition, this new generation of turbines offers improved reliability and access to better wind resource via larger rotors on taller towers. Suppliers will refine and improve these designs to give even better performance and reliability, as well as developing even larger turbines, rated 10MW and higher, to come to market early next decade.

Following turbines, foundation technology is advancing. The tubular steel monopile has been the most cost-effective and commonly used foundation for turbines and industry has continually refined the design, manufacturing and installation processes to drive down costs. Most recently, cross-industry collaboration has allowed the industry to extend their use to support larger turbines on deeper water sites than previously anticipated. Industry is also industrialising the production and installation of jacket and concrete gravity foundations, making them increasingly competitive with monopiles, especially in deeper water.

For array cables, there is industry collaboration to support the introduction of 66kV cables, which offer cost and efficiency savings for larger turbines.

The last five years has seen strong investment in bespoke vessels and tooling for turbine, foundation and cable installation, and this is expected to continue into the future. This means developers can install projects more quickly and with fewer delays due to weather conditions. In the long term, installation of complete turbine and foundation assemblies (float-out-and-sink) could significantly reduce costly offshore work.

Industry is stretching the distance at which high voltage alternating current (HVAC) transmissions systems can be used and reducing the hardware requirements. It is also developing more cost effective and flexible high voltage direct current (HVDC) systems.

So far, the operation, maintenance and service of most projects has been carried out from the closest port using small, fast personnel transfer vessels (PTVs). New designs for larger PTVs have been developed that can safely transport technicians onto turbines in increasingly difficult sea conditions.

With the development of projects further offshore, there is also going to be a move to larger service operation vessels (SOVs) that remain at site for longer periods. These vessels will have more sophisticated personnel access systems and cranes and further reduce downtime.

Alongside these logistic advances, companies are also developing proactive condition-based maintenance methods and a fix-first-time approach to reduce operating costs and increase energy production.

A MATURING SUPPLY CHAIN

Increasing levels of competition and collaboration in a maturing supply chain means companies are passing through cost reductions to energy users, though increases in productivity.

Evidence of this process includes improved vertical collaboration and sharing of experience in project teams, more effective contracting methods, increasing information sharing between industry players across projects, and more joint industry projects on standards and standardisation.

The industry is also investing in new coastal facilities and infrastructure that will allow more productive manufacturing and lower logistic costs.

REDUCING COSTS OF CAPITAL

Continental project-financed projects have managed to secure low-cost debt through improved risk management and packaging of construction contracts.

The UK has had a market designed around utility balance-sheet financing of construction, but this financing is now in short supply. As the industry moves to a world of project finance and more sophisticated refinancing, lower merchant risk due to the new Contract for Difference (CfD) process and a history of delivery will enable a lowering of financing costs for UK projects.

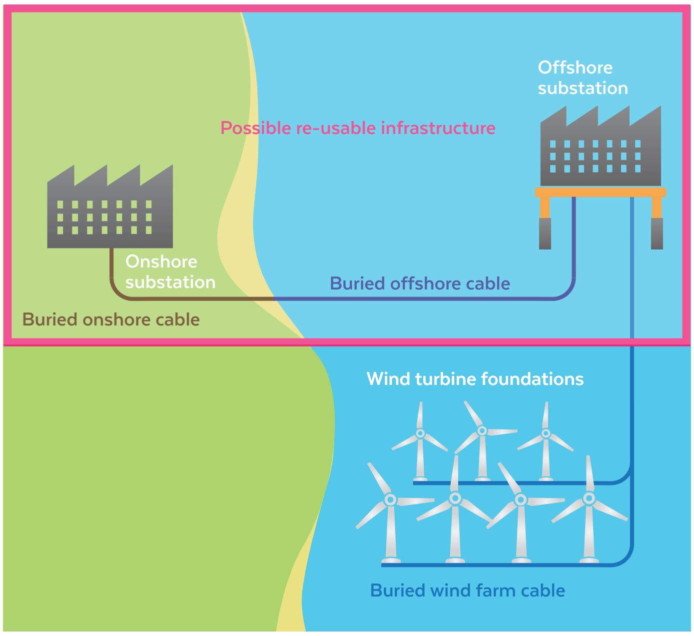
REPOWERING WIND FARMS

Project owners can be expected to "repower" projects as they come to the end of their economic life, starting in the late 2020s. Repowering is the process of replacing the old generating assets with the latest technology which is lower cost and higher output. This trend is already seen in other mature renewables sectors such as hydropower and onshore wind.

There are many upsides to repowering offshore wind. Alongside providing a long term source of low carbon energy there is the scope for ongoing cost reductions and also a significant industrial opportunity.

