Offshore Wind: A 2013 supply chain health check

A report prepared by BVG Associates for The Crown Estate

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BVG Associates

BVG Associates is an independent consultancy with a global outlook, specialising in the technology, delivery and economics of wind and marine energy generation systems.

We specialise in market analysis, supply chain development, technical innovation and project implementation enhanced by our hands-on experience and deep understanding of technology. Our team has the best objective knowledge of the market and supply chain for wind turbines in the UK, derived from over 130 combined years of experience. Our sole purpose is to help clients establish renewable energy generation as a major, responsible and cost-effective part of a sustainable global energy mix.

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Summary

The Crown Estate commissioned this analysis to help the maturing European offshore wind industry understand the supply chain challenges it faces and consider how they might be resolved. It forms part of The Crown Estate's work in supporting the Offshore Wind Programme Board (OWPB), and updates and extends previous gap analyses undertaken by BVG Associates in 2009, 2011 and 2012. As before, it is based on extensive consultation with, and feedback from, developers and suppliers in key areas of the supply chain.

For each "subelement" of the supply chain, the analysis not only considers the capacity of the industry to meet demand but also the development of the technology and supply chain as the industry strives to reduce cost of energy. As previously, each subelement is graded as red, amber or green. This time, however, this grading is derived after consideration of six key criteria, quantitatively scored in radar plots for each subelement.

The UK has for a long while been the largest offshore wind market globally, and the industry as a whole has been affected by the implementation of the UK Coalition Government's Electricity Market Reform (EMR), which replaces the Renewables Obligation with a feed-in tariff with contracts for difference from the end of March 2017. The interim final investment decision (FID) enabling arrangements for projects that may not be built in time to qualify for the Renewables Obligation, but will be ready for commitment before confidence is established in the enduring feed-in tariff regime, emerged during the course of this analysis.

Judgements about the supply chain were made in the context of demand from a UK market that reaches 15GW installed capacity by 2020 and 40GW by 2030 and a market for the rest of Europe that is only slightly smaller. This report therefore considers the demand for the whole of Europe and not just the UK. The UK market to 2020 was intended to be at the optimistic end of what could be achieved within the budget provided within the Levy Control Framework. The confidence of the industry to invest depends on the certainty and size of the future market and we have therefore assumed that industry confidence is commensurate with the projected market size. Judgements were also made in the context of the imperative for the industry to reduce the cost of energy. In some cases, it is recognised that, although there may not be a barrier to sufficient supply as such, sufficient supply at a cost following the trajectory that the industry has committed to is harder to achieve. Due to the fundamental importance of reducing the cost of energy, this aspect is more thoroughly captured here than in similar work to date.

The grading for each supply chain subelement is summarised in Table 0.1, against the definitions provided in Section 2.

In 2012 we identified two key areas of concern, graded red, which remain for this analysis: offshore wind turbines and subsea DC export cables. On this occasion, we have also graded foundation installation red.

Across the supply chain, only the capacity to supply high voltage export cables has the potential to constrain the growth of the industry without new investment within the next 18 months. This investment may come from existing suppliers or new entrants to the market. For DC high voltage export cables, only a subset of suppliers currently can produce the extruded export cable preferred by the industry and hence this subelement is one of the three graded red. The necessary investment could be unlocked by an intervention that is linked to the future demand for subsea interconnector projects.

Turbine supply and foundation installation are the other two subelements graded red. In these cases, it is the capacity of the industry to supply products that offer the prospect of reductions in the cost of energy that drives the grading. For turbines, the industry will not benefit from the significant cost of energy reductions offered by next generation products without new investment in coastal manufacturing facilities and sufficient competition between turbine suppliers and there is a danger that the market may be too small to facilitate both of these. Action is also needed to provide timely and economically viable test and demonstration sites. With uncertain economics for dedicated demonstration wind farms, it is suggested that there should be greater emphasis on extensions to existing or future wind farms. Work is also needed to increase assurance of turbine reliability for developers and investors (as lack of certainty of turbine reliability is the dominant driver of uncertain operational expenditure, or OPEX). Measures are also needed to further de-risk first commercial projects using next generation turbines to hasten their commercialisation as a key part of reducing the cost of energy from offshore wind.

There is uncertainty over the future choice of foundation technologies as the industry moves to larger turbines installed in deeper waters. There has been a growing recognition that the use of XL monopiles can offer lower combined supply and installation costs than space frame structures, such as jackets, for a wider range of conditions than previously expected. Potentially disruptive alternative designs, including more easily installed concrete solutions suitable for deeper water, are yet to establish. The impact of this uncertainty will not only be felt in the supply of foundations but also in the availability of vessels to install them. There has been significant investment in wind farm installation vessels but not all of these have the capability to lift XL monopiles, none have sufficient deck space to install jackets optimally, and most will be also be deployed for turbine installation. Without greater clarity on technology trends, investment in optimal foundation installation vessels is likely to be slow and this subelement has been graded red for this reason.

Foundation supply has remained amber, except for monopiles. A concern in 2012 was the need for investment in manufacturing facilities for alternatives to monopiles. There has been little progress and, while the use of XL monopiles in the short term means that the situation has not deteriorated, investment will be needed if costs of projects in waters deeper than 40m are to reduce. For novel foundations also, action is needed to accelerate the availability of test sites.

Overall, the picture across the supply chain has improved compared with the 2012 analysis. For four of the subelements there is less concern; only for foundation installation is there increased concern. In general this reflects the maturing of the offshore wind supply chain, the progress that has been made in commercialising technologies and the lower market projection. Subsea AC export cables has now been downgraded to amber to reflect the growing interest in the market from Asian manufacturers, one of which has won its first European offshore wind contract. There is less concern around subsea cable installation, recognising that progress has been made in consolidating the learning from projects to date and the growing presence in the market of well-backed contractors. There is also an improving picture for monopile supply with the investment in new capacity, much of which has the capability to produce XL monopiles.

In addition, communication between industry parties has started to mature, both on a supply level and in addressing cross-industry issues, at least within the UK. Following the publication of The Cost Reduction Task Force Report in 2012 and the formation of the Offshore Wind Programme Board (OWPB), we have seen the reformation of the Offshore Developers Forum (OWDF) as the Offshore Wind Industry Council (OWIC).

Teams at the Department for Business, Innovation and Skills (BIS) and the Department of Energy and Climate Change (DECC) now actively support and monitor industry’s progress in developing the UK supply chain. They are helping the industry to address the requirement to implement plans to support industrial development captured in the award process for the new Contracts for Difference (CFDs). The establishment of the Offshore Wind Investment Organisation (OWIO), the GROW Offshore Wind programme (and analogous schemes outside England), the Offshore Renewable Energy Catapult and the publication of the Offshore Wind Industrial Strategy all work to reinforce the intent captured in the new EMR legislation.

Vital, however, for meeting the Government’s cost of energy reduction ambition is for the Government to give sufficient confidence in the market up to and beyond 2020 in order for the supply chain to invest. In a relatively low-margin sector with long project and product gestation times, that investment case often needs to be made for a market lasting at least 10 years and the UK, as the dominant market in Europe, is looked to for leadership.

While the development of a robust revenue mechanism and policies to encourage industrial development are vital elements, little has been provided to support long-term confidence in the market post-2020. Industry knows that it needs to reduce cost of energy as it has indicated. It continues to seek assurance that, if it does so, the Government sees a key ongoing role for offshore wind looking towards 2030. With confidence in this, the track record of the wind industry and its “can-do” attitude in delivering growth, technology development and cost of energy reduction, positions it to deliver significant amounts of electricity and sustainable jobs at a competitive cost.

Table 0.1 Summary of assessments for the supply chain subelements considered in this study.

Traffic light[1]	Supply chain subelement	Supply chain element
G ↑	Wind farm design	Development and project management
G	Survey vessels	
R	Offshore wind turbines	Turbine supply
G	Blades	
G ↑	Castings and forgings	
G	Gearbox, large bearings and next generation generators	
G	Towers	
G	Subsea array cables	Balance of plant supply
A	Subsea AC export cables	
R	Subsea DC export cables	
G	AC substation electrical systems	
A	DC substation electrical systems	
G	Monopile foundations	
A	Non-monopile steel foundations	
A	Concrete foundations	
G	Installation ports	Installation and commissioning
R ↓	Foundation installation	
G ↑	Subsea cable installation	
G	Turbine installation	
G	Routine maintenance vessels and equipment	Operation, maintenance and service
G	Large component replacement vessels	
A	Full-scale test facilities	Support services

[1] Definitions of traffic lights are provided in Section 2.5. Arrows indicate how the traffic light grading has changed since *Towards Round 3: the offshore wind supply chain in 2012*, published in June 2012 (↑ situation improved, ↓ situation worsened). No arrow indicates either no change or a new or amended category title since 2012.

1. Introduction

1.1. Purpose

As part of its work in supporting the Offshore Wind Programme Board (OWPB), The Crown Estate has commissioned this analysis of the offshore wind supply chain in Europe. It updates and extends previous studies undertaken by BVG Associates in 2009, 2011 and 2012.

This work was undertaken at a pivotal time in the development of the UK offshore wind industry. During the course of the analysis, the Government provided further detail on its electricity market reform (EMR), in particular, the mechanism and strike prices for the contracts for difference (CfDs), and the transitional enabling arrangements for projects likely to achieve final investment decision (FID) before the withdrawal of the Renewables Obligation (RO) at the end of March 2017.[2] The Government also published its *Offshore Wind Industrial Strategy*, which aims to ensure that the UK captures the maximum economic benefit from deploying offshore wind in domestic and overseas markets.[3] These developments are discussed in Section 4.1.

Notable milestones in 2013 have also been the construction of the first 500MW offshore wind farms in the world with the completion of Greater Gabbard (504MW) and London Array (630MW), and the start of construction of Gwynt y Môr (576MW). As of November 2013, the UK has about 3.6GW of offshore wind installed capacity, out of a total European capacity of about 5GW.

1.2. Approach

This analysis has been focused on the supply of components and services but industry issues such as government policy, grid connections, consenting, and health and safety were also considered to provide a context for the discussion of the supply chain. This report also discusses some of these industry issues, capturing the feedback that we received during the course of our interviews with companies. While the analysis of supply chain components and services has a global emphasis, recognising that their availability for UK projects needs to be placed in the context of the European market at least, the industry issues discussed relate more specifically to the deployment of offshore wind in the UK.

As previously, the analysis considers about 20 elements of the offshore wind supply chain and each is graded with a red, amber or green "traffic light. Past gap analyses commissioned by The Crown Estate have been primarily concerned with the capacity in the supply chain to meet the demand of a rapidly growing industry.[4] The brief update in 2012 evolved this approach in the context of the *Offshore Wind Cost Reduction Pathways Study* to consider not only whether supply could meet demand but also the extent to which future demand could be met while following a downward trajectory in the cost of energy.[5]

This 2013 analysis has developed the methodology further by considering a number of aspects that could constrain cost effective project delivery to produce what could be described as a supply chain "health check". Each of these aspects has been scored using semi-quantitative criteria to support the grading of each element.

This study has been facilitated by the informed dialogue, detailed input and thorough peer review of a range of wind farm developers and suppliers. BVG Associates and The Crown Estate are grateful for all the companies that gave time and insight so openly.

As ever, we welcome any feedback on our analysis and conclusions.

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[2] See www.gov.uk/government/publications/electricity-market-reform-contracts-for-difference, last accessed August 2013 and *Levy Control Framework and Draft CfD Strike Prices*, available online at www.gov.uk/government/uploads/system/uploads/attachment_data/file/209361/Levy_Control_Framework_and_Draft_CfD_Strike_Prices.pdf, last accessed August 2013.

[3] *Offshore Wind Industrial Strategy - Business and Government Action*, HM Government, August 2013, available online at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/226456/bis-13-1092-offshore-wind-industrial-strategy.pdf, last accessed August 2013.

[4] *Towards Round 3: Building the Offshore Wind Supply Chain*, BVG Associates for The Crown Estate, May 2009, available online at www.bvgassociates.co.uk/Publications/BVGAssociatespublications.aspx, last accessed August 2013

[5] *Ibid* and *Offshore Wind Cost Reduction Pathways Study*, The Crown Estate, May 2012, available online at www.thecrownestate.co.uk/media/305094/Offshore%20wind%20cost%20reduction%20pathways%20study.pdf, last accessed August 2013.

2. Methodology

2.1. Process of engagement

Our engagement with industry is at the heart of this analysis. We used a process that aimed to maximise the value that companies could provide while limiting our demand on senior individuals' time. The stages were:

1. **Production of a project briefing or "pre-read"**. To inform interviewees and facilitate discussion, we made an initial assessment of the issues concerning the supply of components and services. Interviewees were invited to challenge these figures or indicate if they did not feel able to present a view. Our intent was to discuss subelements only with those with first-hand knowledge of those subelements. The document also presented the purpose and scope of the analysis so that interviewees could be well prepared.
2. **Structured interviews**. We held interviews with developers and suppliers based on a detailed questionnaire structured around the assessment criteria described below for each supply chain subelement.
3. **Informal interviews**. We held a number of shorter interviews to confirm factual information relating to specific elements of supply or to test conclusions.
4. **Verification**. We issued our interim findings, which were similar to the summary tables presented in this report, to a range of companies for review and feedback. We then issued drafts of sections of this report for review and comment by senior individuals. The report was then presented to the members of the OWPB for comment before revision and final customer acceptance.

2.2. Evidence and confidentiality

Some of the information shared with us was commercially sensitive and therefore this has been aggregated and anonymised for publication.

After each formal interview, we issued draft notes presenting our understanding of the level of sensitivity demanded for each item of input received. Interviewees then had the opportunity to refine these notes and confirm the level of sensitivity, thereby allowing us to maximise the accuracy and detail presented, while respecting the commercial position of each company with which we engaged.

2.3. Coverage

The supply chain was analysed by breaking it down into six elements:

- Project management and development
- Turbine supply
- Balance of plant supply
- Installation and commissioning
- Operation, maintenance and service (OMS), and
- Support services.

Each element was divided into subelements for detailed analysis. Not all components and services were included as the intention was to choose subelements where bottlenecks could conceivably occur. These generally involved the supply of components or services for which a significant outlay in specialist equipment is needed with potentially long lead times.

2.4. Modelling

For each subelement, where possible, we derived a demand projection from 2013 to 2022. This was based on the installed capacity projection presented in Section 3. Where necessary, the demand was offset by up to two years from the installed capacity projection to reflect when the supply chain activity occurs. For example, substations are typically manufactured two years before turbine commissioning.

The top-down demand projection was reconciled with a bottom-up up, probabilistic project-by-project forecast covering a total of about 150 wind farm projects across Europe. For each subelement, demand was based on the timing and specific needs of each of these wind farms. A set of assumptions was developed to estimate any unknown parameters and characteristics. These include turbine rated power, cable lengths, foundation technology and the type of electrical transmission system. Unless stated, our assumptions are the same as those used in our *Building an Industry* report for RenewableUK, published in June 2013.[6]

For subelements graded red, we undertook a supply analysis to assess current levels of supply and opportunities to increase this supply. In some cases, this focused on specific technologies within each subelement.

2.5. Grading

Each subelement of the supply chain was graded red, amber or green, using the following definitions:

G **Green.** Not currently an area of concern. Where problems have been identified, there are reasons to believe that these will be rectified by market pressures. A watching brief should be maintained,

[6] *Building an Industry: Updated Scenarios for Industrial Development*, BVG Associates for RenewableUK, June 2013, available online at http://www.renewableuk.com/en/publications/index.cfm/BAI2013, last accessed August 2013.

recognising that significant investment and supply chain development is still required in some cases in order to deliver sufficient capacity.

A **Amber.** An area of concern. Some proactive intervention is required in order to address market disconnect. This may relate to the lack or availability of optimal solutions, with the industry forced to use more expensive components and services.

R **Red.** An area of significant concern. The issue demands further analysis and strategic action. Again, this may relate to the availability only of non-optimal solutions.

Criteria

In forming a judgement we used a semi-quantitative scoring system for a number of criteria, which are described below. The traffic light grading was not derived mathematically from these scores, recognising that, for different subelements of supply, different criteria may be more important than others.

Current capacity and investment lead time: How much can be delivered today against the future requirement modelled from the demand projection.

1 = Existing capacity is limited or is non-existent.

2 = Supply is sufficient in the short term. Efficient future demand can only be met by investment at new facilities.

3 = Supply is sufficient in the short term. Future demand can be met by incremental investment at existing facilities.

4 = Future demand can be met without significant investment.

Investment status: The degree to which investment decisions have been made about new supply chain capacity.

1 = It is unclear if there are any investment plans or investment plans are insufficient to meet short-term demand.

2 = Companies have indicated their intention to invest but plans have not been made publicly available.

3 = Companies have well advanced plans and are known to be pending FID.

4 = Investment decisions have been made and further new capacity is to come on line.

Synergy with parallel sectors: Synergy may be positive in lowering investment risk or negative if the supply chain capacity is unavailable due to the demand from other sectors.

1 = The technology has an application in other sectors which is a disadvantage to offshore wind.