Turbines, foundations and cabling within the wind farm will need to be replaced with larger and more cost effective technology. With some refurbishment, however, owners are likely to be able to re-use the transmission system (export cables and substations) that connect the wind farms to the onshore grid. Given that the transmission system cost is a significant part of the original investment, the cost of energy from a repowered site will be significantly reduced.

Repowering not only reduces costs and risk, but also creates an additional market for the supply chain. It will involve the manufacture, installation, and operation of at least one further generation of plant on the same site. Put simply this leads to at least a doubling of the total market size and duration and acts as a strong draw for further inward investment to the UK.



UK POLICY

To date, the UK Government has given strong support to the offshore wind industry as it has helped it move from early demonstration projects through to full-scale commercial deployment.

The establishment of the CfD regime is helping to reduce the cost capital by decreasing revenue risk and increasing competition and supply chain productivity through its auction process.

The streamlining of the planning process and the creation of the Green Investment Bank have also help knock down barriers to sustainable growth.

The requirement for developers to submit supply chain plans to the Government, is helping focus attention on what actions they can take to increase competition, support innovation and develop skills.

Offshore wind also benefits from Government policies on productivity, making the UK tax system better for business and on making the most of its R&D capability, including via its world-class universities and Catapult centres.

In the future, greater clarity about the Government's short- and long-term ambitions for offshore wind will help developers and the supply chain to plan their investment more efficiently and focus on implementing innovation.

THE COST OF ENERGY TRAJECTORY, 2005 TO 2030

In this section, we explore how the practical steps described in the section above are reducing the cost of energy from offshore wind.

We then compare the trajectory of cost of energy from offshore wind farms with new-build CCGT plant and show how it becomes competitive within a decade.

MODELLING THE COST OF ENERGY FROM OFFSHORE WIND

Our analysis focuses on six snapshots of the UK industry at five year intervals, each one describing the state of the

industry as project developers make their final investment decision (FID) for a new wind farm in that year.

For each snapshot, we carried out a detailed, bottom-up analysis of the breakdown of capital and operational expenditure and electricity generation of four representative, real-life UK projects reaching FID around the time of each snapshot. This analysis took account of the specific characteristics of each site and typical technology used at that point in time. It is described in more detail in the Technical Annex.

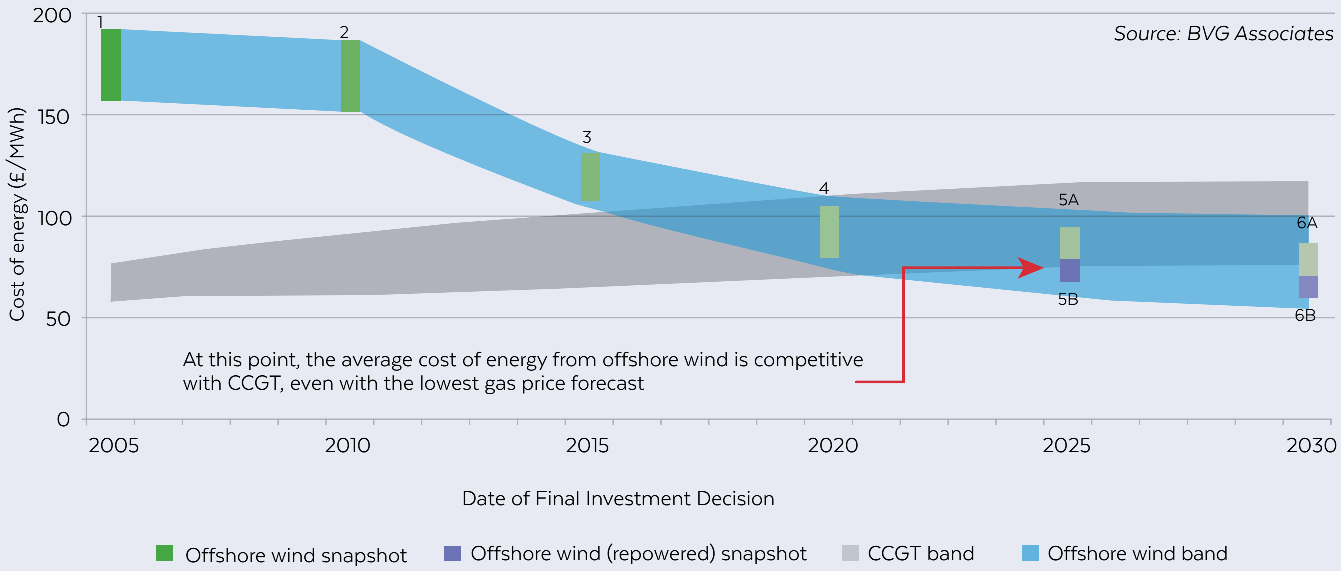
On the following pages, we describe the status of technology, supply chain and finance at the time of each snapshot. A numerical summary of the range of characteristics of the individual projects we modelled to derive a cost of energy for each snapshot is also included in the Technical Annex.

CCGT IS THE MOST SUITABLE TECHNOLOGY FOR COMPARISON

In assessing the relative cost of energy from offshore wind, it is sensible to compare it with the lowest cost alternative that could be built in its place to replace the UK's current fleet of ageing generation plant. Current understanding is that this is likely to be CCGT. It also has a lower carbon footprint than coal, can be deployed at scale and can be easily incorporated into the current transmission network. There is, of course, uncertainty over future gas price, hence the relatively wide range of cost of energy from CCGT that we present.

We could have used new nuclear build (much slower to deploy; at the upper end of CCGT costs and higher uncertainty of true lifetime cost), other renewables (cannot deploy at such large scale) or coal-based CCS (where commercial feasibility is yet to be demonstrated). We could also have compared with wholesale electricity prices, but these do not properly reflect the costs of generation from new build capacity, in which the UK must invest.

OFFSHORE WIND: COST COMPETITIVE WITHIN A DECADE



Comparison between cost from offshore wind and combined cycle gas turbine (CCGT) plant.

Offshore wind bars reflect range of cost of four representative, real-life projects reaching financial investment decision (FID) around each snapshot, taking into account site conditions and available technology. See description below of the status of technology, supply chain and finance at the time of each snapshot.

The broader bands incorporate the potential for fluctuations in commodity prices, including fuel, which affect the cost of energy.

The graph compares the changing cost of energy from offshore wind and CCGT plant over time, from 2005 to 2030. The bars represent the range in cost of energy from the typical offshore wind projects analysed at each snapshot. The broader, blue band also incorporates the potential for fluctuations in commodity prices, including fuel, which would affect the cost of energy at that snapshot. The broad grey band represents the range in cost of energy from new-build CCGT plant, reflecting uncertainty about future gas price.

The graph shows the strong reductions of cost in offshore wind that we are seeing today. This trend is backed up by a growing body of evidence, including the results of the UK's 2014/15 CfD auction, the recent auction for Horns Rev 3 wind farm in Denmark and the maximum prices for the upcoming auction rounds in the Netherlands. It is also supported by independent analysis, such as the Offshore Wind Programme Board's *Cost Reduction Monitoring Framework*.

Cost of energy is set to reduce further in the 2020s as the supply chain matures, becomes more competitive and productive and technology development continues to make a difference, more and more driven by the UK's world-class universities, creative SME community and Catapult centres. By the mid 2020s, the cost of energy from offshore wind will have more than halved in 15 years, which is line with existing experience from the onshore wind market.

This will mean that offshore wind projects going into construction in 5 years will be competitive with new CCGT plant. Indeed, with DECC's high gas price forecast, the cost of energy from any new offshore wind project could be cheaper than new build CCGT as early as 2020.

The repowering of the oldest projects with the most modern turbines could, from the late 2020s, see the advent of offshore wind plant that is cheaper than CCGT, even under the Government's lowest gas price forecast.

Improvements in the cost of energy from offshore wind mean that well within a decade, most new offshore wind projects will be a lower cost option than new CCGT plant, the cheapest alternative.

SIX SNAPSHOTS OF COST OF ENERGY BETWEEN 2005 AND 2030

To show the real, practical steps that will allow this level of cost of energy reduction, we describe the status of the industry and trends in project characteristics, at six snapshots, one every five years from 2005 to 2030. For each snapshot, we modelled four real projects typical of those reaching FID at the time. A summary table of the ranges of each of the main project characteristics over these four projects for each snapshot is provided in the Technical Annex.

SNAPSHOT 1

NEW PROJECTS THAT REACHED FID IN 2005

- At the start of 2005, the UK had 120MW installed, with 500MW in the rest of Europe and none in the rest of the world.
- Projects were located in shallow waters and close to shore and were typically small (25-30 turbines, with total rated capacity up to 90MW).
- Developers used marinised versions of 2MW to 3MW turbines designed for onshore projects.
- All projects used monopile foundations and 33-36kV array cables.
- Installation used mainly adapted oil and gas technology.
- Operation, maintenance and service (OMS) activity for these projects is carried out from the nearest ports using personnel transfer vessels (PTVs).
- The supply chain was still relatively inexperienced and learned some tough lessons about doing repeat work in harsh offshore conditions.
- Large utilities funded all UK projects on their balance sheets.