2 = The technology is unique to offshore wind.

3 = The technology has an application in other sectors but the benefit to offshore wind will depend on the demand from the parallel sector.

4 = The technology has an application in other sectors which overall is of benefit to offshore wind.

LCOE reduction due to technology development: How much progress is being made from the 2011 baseline of £140/MWh in achieving potential levelised cost of energy (LCOE) reductions as a result of technology developments, as identified in the *Offshore Wind Cost Reduction Pathways Study.*

1 = There is no evidence of progress in reducing LCOE through technology change.

2 = The value of the innovation is accepted by the industry but little progress is being made.

3 = The innovation is being incorporated into products but the benefits may not be realised quickly.

4 = Progress is on track or not required.

Technology shift: If innovation other than for LCOE reduction is necessary to meet the demands of future projects.

1 = Future projects will require new technology but it is uncertain what form it will take.

2 = Future projects will require a new technology that is well developed in concept but is unproven.

3 = Future projects will require new technology but some testing is required before it can be deployed.

4 = Future projects will not require new technology or will require new technology that has been used in other contexts and can be quickly deployed.

LCOE reduction due to supply chain development: How much progress is being made from the 2011 baseline in achieving potential LCOE reductions as a result of supply chain developments (such as increased competition, supply chain partnerships and supply from low cost countries), as identified in the *Offshore Wind Cost Reduction Pathways Study*.

1 = There is no evidence of progress in reducing LCOE through supply chain innovations or developments.

2 = There is evidence of supply chain innovations or developments but only by a small number of projects.

3 = There is evidence of supply chain innovations or developments but not all projects will benefit.

4 = Supply chain innovations or developments are likely to realise the potential benefits across all projects or are not required.

2.6. Assessment of capability

In each summary table in Sections 5 to 10, we have provided a non-exhaustive list of proven suppliers and additional future capability. Proven suppliers are those that have supplied the equivalent of 200MW to the European offshore wind market. We recognise that a number of Asian suppliers have met the capacity requirement for the Chinese market but these have been excluded unless there is evidence that they are making substantive efforts. to enter the European market. We have also excluded companies that have met the 200MW criterion but are believed to be no longer active in the market.

Companies that are not proven using the definition above but have supplied the industry, or could do so, have been included in the summary tables as "additional future capability". The list is skewed towards UK suppliers.

3. Capacity projection

The required capacity of the supply chain was derived from a projection of future installed capacity in the UK and the rest of Europe (see Figure 3.1). The projection for the rest of Europe is based on forecasts by the European Wind Energy Association, moderated by feedback that the UK was likely to host half of Europe's installed capacity between 2020 and 2030.

The projection is based on the build out of individual UK projects which is based on the *RenewableUK Offshore Wind Project Timelines 2013* and moderated using our market knowledge.[7] The build out in other European countries is based around our knowledge of individual markets. In Germany, the timelines for projects have been derived broadly from the project timelines, publicly available market forecasts and the timetable for grid connections. Figure 3.2 shows the national breakdown of projected cumulative installed capacity in the whole of Europe in 2020.

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[7] *Offshore Wind Project Timelines 2013*, RenewableUK, June 2013, available online at www.renewableuk.com/en/publications/index.cfm/offshore-wind-Project-timelines-2013, last accessed August 2013.

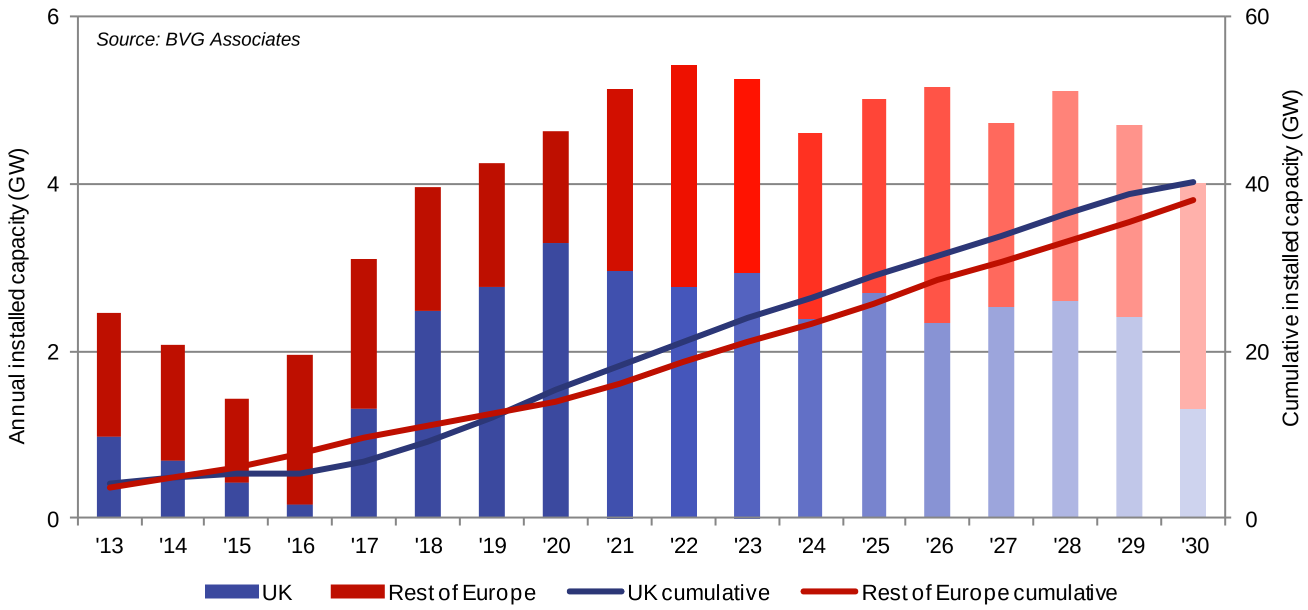

Figure 3.1 Projected UK and rest of European offshore wind capacity to 2030. This is used as a basis for the analysis in this report.The bars after 2020 have been shaded lighter to reflect the decreasing certainty for new installed capacity after this point.

The capacity projections were agreed with The Crown Estate before industry engagement and are intended to be ambitious but achievable.

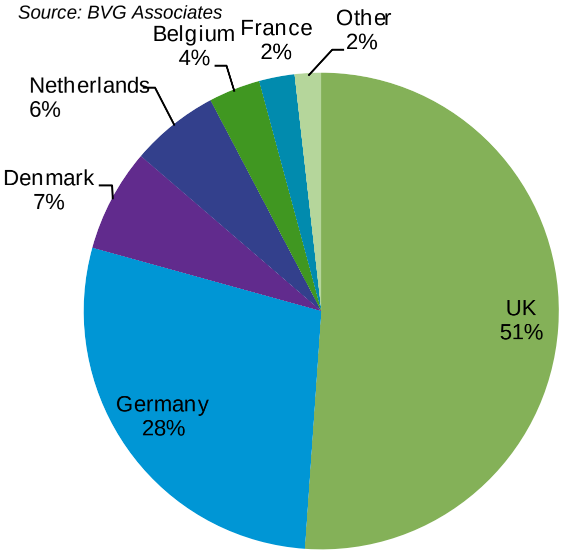

Figure 3.2 National breakdown of projected cumulative installed capacity in Europe in 2020.

3.1. Industry feedback

Industry feedback indicates that the projections used for this were optimistic, but a reasonable basis on which to judge supply. Many companies were cautious about expressing a view at a time when the full details of EMR and the *Industrial Strategy* were yet to be published, although the industry response to recent announcements suggests that the views presented to us will not have not changed significantly since the publication of the *Industrial Strategy*.

In general, developers report that they do not have a clear view of installed capacity after 2020.

Many of the investments discussed throughout this report will only happen with confidence in the market. The assessments made in this analysis are based on the market projection shown here. For this analysis, we considered that the figure of 30GW by 2020 in Europe could only be reached with market confidence and therefore our conclusions have been formulated in this context.

4. Industry level issues

4.1. Government policy

Along with most other energy sectors, offshore wind is a subsidised industry and its growth is dependent on the level and type of support mechanism offered. While most foresee a time in the next decade when onshore wind will be competitive with conventional fossil fuel generation, this is anticipated to take longer for offshore wind. Political debate has often been polarised. There is recognition that offshore wind is a secure source of energy that can be deployed at scale. Proponents of competing energy sources such as shale gas and nuclear, however, typically oppose the development of offshore wind in the UK, making it difficult for industry to have long-term confidence in Government policy.