SNAPSHOT 2

NEW PROJECTS THAT REACHED FID IN 2010

- At the start of 2010, the UK had 900MW installed, with 1.2GW in the rest of Europe and less than 100MW in the rest of the world.
- There was a shift to investment in much larger projects, rated up to 500MW, although still in relatively shallow water depths and close to shore.
- Suppliers mainly used specially adapted versions of existing turbine designs up to 4MW rating, with larger rotors and increased durability for offshore use.
- Almost all projects continued to used monopile foundations and HVAC transmission systems.
- There was strong investment in offshore wind-specific installation and service vessels.
- OMS activity for these projects continues to be carried out from the nearest port using PTVs, but new vessels are being designed.
- The supply chain was growing and maturing, but remained largely Continent-based.
- UK projects were still funded on the balance sheet of utilities, although developers of Continental projects were seeking project finance.
- Non-utility players were starting to invest through post-construction refinancing and through the offshore transmission owner (OFTO) regime.

SNAPSHOT 3

NEW PROJECTS THAT ARE REACHING FID IN 2015

- At the start of 2015, the UK has 4.6GW installed, with 4.7GW in the rest of Europe and 1.1GW in the rest of the world.
- Projects will be constructed further offshore and in deeper water, with the additional cost offset by higher wind speeds.
- Most projects are typically at least 400MW with some larger projects reaching about 700MW.
- A new generation of much larger, offshore-specific turbines (6-8MW) are now available.
- Improved designs of larger monopiles mean they remain competitive in deeper water sites with larger turbines, though jacket foundations are also being used in more projects.
- HVAC technology has improved so it remains more competitive than HVDC systems, even relatively far from shore.
- Some developers are starting to use larger service operation vessels (SOVs) for OMS activity, to take advantage of their more capable access systems and reduced weather restrictions.
- Some established players are investing in new UK manufacturing facilities to address market growth and respond to the need for logistically efficient, coastal facilities handling increased component size.
- Some UK developers are using project finance, while post-construction re-financing is becoming commonplace.
- The Contracts for Difference (CfD) support system is contributing to a fall in the cost of capital by decreasing revenue risk and increasing competition through the auction process.

SNAPSHOT 4

NEW PROJECTS THAT REACH FID IN 2020

- At the start of 2020, the UK will have 10GW installed, with 12GW in the rest of Europe and 7GW in the rest of the world.
- There will be a mix of deep/near-shore and shallow/far-shore projects.
- Most projects will have a capacity of between 500MW and 1GW, although larger projects, constructed over a number of tranches, may also be kicked-off.
- Turbines suppliers will introduce larger variants of their existing turbines and will be progressing the designs of another generation of larger turbines.
- Developers will continue to use monopiles where they are suitable, but jackets and concrete gravity base foundations will become increasingly competitive through industrialised manufacturing and installation.
- Array cables at around 70kV will be standard.
- UK developers will start to use HVDC transmission systems on far-shore projects.
- The increasing number of far-shore projects means SOVs are now being more commonly for OMS activity and industry gaining insight to optimise their design and operation.
- The supply chain will mature with experience, with more companies investing in facilities in the UK.
- The cost of capital will continue to fall as the finance community becomes increasingly comfortable about offshore wind.

SNAPSHOT 5A

NEW PROJECTS THAT REACH FID IN 2025

- At the start of 2025, the UK could have 17GW installed, with 21GW in the rest of Europe and 17GW in the rest of the world.
- There will continue to be a mix of project types but large, multi-gigawatt projects may become more commonplace, delivering economies of scale.
- Turbine suppliers will be commercially deploying their new generation of turbines, with rated capacities of 10MW or more, incorporating improved aerodynamic control through look-ahead wind measurement, for example.
- Further innovation will enable monopiles to remain competitive with jackets and concrete foundations with this new generation of turbines.
- The cost of transmission systems will be reducing and there will be greater opportunities for sharing transmission arrangements between wind farms located close together and with transnational interconnects.
- Developers are collaborating on OMS activity to combine SOV fleets to reduce cost and give greater coverage.
- Given a steady pipeline of projects, there will be increasing levels of collaborations between players as strong partnership between developers and different suppliers emerge.
- More new coastal manufacturing facilities with optimised tooling for large-volume production will be established.
- Some mature developers with a strong track record of successful delivery may be accessing funding through investment grade bonds.