Electricity Market Reform

In the UK, the Coalition Government has been undertaking EMR which introduces a form of feed-in tariff known as the contract for difference (CfD), which replaces the Renewables Obligation (RO), which supports most currently operating UK offshore wind farms. The CfD guarantees fixed revenue per MWh, compared with the RO which provides revenue over and above the wholesale electricity price. The RO was seen by the Government as expensive and bureaucratic and the CfD was favoured as it combines guaranteed revenue per MWh to the generator, thus more efficiently reducing their risk, with retention of the link to the wider electricity market.

The wind industry has been uncomfortable about the EMR process, not from a principled objection to CfD, although some were concerned by the lack of market pull for renewable energy, but more from the uncertainty that the change has created and the slow process of moving from concept to detail.

From June 2013, the detail started to emerge. *Electricity Market Reform: Delivering UK Investment* was published with the 2013 Spending Review.[8] It included an annual budget for the Levy Control Framework, which is the funding cap for the price support of a range of energy technologies under the new CfD and existing arrangements under the RO and the feed-in tariff for small scale generation. The Levy Control Framework will rise to £7.6 billion in 2020.

In the *Consultation on the draft Electricity Market Reform Delivery Plan*, the Department of Energy and Climate Change (DECC) indicated that installed capacity of offshore wind in 2020 would range between 8 and 16GW.[9] The document also contains draft strike prices which are to start at £155p/kWh in 2014/15 falling to £135p/kWh in 2018/19. The strike prices are designed to be broadly equivalent to the support provided under the current RO regime, recognising that the contract period is reduced to 15 years. Confirmed strike prices are due to be published in December 2013.

Before the publication of the draft delivery plan, feedback from industry was that, for capital investments in UK manufacturing facilities to be made, the Government needed to give signals of a growing and long-term market in offshore wind generation, beyond 2020. A concern was that the forecast installed capacity range would not have sufficient certainty attached to it to stimulate the investment needed to reduce LCOE sufficiently quickly to maintain the attractiveness of offshore wind to government by keeping up with the expected trajectory of reducing strike price.

Although it is recognised that it is a market decision how to respond to DECC's enabling framework, the draft EMR delivery plan contains several scenarios for UK energy generation up to 2030, of which three project different technology choices: high carbon capture and storage, high nuclear; and high offshore wind deployment scenarios. This last scenario was based on offshore wind LCOE falling to £95/MWh for projects commissioned in the mid-2020s. The Offshore Wind Cost Reduction Task Force concluded that an LCOE of £100/MWh could be achieved for projects reaching FID in 2020 by a sector confident to invest in its future. This is a trajectory consistent with the £95/MWh. This means that given (as yet not established) confidence in government intent beyond 2020, the high offshore wind scenario is in some ways a reasonable central scenario for the offshore wind industry.

A significant issue for the industry is the form of the transitional CfD arrangements that are offered to enable FIDs on projects before the RO is fully replaced by the CfD. The transitional arrangement, by which an early form of CfD is offered to developers, is called FID-Enabling (FIDe) for Renewables.[10] In its guidance on Investment Contract

[8] *Electricity Market Reform: Delivering UK Investment*, Department of Energy & Climate Change, June 2013, available online at www.gov.uk/government/uploads/system/uploads/attachment_data/file/209276/EMR_Spending_Review_Announcement_-_FINAL_PDF.pdf, last accessed August 2013.

[9] *Consultation on the draft Electricity Market Reform Delivery Plan*, Department of Energy & Climate Change, July 2013, available online at www.gov.uk/government/uploads/system/uploads/attachment_data/file/238867/Consultation_on_the_draft_Delivery_Plan__amended_.pdf, last accessed August 2013.

[10] *Final Investment Decision Enabling for Renewables: Update 2: Investment Contract Allocation*, Department of Energy & Climate Change, June 2013. available online at www.gov.uk/government/uploads/system/uploads/attachment_dat

Allocation, DECC announced that the FIDe applications will be scored against two criteria: project deliverability (75%) and impact on industry development (25%). This second criterion marks a potentially significant development in policy and is in line with the UK ministers' foreword to the Offshore Wind Industrial Strategy, which stated that that increased UK content is a high priority. With the award of CfDs likely to be a competitive process, feedback from developers was that this uncertainty represented a significant risk for them. Awards of contracts under FIDe are anticipated in quarter 1 of 2014.

CfDs will be available to a range of generation technologies. Also of concern is that the published criteria for assessment under the FIDe arrangements, which are likely to be retained for the enduring regime, do not indicate how judgements will be made between different technologies. If scoring is based on the cost of energy then technology-specific allocations will be necessary if, for example, offshore wind projects are to progress alongside onshore wind projects.

Industrial strategy

In August 2013, the Department for Business, Innovation & Skills (BIS) published its *Offshore Wind Industrial Strategy: Business and Government Action*.[3] Industry fed back that the process of developing the strategy was as important as the publication of the document. It is the first time the UK Government had clearly stated an ambition for offshore wind that goes beyond climate change and security of supply, by focussing on the potential economic benefit to the UK. The development of the strategy involved significant dialogue between relevant Government departments and industry, and companies welcomed the new lines of communication that this created.

A concern for industry is that the industrial strategy and the EMR delivery plan are not fully aligned. For the UK to maximise the benefit from its market lead, it needs a critical mass of projects for a long enough period to support the business case for investment in the UK supply chain. Of all the scenarios shown, only DECC's high offshore wind scenario has such capacity installed after 2020. Feedback from industry is that there is little certainty of the construction for wind farms scheduled after the FID-enabled projects and that the signals from government have been consistently negative about the growth of UK offshore wind beyond 2020.

4.2. Finance

Two main approaches to financing offshore wind projects have been taken to date:

- **Balance-sheet funding.** Much of the installation by utilities has been funded in this way to date. We believe that these developers could fund around half of the capital investment required for the UK market over the next 10 years on balance sheet, assuming the recycling of capital from projects through partial sale post-construction.
- **Project finance**. The first project-financed wind farm construction activity was the Dutch Princess Amalia (Q7) project in 2006, followed by phase 1 of the Thornton Bank project. There has yet to be a project-financed offshore wind farm in the UK.

Some utility developers have already sold equity shares in developments and generating assets to raise funds for new projects. This may take place before or after construction. Pre-construction investments have been made at Gwynt y Môr (by Siemens Project Ventures and Stadtwerke München) and at London Array (by Masdar). Post-construction sales were made by RWE, selling the majority of the North Hoyle wind farm, and Centrica, selling a 50% stake in the Lynn and Inner Dowsing wind farm to help finance the Lincs project.

To date, balance sheet funding has dominated, accounting for 77% of the €16 billion invested in Europe's 5GW of offshore installed capacity.[11] There is a trend towards greater project financing, for example, in 2011 and 2012 a third of investment was project-financed and most of this has been with construction risk. This is likely to continue as projects become larger. There has also been pressure on utilities' capital spend, evidenced by Vattenfall's decision to seek new investors in the European Offshore Wind Deployment Centre in Aberdeen Bay and RWE's signalled step back from balanced sheet financing of its offshore wind activities.

Reducing risk is key to improving the attractiveness of projects to external funders, especially in the following areas:

- Construction risk, especially of very large projects far from shore and in deeper water
- Operational (technology) risk, which may lead to conservative technology choices, and
- Supply chain risk, which has been mitigated through the use of balance of plant engineering, procurement, and construction (EPC) contracts (see also Section 4.5).

a/file/209367/2013_-_06_-_27_FIDe_Update_2_Master_Draft__2_.pdf, last accessed August 2013.

[11] Clément Weber, *Market trends defy negative sentiment on PF for offshore wind*, Green Giraffe Energy Bankers, Presentation made at the RenewableUK Offshore Wind 2013, Manchester, 12 June 2013.

The strategy adopted by developers in mitigating these risks will depend on whether or not they are looking for pre-construction or post-construction finance.

Concerns about the availability of finance for renewable energy projects have been widely recognised and there have been initiatives at the UK and EU levels to address any potential market failure. The European Investment Bank has provided finance to a number of offshore wind projects, including Bligh Bank, Borkum West, Gunfleet Sands and London Array. The Green Investment Bank in the UK was set up in October 2012 with a £1 billion fund, some of which may be used to support offshore wind farm construction. So far, it has invested in the operating wind farms at London Array, Rhyl Flats and Walney.

4.3. Grid and transmission

Industry levels concerns about grid connections fall into two main categories:

- The transfer of assets to the offshore transmission owner (OFTO), and
- The design and construction of integrated offshore grids.

The supply of cables and substations is considered in Sections 7.1 to 7.5.

Offshore transmission assets

The Office of Gas and Electricity Markets (Ofgem) requires that the generation and transmission assets for a wind farm with a high voltage grid connection are under separate ownership. The intention is to promote separate open competition between leading players in the two distinct asset classes, encourage innovation and bring in new technical expertise and finance.

Ofgem undertakes a tendering process to identify preferred bidders, who are eligible to bid for specific transmission assets. The OFTO is paid a fixed annual fee by National Grid based on its bid for the assets. National Grid recovers the cost through transmission charges paid by the generator.

One concern for wind farm developers has been that, if the OFTO is responsible for constructing the grid connection, they risk developing “stranded” generating assets if the OFTO does not deliver in time. This has been a problem in Germany where projects, such as RWE’s Nordsee Ost, have been delayed because of a delay to the grid connection or turbines have been stranded without a grid connection, as occurred for Riffgat. As a result, developers in the UK lobbied successfully for a “generator build option” which allows the developer to construct then sell on the transmission assets to the OFTO once complete. Feedback from the developers is that, generally, they favour this option but some are yet to make a decision about upcoming projects.

Although they are under separate ownership, in a number of cases the generation asset owner also maintains the transmission assets as a contractor to the OFTO. This arrangement is logical because the generation asset owner has a base close to the transmission assets and has an interest maintaining the integrity of the connection. There remains a concern that the incentive and penalty mechanism to encourage the OFTO to provide a fully operational system seems disproportionately weak compared with the potential loss of revenue suffered by the generation asset owner in the event of a fault.

For DC offshore grids there is an added complication in that the availability and performance guarantees for the HVDC system are typically conditional on the supplier carrying out maintenance and support. As the OFTO process does not allow for a supplier to be mandated to undertake maintenance, there is a risk that the traditional guarantees on an HVDC system would not flow through from a generator builder to an OFTO.

A further concern for developers is whether they will recoup the costs of building the grid connection by selling it on to the OFTO. This represents a significant risk in that the price is fixed externally by Ofgem.

Integrated offshore grids

As more projects are developed around the coast of the UK (and in the North Sea in particular) a more coordinated approach to offers the potential for cost reductions as long as later projects are constructed. By linking the electrical transmission systems of a number of projects together, it is possible for developers to share the cost of offshore and onshore substations and cables and thereby reduce overall capital expenditure.

This approach also enables narrower offshore cable corridors, fewer cable landings and less onshore infrastructure which reduces environmental impacts, lessens the risk of planning constraints and facilitates more strategic reinforcement of the onshore grid.

An interconnected offshore network would also mean that power could still be routed onshore in the event of a system failure at one point, increasing security and reliability.

The challenges for such a coordinated approach include the complexity of coordination and the significant early financial commitment and risk borne by early movers. It could mean, for example, a developer building a 1GW grid connection for its 500MW wind farm to share with a wind farm without planning consent. Not all projects would benefit equally from a coordinated approach and feedback indicates that coordination will only occur with the necessary government legislation to enable anticipatory investment.

A project by RenewableUK considered the creation of a design authority which could help ensure that optimal networks are built using standardised substation design and could coordinate anticipatory investment. It rejected the idea on the basis that it would take too long to set up and its functions could be achieved by better use of existing structures within Ofgem and the National Electricity Transmission System Operator.

In the absence of coordinated progress, with most Round 3 developers having grid connection offers in place they will continue to design grid connections for their projects and an opportunity for cost reduction through a coordinated approach will be lost.

4.4. Consenting

There are three types of concerns over consenting process:

- The process of securing planning consent
- Specific obstacles to securing consent, and
- The supply of products or services to gather the evidence to secure consent.

The first two are considered in this section while the third is covered in Section 5 of this report.

Consenting process

In the different countries of the UK, planning consent is secured by different processes:

- In England and Wales, through the Planning Inspectorate (PINS)
- In Scotland, through Marine Scotland for the offshore parts of the wind farm and through local councils for the onshore infrastructure, and
- In Northern Ireland, through the Planning Service of the Department of Environment.

PINS absorbed the Infrastructure Planning Commission (IPC) in April 2012, retaining similar processes but with a final decision from the Secretary of State at DECC. Developers are required to undertake all necessary consultations before an application is accepted by PINS but, once accepted, a recommendation to the Secretary of State is made within 12 months. The system replaced the potentially lengthy and uncertain process in which an application went through a number of iterations until all issues raised by statutory consultees had been addressed.

The stages now are:

- Pre-application consultation
- Application
- Acceptance
- Pre-examination
- Examination, and
- Decision.

In previous gap analyses, concern was expressed that this streamlined process required greater certainty of the project scope, leading to a narrowing of the “Rochdale envelope” in which some flexibility in project scope is retained. The first offshore wind farm to negotiate PINS successfully was Galloper, which was approved in May 2013. Galloper had been seen as a test case as it specified up to 140 turbines with up to a 164m rotor diameter and a total wind farm capacity of 540MW, which gave the developers the option of using established or most next generation turbines. Its approval suggests that a reasonable level of flexibility will be possible in current and future applications.

Table 4.1 Status of UK offshore wind farms in the planning system since the formation of the Infrastructure Planning Commission.

Wind farm	Status (offshore)	Jurisdiction
Galloper	Approved	PINS
Triton Knoll	Approved	PINS
East Anglia ONE	Examination	PINS
Hornsea Project One	Examination	PINS
Rampion	Examination	PINS
Atlantic Array	Pre-examination	PINS
Burbo Bank extension	Pre-examination	PINS
Walney extension	Pre-examination	PINS
Dogger Bank Creyke Beck	Accepted	PINS
Dogger Bank Teesside	Pre-application	PINS
East Anglia FOUR	Pre-application	PINS
East Anglia THREE	Pre-application	PINS
Hornsea Project Two	Pre-application	PINS
Navitus Bay	Pre-application	PINS
Neart na Gaoithe	Submitted	Marine Scotland
Beatrice	Submitted	Marine Scotland
Inch Cape	Submitted	Marine Scotland
Moray Firth Eastern	Submitted	Marine Scotland
European Offshore Wind Deployment Centre	Approved	Marine Scotland

Another long-standing concern has been the capacity of statutory consultees to deal with the demands placed on them. Feedback is that this problem persists and, as Table 4.1 shows, there are now a significant number of offshore wind farms in the planning process. The PINS process in theory demands that significant consultation takes place before acceptance. The result has been that it is taking developers longer to secure and consider the responses of consultees, causing a delay to some submissions. Some consultation has also continued after the application has been accepted. This has had an impact on developers' consenting teams as they had anticipated that, after acceptance of the application by PINS, they could move teams on to other projects.

Overall, however, the PINS process is giving greater confidence over the timescales for planning consent in England in Wales.

The process used by Marine Scotland is similar to the pre-IPC/PINS system used in England and Wales. The burden on statutory consultees is equally problematic in Scotland. While Marine Scotland gave an undertaking to make a decision within nine months, in practice, this timescale has proved hard to meet.[12]

A further challenge in Scotland is that consent for the onshore infrastructure is awarded by the local council, which adds additional uncertainty to the project.

The burden on the system is intensified by the increasing length of environmental statements. This is not a problem specific to offshore wind and has been a concern of the Institute of Environmental Management and Assessment.[13]

Obstacles to consent

Offshore wind developers face a number of obstacles in securing planning consent. Human impacts are a significant challenge for onshore grid connections deemed to be easily visible from areas of outstanding natural beauty and for projects with an impact on the fishing and leisure industries. Objections from civil and military aerospace authorities have arisen which have largely been addressed through investment in upgraded radar systems.

The impact on birds from collisions and behavioural disruption has been the biggest concern for developers in the UK. The most significant have been the potential

[12]See www.scotland.gov.uk/Topics/marine/marineenergy/background/licensing, last accessed August 2013.

[13] *Special Report – The State of Environmental Impact Assessment Practice in the UK*, Institute of Environmental Management and Assessment (IEMA), June 2011, available online at www.iema.net/state-environmental-impact-assessment-eia-practice-uk, last accessed August 2013.

impact on the sandwich tern, which led to consent refusal for Docking Shoal, and on the red-throated diver in the Thames Estuary, which may affect the delivery of the London Array phase 2 project.

The reduction in the potential impact of piling on sea mammals has affected the industry most significantly in Germany but may become a bigger issue in the UK, especially if there are a number of projects under construction at the same time, hence with increased likelihood of cumulative impact.

Mitigation solutions are under development, either involving a barrier to limit the propagation of sound waves underwater or developments to the piling process such as vibratory hammers. The latter were used in installing monopiles at Riffgat and tripods at Global Tech 1.

4.5. Supply chain

The *Offshore Wind Cost Reduction Pathways: Supply Chain* Work *Stream* report identified several supply chain levers that impacted LCOE:

1. Increased competition from European players
2. Increased competition from low cost jurisdictions
3. Horizontal and vertical collaboration (which includes interface risk)
4. Asset growth and economies of scale, and
5. Changes in contract forms or terms.[14]

Items 1, 2, and 4 are mainly subelement-specific and are considered in Sections 5 to 10 of this report. Vertical and horizontal collaboration are considered here.