SNAPSHOT 5B
REPOWERED PROJECTS THAT REACH FID IN 2025

- Owners of some of the oldest projects will start to repower by replacing turbines, foundations and array cables with larger, up-to-date designs and refurbishing and re-using existing transmission assets.
- This repowering will take place alongside the continued development of new projects, representing an additional market for the supply chain.
- Repowered project are likely to have reduced financial risks because of the owner's familiarity with the site and wind conditions.

SNAPSHOT 6A
NEW PROJECTS THAT REACH FID IN 2030

- At the start of 2030, the UK could have 24GW installed, with 37GW in the rest of Europe and 32GW in the rest of the world.
- More projects will be built-out as part of a pipeline approach by developers and their supply chains.
- Turbine suppliers will introduce larger variants of their new generation of turbines, incorporating further advances in aerodynamic control and durability.
- We may see regular use of innovations such as DC generation and array cabling (decreasing losses and on-turbine electrical hardware), float-out-and-sink foundation technology (avoiding the need for traditional installation methods) and advanced, adaptive wind farm control.
- The upper end of the supply chain is likely to be dominated by fewer, larger players with activities also in other related sectors.
- As an established asset class with predictable revenues, offshore wind will be seen as an attractive investment for many, thereby further reducing the cost of capital.

SNAPSHOT 6B
REPOWERED PROJECTS THAT REACH FID IN 2030

- Repowering will be particularly important into the 2030s as more as larger projects reach the end of their design life.
- As these projects are located further from shore, the cost benefit of reusing transmission assets will be even greater.

THE INDUSTRIALISATION STORY: GROWING UK CONTENT & HIGH QUALITY UK JOBS

Offshore wind offers a major economic opportunity for the UK. The sector is generating long-term manufacturing, construction and service employment. This is creating value in key areas around the country and has the potential to contribute to rebalancing the UK economy.

This section considers how UK projects are delivering increasing levels of UK content, why repowering increases the market size available to the supply chain and why the UK's leading position in this industry means it can secure strong, long-term export growth.

In doing so, we consider the level of employment created, the value of activity that UK companies are anticipated to secure and the scale of industrial infrastructure, such as ports and factories, that will be established.

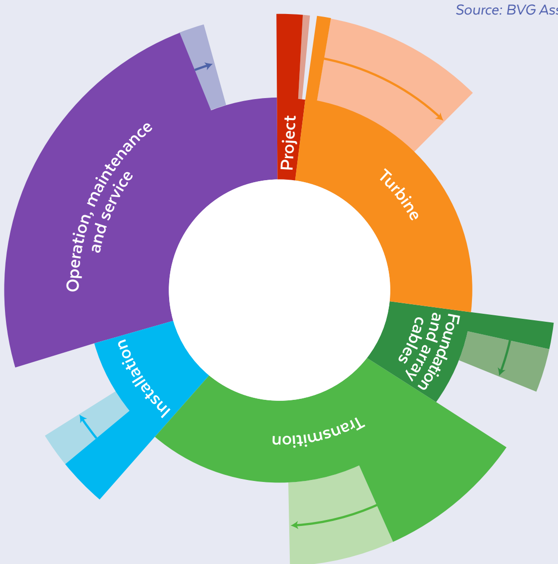
INCREASING LEVELS OF UK CONTENT

The UK's position as the global leader in offshore wind means it is already attracting supply chain investment – such as the construction of major new port infrastucture and factories in Hull, and in several foundation, cable and vessel facilities – and creating UK jobs. This trend will continue as the industry matures and the need for new manufacturing and operations capacity increases.

The earliest UK wind farms generally had relatively low UK content, but this is now changing rapidly. Projects that are more recent have anticipated lifetime UK contents of approximately 40%. This should rise to 60% for new projects by the middle of the next decade as new UK facilities come online, also driving growth further down the supply chain.

The chart below shows how this UK content breaks down for a typical UK project to date and for a UK project with go-ahead in 15 years' time, based on a review of published work.

Source: BVG Associates



To-date UK content (40%), and expected future UK content (60%) of the various parts of an installed offshore wind turbine.

The inner ring shows total spend. The outer ring shows UK content (full colour represents UK content to date, half colour, the expected picture in future projects).

Based on a UK market with an operating capacity of 24GW in 2030, a deployment rate of 1.7GW and 60% UK content for new or repowered projects, we expect that supply to UK projects alone will support about 18,000 direct, long-term full time equivalent employees in 2030.

In this scenario, the UK market opportunity will be worth approximately £5 billion per year in 2030 and £75 billion cumulatively between the start of 2015 and the end of 2030. Of this, UK companies will secure more than £3 billion in 2030 and more than £36 billion between the start of 2015 and the end of 2030.