Most recent UK projects have used a multi-contracting strategy with about 10 main packages. This approach has been favoured for the following reasons:

- Early EPC contracts were unprofitable and hence process were increased and developers concluded that project risk was best mitigated by contracting suppliers directly, and
- Since UK projects have been mainly developed by utilities and financed from balance sheet there was less pressure to minimise residual project risk to attract project finance.

There are reasons why this trend is likely to change:

- Suppliers have been exposed to significant risk which, in the case of cable installation contractors, has led to company failures with knock-on impacts for the project as a whole
- Future projects will mostly be larger and many developers will need to attract early finance, and
- The growing maturity of the offshore supply chain means that developers may feel less need to have a direct relationship with so many members of supply chain.

A number of established EPC contractors with oil and gas backgrounds are seeking to enter the market, including Bechtel, Subsea7 and Technip. These join contractors including Fluor, KBR and Van Oord which have already delivered EPC contracts in the industry. There is a risk to the offshore wind industry that EPC contractors active in markets such as oil and gas will ultimately find these markets more attractive than offshore wind.

Any trend towards use of a single EPC contractor will not be even and, from feedback, developers are falling into two camps: those which wish to move to a single or a small number of packages; and those which believe that their knowledge of the technology, supply chain and project delivery means they will do better by managing the process internally than by using EPC contractors.

Feedback reflects that, although some developers favour the collaborative approach to projects used in the oil and gas industry, there are misgivings about their dealings with EPC contractors. A challenge for EPC contractors is that a developer needs to make an early decision to follow the EPC route and it needs to be persuaded that this will offer cost savings to them. Despite this, the collaborative approach is gaining favour with contracts increasingly awarded to suppliers on the basis of their commitment to collaborate.

Even where companies intend to continue with the multicontract approach, fewer packages are likely to be adopted in the future. Foundation supply and install packages are common already, with MT Højgaard and Per Aarsleff/Bilfinger Berger among the contractors. Other packages that could be consolidated are the grid connection package (including the cables and installation), and array cable supply and installation.

There is no clear trend towards more framework contracts over multiple projects. Beyond the agreements that DONG Energy has with Siemens (for turbines), Nexans (for array cables), Bladt (for monopiles) and Swire Blue Ocean (for installation services), there are relatively few long-term agreements.

4.6. Health and safety

The significant increase in offshore operations for Round 3 and the much increased distances from shore raise new health and safety issues.

[14] *Offshore Wind Cost Reduction Pathways: Supply Chain Work Stream,* May 2012, EC Harris for The Crown Estate, available online at www.thecrownestate.co.uk/media/305090/echarris_owcrp_supply_chain_workstream.pdf, last accessed August 2013.

A key issue is that vessels and equipment must be fit for purpose. Continuing to use small vessels to work further offshore introduces new risks. Industry is also aware of the importance of addressing the onshore risks at ports and substations.

Feedback from industry is that there is also an important balance to be struck regarding environmental conditions in which activity can take place. In an effort to reduce costs during the construction and operational phases, attempts are being made to extend the range of conditions in which offshore operations are undertaken. The full consequences of these need to be considered.

It is recognised also that, with an increase in the distance from wind farms to emergency medical care from tens to hundreds of kilometres, changes in protocols and facilities are needed from the very first activities of offshore wind farm development in order to protect staff. This may include the early use of fully equipped offshore fixed or floating “hotels” with significant emergency medical care facilities.

A difficulty is that, while the oil and gas industry has well-developed safety procedures, these do not easily map onto offshore wind. In offshore wind there are a large number of short visits to turbines, each by a small number of people, whereas oil and gas activities typically require lengthy offshore stints with fewer movements of a larger number of personnel at a time. A priority is to learn from other sectors, including the oil and gas industry, and to develop relevant industry-specific practice.

Offshore wind is unique, with the intensity of manual tasks and multiple operatives. Close collaboration between asset owners is essential, involving sharing of knowledge and equipment.

Another focus for the industry needs to be improving turbine reliability and maintainability. The vast majority of crew transfers over the life of a wind farm currently relate to turbine unreliability and improvements will not only reduce operational expenditure (OPEX) and operating time, but will also have a positive impact on health and safety risks, simply by reducing the number of offshore operations.

5. Development and project management

This section covers the development and project management of the offshore wind farm from the lease exclusivity agreement to the construction works completion date. This includes the internal engineering studies and project management, and the managing of external engineering studies, planning applications, environmental impact assessments (EIAs), site investigations, environmental services and construction contract management activities.

Two particular areas of concern have been identified for further analysis: wind farm design and survey vessels.

5.1. Wind farm design

Wind farm layout, support structure choice and design, electrical architecture and installation methods for each wind farm are developed through an iterative engineering process typically taking around two years. The process typically involves various engineering teams and organisations. Most commonly for utility developers, the initial concept is developed in-house during the pre-front end engineering and design (FEED) stage through a constraints analysis and study of wind conditions. The constraints analysis defines the available areas for development within the lease area, based on the knowledge of the activities of other sea users, such as the shipping and fishing industries, the presence of sea bed infrastructure such as oil and gas pipelines and telecommunication cables, and geological features such as sand banks.

The study of wind conditions is used to generate an initial turbine array layout considering basic array shape, spacing and orientation. Detailed design and optimisation occurs during FEED studies that are delivered via a mix of developer in-house expertise and contracted services.

Current capacity and investment lead time

There are insufficient experienced personnel and tools to develop optimal wind farm design. There are a number of consultancies in the market and many competent players from parallel sectors, but their ability to meet anticipated demand is limited by the difficulty of recruiting or retraining staff. This issue is not in delivering wind farm designs pre-se, but in delivering sufficiently optimal designs to help reduce cost of energy.

For electrical transmission design, there has been a persistent concern over the lack of supply of electrical engineers in the UK for many industrial sectors. There has been significant overseas recruitment to compensate for this deficit, but this has become harder in recent times.

A slow market may avoid the dilution of experienced design teams. The potential shortfall in skilled personnel described above may not be as acute because of the current short term lull in the market. Industry feedback is that this slower pace may give developers and consultancies the opportunity to consolidate teams and retain lessons learned from previous projects.

If the market is too slow, however, experienced individuals may move out of the sector and the experience may be lost to future projects and effort will not be put into developing tools to increase enable more optimal designs to be developed. Industry feedback indicates that most developers have a sufficient pipeline to sustain design teams at the moment but this could change if projects are delayed further and as uncertainty about construction post 2020 impacts more.

Investment status

Incremental investment continues to deliver sufficient capacity for most services. Most investment in this element of the sector is spent on recruiting and training skilled personnel. Teams are brought together to meet the needs and timetables of individual projects. There is significant movement of experienced individuals between developers and suppliers.

Synergy with parallel sectors

Offshore wind farm design is highly specialised. With the exception of onshore grid infrastructure, offshore wind farm design has few parallels with other sectors. Even in onshore wind, issues relating to turbine siting and balance of plant are different.

LCOE reduction due to technology development

The *Offshore Wind Cost Reduction Pathways Study: Technology work stream* concluded that developments in array optimisation and FEED could reduce the LCOE by about 1%, mainly through impact on increased energy production and reduced construction costs, rather than savings in design-phase costs.[15]

There is insufficient early spend on activities which reduces construction cost and risk. Uncertainty in the market has not encouraged developers to invest early which means that significant uncertainties remain through to construction. Some developers report that they have merged their consenting and delivery teams to ensure that practical considerations are considered in making

[15] *Offshore wind cost reduction pathways: Technology work stream*, BVG Associates for The Crown Estate, May 2012, available online at http://www.thecrownestate.co.uk/media/305086/BVG%20OWCRP%20technology%20work%20stream.pdf, last accessed August 2013.

decisions early in the project, thereby having some positive impact.

There is little progress with software for array optimisation. As the understanding of offshore conditions and technology improves and the size and complexity of projects increase, the opportunities for optimising turbine positions also grow.

The *Offshore Wind Cost Reduction Pathways Study* analysis indicated that there is an attractive potential reduction in LCOE from design tools that consider a range of variables including lack of site homogeneity, wake effects, array cable cost, support structure cost, consenting constraints, installation processes and operational costs. Industry feedback is that developers are making some progress by using their experience to streamline the iterative processes they have been using. This includes analysing the cost of energy of individual turbine locations but this work still falls short of what could be achieved with more sophisticated and holistic design tools.