REPOWERING OFFERS AN IMPORTANT LONG-TERM OPPORTUNITY

The UK will not just build out its current pipeline of projects and stop. As wind farms reach the end of their design lives, their owners are likely to decide to re-use and repower the sites, stimulating fresh demand in the supply chain.

Repowering the UK fleet of projects will at least double the total size and duration of the market, by putting at least two generations of assets on each site, each being operated for 25 years.

Indeed, looking long-term and assuming a potential UK fleet capacity of 40GW, a wind farm design life of 25 years gives a sustainable, ongoing demand for repowered projects of over 1.5GW of new plant per year indefinitely, along with 40GW of capacity to operate. The amount of purple in the outer ring of the pie chart opposite shows just how important operation, maintenance and service is, in terms of UK content. Each new or repowered offshore wind farm offers guaranteed, stable jobs for another 25 years for local coastal communities.

Combined with the strong, early commitment of the UK to offshore wind, this ongoing repowering opportunity will create a strong draw for inward investment into manufacturing and service capacity, increasing the likelihood of high UK content. This will be supported by the Government's policy to minimise corporation tax and drive up UK productivity.

Such a market will sustain and grow the levels of employment and value generation described above for 50 years or more.

A GROWING EXPORT OPPORTUNITY

The UK supply chain is not just delivering on UK projects, but it is already active delivering on wind farms in the rest of Europe and beyond. These markets are anticipated to grow rapidly, especially during the 2020s and UK businesses will be well placed to secure export opportunities around the world.

In particular, the UK will be well placed to export high value, high productivity engineering and specialist services, following closely the proven North Sea oil and gas model.

In 2030, we assume there will be:

- A market in the rest of Europe, with an operating capacity of 37GW and deployment rate of 2.5GW, with approximately 20% UK content for new projects
- A rapidly growing market in the rest of the world, with an operating capacity of 32GW and deployment rate of 2.8GW, with approximately 5% UK content for new projects

Based on these assumptions, we expect the export market will support more than a further 8,000 direct, long-term full time equivalent employees in the UK in 2030.

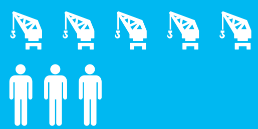
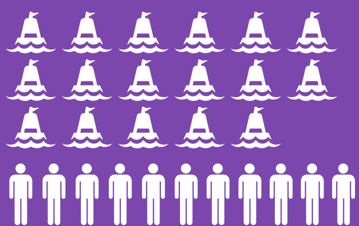
This export market opportunity will be worth approximately £16 billion per year in 2030 and £210 billion cumulatively between the start of 2015 and the end of 2030. Of this, UK companies will secure almost £2 billion in 2030 and more than £16 billion between the start of 2015 and the end of 2030. These levels can be expected to increase further as we look into 2030s as more, new markets establish, and repowering starts in other existing markets.

UK INDUSTRIAL FOOTPRINT IN 2030

In total, we expect the domestic and export offshore wind market will support more than 26,000 direct, long-term full time equivalent employees in 2030, many in focused in the Northern Powerhouse and in coastal areas of traditionally high unemployment. This level of employment is likely to grow for the next 50 years and will drive the need for apprenticeships in electro-mechanical and other valuable, technical skills.

The global market opportunity will be worth approximately £22 billion in 2030 and £285 billion cumulatively between the start of 2015 and the end of 2030. Of this, UK companies will secure almost £5 billion in 2030 and more than £52 billion between the start of 2015 and the end of 2030.

The table below sets out the likely number of primary, coastal factories, offshore facilities and full time equivalent employees created in the UK in 2030 based on this global opportunity. Again, the UK could expect to secure additional facilities, infrastructure and employment beyond 2030 as the supply chain continues to mature and new export opportunities develop.

IMPACT IN INFRASTRUCTURE AND EMPLOYMENT	DETAIL
	**Project development/management**: This includes project-specific teams with up to 200 engineers and commercial staff. These teams will also use subcontractors for a range of planning and survey tasks.
	**Turbine manufacture**: This includes two facilities for assembling nacelles, two facilities manufacturing blades and three facilities manufacturing towers. These facilities will also stimulate many UK sub-suppliers of materials and sub-components.
	**Balance of plant manufacture**: This includes three facilities for manufacturing foundations, two facilities producing cables and two construction facilities for offshore substations. Again, these facilities will stimulate a much wider UK supply chain for materials and sub-components.
	**Installation**: This includes five construction ports located around the UK coastline for turbines and balance of plant, plus management and operational staff for UK-based contractors.
	**Operation, maintenance and service**: This includes 17 local port facilities for service and maintenance crews (some hosting multiple bases), including management teams, as well as local and centralised operational staff. *Source: BVG Associates*

 : A Tier 1 manufacturing facility (plus associated sub-suppliers)

 : A construction staging port suitable for turbine and balance of plant installation vessels and waterside construction facilities for offshore substations

 : An OMS port suitable for crew transfer vessels (nearshore projects) or service operation vessels (farshore projects)

 : 1,000 direct full time equivalent (FTE) employees

TECHNICAL ANNEX

ASSUMPTIONS USED IN DERIVING THE COST OF ENERGY

In this report, we use cost of energy to compare the cost of electricity generation by different technologies.

Cost of energy (also called levelised cost of energy or LCOE) is the average revenue required per unit of electricity generated to make a market rate of return on the total lifetime investment in a project. We calculate this by combining the estimated lifetime capital and operational cost and dividing it by lifetime energy production, taking into account the timing of income and expenditure and the cost of capital.

This analysis does not take account of taxation, the costs associated with the wider transmission network for either offshore wind or CCGT, the need for balancing capacity or the cost benefit of reduced exposure to international gas markets.

One approach to establishing a trajectory of cost of energy would be to model future projects but derive cost of energy to date from available data for specific projects. Often such data is incomplete, sensitive and shows significant scatter. Instead, we have modelled all costs, with models informed by published and other data, to give a clearer view of changing costs.

THE COST OF OFFSHORE WIND

Most investment in an offshore wind farm is made near the start of the project with the purchase and installation of the main components, including the turbines, foundations, cables and substations. Once the wind farm is complete, there are also ongoing costs to cover its long-term operation.

The chart on the right illustrates how these different costs contribute to the cost of energy for offshore wind.

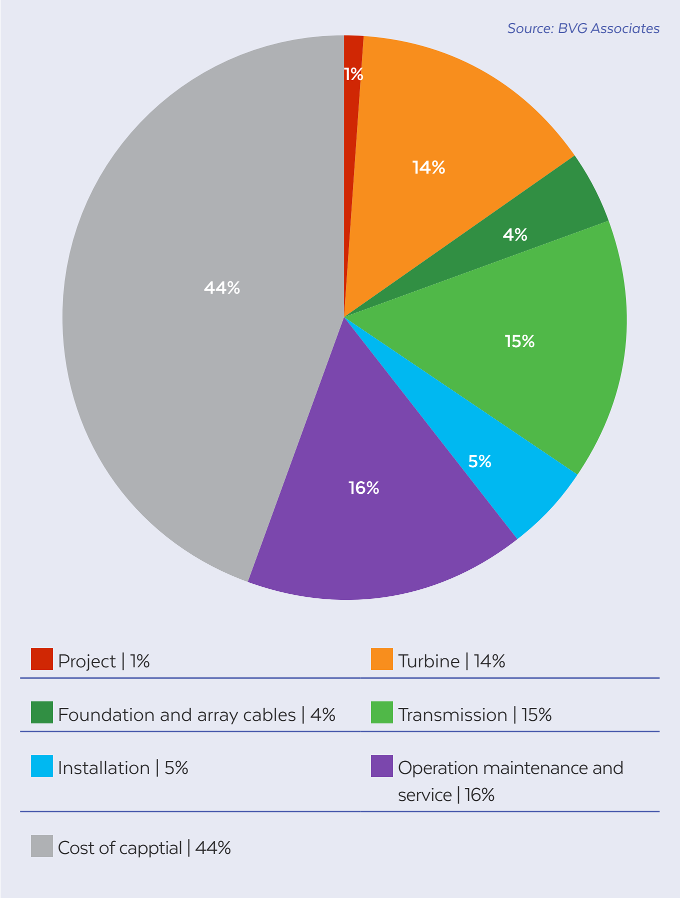
For more information about the cost of energy from offshore wind, see *The Crown Estate's Cost Reduction Pathways Study*.

ILLUSTRATIVE BREAKDOWN OF COST OF ENERGY FOR A TYPICAL UK OFFSHORE WIND PROJECT.

We calculated the cost of energy at each snapshot from offshore wind using existing in-house models. These models calculate cost of energy from a bottom-up analysis of progress in each element of the wind farm, rather than applying a simple, top-down learning rate. Each element has a rigorous definition of scope and we have a long list of global assumptions that may be set to project-specific values, if required. A range of individual supply chain and technology innovations are modelled to impact the cost of energy, as the industry matures. For each snapshot, we model four real-world sites, using the main cost-driving characteristics of each site, including:

- Year of FID
- Turbine size (MW)
- Project size (GW)
- Water depth (m)
- Distance to port and grid (km)
- Wind speed at 100m (m/s)

The projects selected for each snapshot were representative of the industry at that point.