New design tools are in development but it is taking time for them to be linked together to become suitable for use on a large scale commercial wind farm. Such activity could be accelerated through work by the Offshore Renewable Energy Catapult or others.

Technology shift

Larger, more complex projects benefit more from tools to optimise wind farm design. The demand for more sophisticated design tools is increasing as developers consider multiphase zones with projects that each have capacities up to 1,200MW.

LCOE reduction due to supply chain development

There are some signs of early engagement of installation contractors in wind farm design. Installation contractors (and, in particular, cable layers) highlight that they have been insufficiently involved early in wind farm design. They claim that this means that the designs do not adequately consider the practical considerations of installation and that the tendering timescale typically prevents installers from developing solutions optimised for an individual project.

Industry feedback suggests that some developers are working to address this challenge with a number not only encouraging collaboration between contractors but also scoring tenders on the commitment of suppliers to do so. Others are driving engagement through package EPC contracting, though not always with provision of sufficient data on site conditions. Elsewhere, feedback indicates that others are continuing with their existing procurement practices.

Overall, there is optimism that best practice will spread as developers recruit experienced project teams for future projects, but that sharing good practice may happen rather slowly.

Development and delivery teams are making decisions that consider through-life costs. A challenge that has been highlighted in the past is for developers to ensure that design teams include personnel with experience in offshore wind to ensure that practical lessons are accounted for in new designs. Developers are increasingly maintaining close links between the pre- and post-FID teams to avoid decisions early in the project that lead to higher costs later. This in itself does not guarantee that the consequences of decisions in the capital phase will optimise operating phase cost, however. Our discussions with industry suggest that the detailed cost modelling and dialogue to achieve this is not yet universal.

There is sufficient competition in the market for basic services. There is no evidence that any constraints in external wind farm design provision are leading to higher costs of procuring these services.

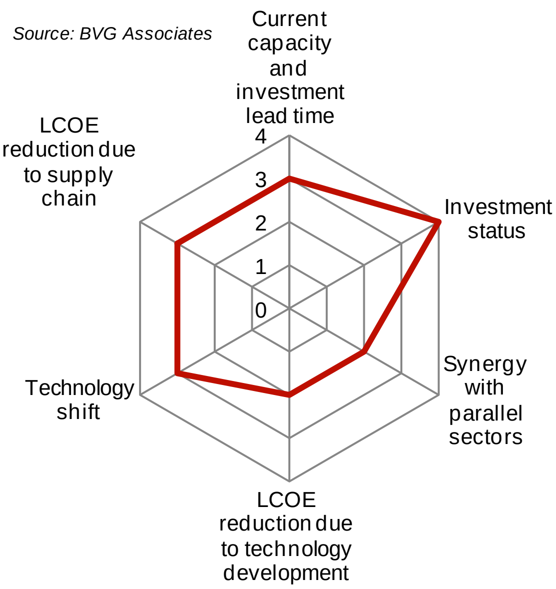

Figure 5.1 Summary of issues concerning wind farm design.

Conclusion

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Wind farm design has been graded green. In-house and external design teams are growing in offshore wind experience and there are signs that lessons are being learnt that will reduce costs during construction and operation. Although more sophisticated design tools are slow coming to the market, which means some lost opportunities for cost reduction, this issue is not constraining project delivery. There would be a benefit from collective action by developers and the sharing of best practice to stimulate the development and application of such design tools.

5.2. Survey vessels

Surveys account for about one third of wind farm development costs and are contracted by the wind farm developer to specialist data acquisition companies. Depending on the survey type, the contract may involve data collection and analysis, such as geotechnical surveys, or data collection only, where analysis is performed by the developer in-house, for example, metocean data.

Environmental and sea bed (geotechnical and geophysical) surveys and data collection start up five years or more before the planned operation of the wind farm. EIA requirements determine critical path items such as ornithological surveys, where a minimum of two years of data is needed as part of best practice guidelines developed with input from the regulators and statutory consultees.

Geotechnical investigation is the most costly part of survey work and hence this has been the main area of concern for developers.

Current capacity and investment lead time

Further investment in vessels and laboratories is needed. Most environmental surveys are undertaken as part of the process of securing planning consent and some level of activity has already taken place for all Round 3 projects. Detailed sea bed investigations take place after consent has been granted and so an increase in survey capacity will be needed after Round 3 projects are consented, which will take place from 2014 onwards. Analysis undertaken for the 2011 gap analysis suggests that the number of vessels needed for the European offshore wind market is likely to be no more than five, although the fleet of vessels will need to serve other offshore sectors. There have been additions to the fleet since then, for example, Gardline converted a new geotechnical survey vessel in 2012 and Fugro took delivery of a new vessel in 2013.

There is a short lead time for the upgrade of new geotechnical survey vessels. Industry feedback states new vessels can be brought into service within six months of an investment decision. Vessels suitable for upgrade need to have a moon pool and be able to deploy a drilling system and need to be fit for working safely, far from shore for long periods.

Investment status

The cost of converting survey vessels cannot be borne by a single project. The cost of upgrading a vessel is significant compared with the value of a single contract. The cost of a more extensive vessel conversion for sea bed investigation can be £15 million and this investment has to be part of a long-term, strategic commitment. Any new vessel will be able to do both geotechnical and geophysical survey work. Operators have already made investments in some new capacity that is yet to come online.

Synergy with parallel sectors

There is potential to deploy oil and gas capacity in offshore wind but at higher cost. Survey vessels have applications in a number of sectors and the most relevant parallel sector is oil and gas. Operators reported that they are likely to maintain sector-specific fleets, as oil and gas vessels tend to be more highly specified with day rates that are typically 50% higher than for offshore wind.

LCOE reduction due to technology development

Survey and site investigation techniques are well established and generally fit for purpose. Although offshore wind work typically requires more samples over bigger areas, the technical approaches are similar to other sectors.

Greater levels of geotechnical and geophysical surveying can secure cost reduction during construction. Often, geotechnical and geophysical data are available only at turbine locations and with a focus on properties far below the sea bed, relevant for foundation design. This leads to significant uncertainties relating to cable design and installation. As an example, an improved knowledge of sea bed conditions, from surveys that focus on other areas of the site or on soil conditions closer to the surface of the sea bed, can lead to cost reductions in array cable and installation CAPEX through earlier design work, and the prevention of conservative overdesign or late design changes.

Industry feedback suggests that developers are increasingly aware of the importance of getting greater levels of accurate geotechnical and geophysical information at this early stage.

Technology shift

Vessels used for Rounds 1 and 2 may be unsuitable for Round 3. A number of companies have gained near shore experience through providing such services for Round 1 and 2 projects but industry feedback suggests that many of the vessels used in these projects cannot be used further from shore. The requirement is for ocean-going vessels that can operate safely offshore for several weeks at a time.

LCOE reduction due to supply chain development

There needs to be coordination between developers on survey timing. Industry feedback is that developers prefer to schedule survey operations between March and October, which leads to higher prices. Operators indicate that greater flexibility over the timing of survey work could offer cost savings, even taking into account reduction if efficiency due to weather conditions.

There is little evidence of sharing data relevant to consenting between projects. There are potential cost savings from sharing data, such as on wind resource and bird behaviour. Industry feedback suggests that there is still discomfort about sharing data between developers. This may arise from concerns over confidentiality or how the data will be interpreted.

Procurement often favours cost over quality. Suppliers report that working in offshore wind is challenging because contractual terms are often more onerous than those found in other sectors. They say that there is an emphasis on price rather than quality and that this is particularly the case if the tendering process is controlled by a procurement team rather than a technical team. For example, there could be several iterations of requiring “best and final offers”, which operators did not typically experience in other sectors and encourages them to lower the level of service offered.

Operators believe that developers would get better value if they allow them greater freedom in defining the scope of work and contract on a day rate basis. Developers prefer a fix cost contract but this leads operators to increase their margin to mitigate the risk they take on.

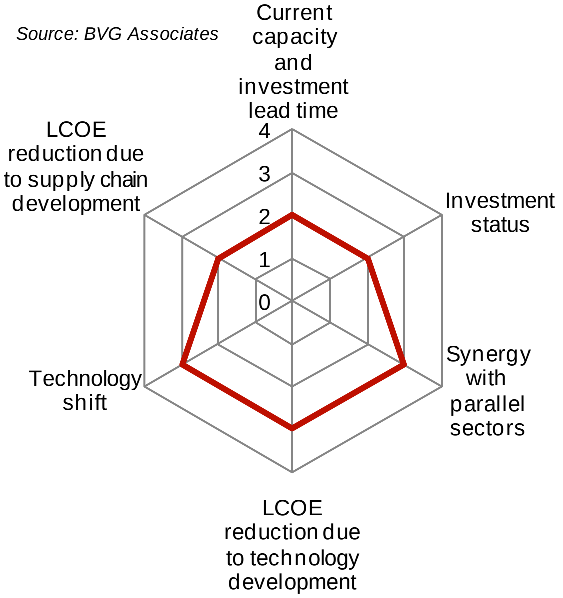

Figure 5.2 Summary of issues concerning survey vessel supply.