Generally, assumptions are in line with those provided in The Crown Estate *Offshore Wind Cost Reduction Pathways Technology Work Stream*.

Information about water depth was sourced from developer websites. Wind speed data comes from the BERR *Marine Renewables Energy Atlas* or from subsequently corrected DNV GL data for wind speeds for the North Sea. Assumptions about technology trends, cost of capital and project timings are based on our industry insight from regular dialogue with organisations across the supply chain. All the costs are in 2015 values.

Combining cost, lifetime and energy generation together in a discounted cash flow model, we derived an LCOE for each project.

In recent years, our models have been regularly verified with a wide range of industry players, both at an element-by-element level and at an LCOE level. The range shown by the bars for each snapshot is the cost of energy from the cheapest and most expensive projects of the four projects considered.

Across all the cost of energy forecasts for the snapshots, the wider band reflects the potential for fluctuations in commodity prices, including fuel. Macro-economic effects are not considered.

REPOWERING

The effect of repowering by refurbishing and re-using transmission assets was modelled by incorporating the cost of:

- Decommissioning and removing existing turbines, foundations and array cables between turbines, without taking benefit of resale or scrap value of any items
- Project development, assuming an existing knowledge of seabed,

environmental and metocean conditions and ecological considerations but where a new offshore consent and wind farm design is required

- Constructing generating assets, consisting of fewer. larger turbines, hence on larger foundations and in a new layout with increased spacing
- Refurbishing key electrical and mechanical components on the offshore substation, including exchange of some components.
- Refurbishing elements of the onshore transmission system

This avoids much development cost and risk, including relating to the onshore transmission system and much of the hardware cost of the transmission system.

The cost of CCGT plant
To calculate the cost of energy for gas-fuelled electricity generation, we used the costs set out in the Department for Energy and Climate Change (DECC) Electricity Generation Costs (Dec 2013).

We calculated the cost of fuel using the DECC Updated Energy and Emissions Projections 2014, using its high and low price scenarios. While there is some concern that DECC's central forecast is pessimistic, industry feedback is that other forecasts fall within the high and low price scenarios.

We calculated the cost of energy assuming a 25-year lifetime, a 7% discount rate and a four-year period between the final investment decision and first generation. This is consistent with the assumptions stated by DECC.

The cost of energy from offshore wind is dominated by the CAPEX, which makes up approximately three-quarters of total undiscounted expenditure. This means the cost of energy of a project is relatively precisely known at the point of commitment. For CCGT plant, however, the capital cost is low and the dominant influence on the lifetime cost of energy of the plant is the purchase of fuel, the price of which is difficult to forecast. Owners may seek to hedge against price volatility through long-term agreements but will pay a premium for such arrangements.

SUMMARY OF SNAPSHOT ASSUMPTIONS AND COST OF ENERGY RESULTS

The table below sets out the typical range of physical and technology characteristics of offshore wind projects at each of the snapshots. It also sets out the forecast range of cost of energy for both offshore wind and CCGT plant. The ranges in cost of energy shown take into account variability in project characteristics, competition, supply chain and fuel prices. These correspond to the wide bands in the chart. The bars in the chart show the ranges in cost of energy, taking into account only the variability in project characteristics.

Year	Turbine size (MW)	Project size (GW)	Water depth (m)	Distance to port / grid (km)	Wind speed at 100m (m/s)	Cost of energy offshore wind (£/MWh)	Cost of energy CCGT (£/MWh)
2005	2-3	<0.1	15 – 25	10 – 30	8.5 – 9.0	157-192	58-77
2010	3-4	0.3 – 0.6	25 – 35	10 – 60	9.0 – 9.5	152-190	61-92
2015	6-8	0.6 – 0.8	20 – 45	20 – 120	9.3 – 9.7	105-136	65-102
2020	7-9	0.6 – 1.2	30 – 45	50 – 240	9.5 – 10.0	76-110	70-110
2025	8-10	0.6 – 1.2	30 – 45	50 – 240	9.5 – 10.2	64-104	75-117
2025 (repowered)	8-10	0.2 – 0.4	15 – 25	10 – 60	8.5 – 9.0		
2030	10-12	0.6 – 1.2	30 – 45	50 – 240	9.5 – 10.2	53-99	76-118
2030 (repowered)	10-12	0.3 – 0.6	25 – 30	10 – 60	9.0 – 9.5		

Source: BVG Associates

BVGassociates