Conclusion

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Survey vessel supply has been graded green, because there are likely to be sufficient vessels available globally to undertake the work for European offshore wind farms. There is a risk that, if demand from developers coincides, the capacity will not be available. This can be mitigated by offering flexibility over the timing of survey work. Although some suppliers report a limited customer understanding of offshore survey work, developers increasingly recognise the lifetime benefits of early investment in surveys in reducing cost and uncertainty during construction.

Table 5.1 Summary of supply chain status and conclusions on wind farm design and survey vessels.

Criterion	Wind farm design	Survey vessels
Proven capability	Garrad Hassan, KBR, ODE, Ramboll, RES, Sgurr Energy	Calecore, Coastline Surveys, ESS Ecology, Fugro, Gardline, GEO, GEMS, MMT, Osiris
Additional future capability	Incremental investment by existing suppliers; new suppliers of specific design services	New investment by existing suppliers; further entrants from parallel sectors
Current capacity and investment lead time	There are insufficient experienced personnel and tools to develop optimal wind farm designs A slow market may avoid the dilution of experienced design teams	Further investment in vessels and laboratories is needed There is a short lead time for the upgrade of new geotechnical survey vessels
Investment status	Incremental investment continues to deliver sufficient capacity for most services	The cost of converting survey vessels cannot be borne by a single project
Synergy with parallel sectors	Offshore wind farm design is highly specialised	There is potential to deploy oil and gas capacity in offshore wind but at higher cost
LCOE reduction due to technology development	There is insufficient early spend on activities which reduces construction cost and risk There is little progress with software for array optimisation	Survey and site investigation techniques are well established and generally fit for purpose Greater levels of geotechnical and geophysical surveying can secure cost reductions during construction
Technology shift	Larger, more complex projects benefit more from tools to optimise wind farm design	Vessels used for Rounds 1 and 2 may be unsuitable for Round 3
LCOE reduction due to supply chain development	There are some signs of early engagement of installation contractors in wind farm design Development and delivery teams are making decisions that consider through-life costs There is sufficient competition in the market for basic services	There needs to be coordination between developers on survey timing There is little evidence of sharing data relevant to consenting between projects Procurement often favours cost over quality
Conclusion[1]	G ↑	G

6. Turbine supply

Turbine supply involves the manufacture, assembly and system-level functional test of all electrical and mechanical components and systems that make up a wind turbine housed within the nacelle, rotor and tower.

The nacelle components typically include the nacelle bedplate, drive train, power take-off, control system, yaw system, yaw bearing, nacelle auxiliary systems, nacelle cover, fasteners and conditioning monitoring system.

The rotor components include the blades, hub casting, blade bearings, pitch system, spinner, rotor auxiliary systems, fabricated steel components and fasteners. The tower components generally include steel, personnel access and survival equipment, tuned damper, electrical system, tower internal lighting and fasteners. Although many components play an important role in the long-term reliable operation of the wind turbine, we see that, for most designs of wind turbines and with careful procurement planning, none of these items presents a significant potential bottleneck in the next few years. In some areas, there has been significant oversupply of components in Europe at the scale required for onshore wind turbines, due to the establishment of local supply in emerging markets and hence a reduction in the need for export.

Of the turbine components, this section will focus on the following, most significant areas:

Offshore wind turbines. This involves the completed product, including whole system design, assembly and system-level functional test of all of the items below.

Blades. Blades form about 20% of the turbine cost. Almost all blades for offshore wind turbines are currently manufactured in-house by wind turbine suppliers. As the final assembly of blades to the turbine only happens at the construction port or on the wind farm site and the transport of blades is a significant consideration, it is relevant to consider blade manufacture as distinct from turbine nacelle assembly and other main component manufacture. If necessary, it can be carried out reasonably efficiently at a separate coastal location.

Castings and forgings. These items include the hub, main shaft (where used), main frame (in some cases), gearbox casings (where used), forged rings for bearings, gears (where used) and tower flanges. For very large offshore turbines, minimising transport of these items will start to become an important consideration.

Gearboxes, large bearings and direct drive generators. All offshore turbines installed in commercial projects to date use gearboxes, but there is a strong trend towards the use of low-ratio gearboxes coupled with mid-speed generators or direct-drive (gearless) drive trains, as summarised in Table 6.1.

Table 6.1 Drive train concept trends for leading manufacturers (examples only).

	Drive train concept		
Wind turbine Supplier	Turbines used in the onshore market	Turbines used in the offshore market	Next offshore turbine
Alstom Power	High speed	-	Direct drive
Areva Wind	-	Mid speed	Mid speed
Gamesa	High speed	-	Mid speed
Mitsubishi Heavy Industries	High speed	-	High speed with hydraulic pump and motors
REpower Systems	High speed	High speed	High speed
Samsung Heavy Industries	High speed	-	Mid speed
Siemens Wind Power	High speed and direct drive	High speed and direct drive	Direct drive
Vestas Wind Systems	High speed	High speed	Mid speed

Bearings are critical supply items for incorporation into the gearbox as well as into nacelle and hub sub-assemblies.

Towers. As for blades, towers need not meet other turbine components until they reach the offshore site, so they can be manufactured separately from turbine nacelles. Again, logistics become critical for very large offshore designs, requiring a move to coastal manufacture. In some onshore markets, towers have been procured by the developer (to the turbine manufacturer's design), but the pattern offshore currently remains for the wind turbine manufacturer to source supply against their own design.

6.1. Offshore wind turbines

In this analysis we will distinguish between first generation offshore wind turbines, most of which have onshore versions of the same platform, and next generation turbines. For the purposes of this study, we have defined a next generation turbine as one that has a capacity of 6MW or greater, has a rotor diameter suitable for the application (specific rating below 450W/m^2, equating to a rotor diameter of above 146m) and has no onshore version.

Although there will continue to be some demand for the current generation of turbines, (such as the "stretched" Siemens 4.0-130), most of the feedback from developers is that even 5MW turbines could be too small to make typical future European projects economically viable.

Current capacity and investment lead time

There is sufficient capacity until 2017. Industry feedback is that the current capacity for existing products is about 2.5GW/year, which is projected to be sufficient until new facilities are available for assembly of the next generation of products. Five European turbine manufacturers have a proven track record (defined as 200MW installed offshore). The market is currently dominated by Siemens but Vestas, Areva and REpower are all contracted to supply turbines over the next two years. Bard has now installed all turbines at its self-developed Bard Offshore 1 wind farm but the future of its product is uncertain.

Using the deployment projection described in Section 2, demand across Europe in 2014-2015 will be lower than in 2013, recovering only in 2016. Feedback from developers is that existing capacity will be sufficient until this time and their concerns rather relate to the availability of proven next generation turbines (discussed in LCOE reduction due to technology development section below). Much of the supply will come from existing infrastructure built to supply the onshore market and the offshore market to date, supplemented by some existing coastal facilities being converted for short-term use from other activities. This can continue to be used to supply early Round 3 projects, although logistics will be suboptimal.

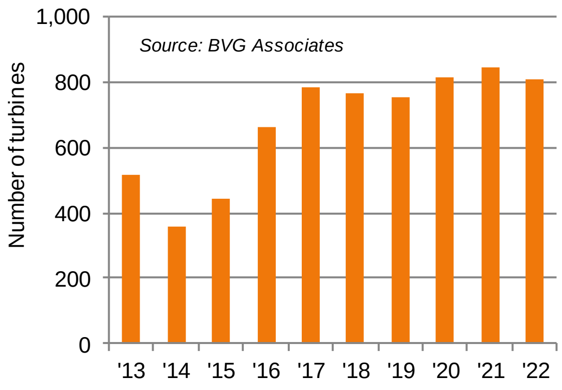

Figure 6.1 Projected demand for offshore wind turbines for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by one year).

Investment status

Beyond 2017, demand will require investment in new manufacturing capacity. There is only one confirmed investment in new turbine assembly facilities, by Alstom at St Nazaire in France, which is scheduled to be operational in 2015. Plans for investment by others are well advanced and pending investment decisions, which are based on a healthy long-term view of the market. For the UK, this requires confidence in a sufficient market size beyond 2020.

Synergy with parallel sectors

Investment risks can be partially offset by the onshore market. For suppliers with an onshore wind business, manufacturing facilities can also serve the onshore market. The 4MW class machines manufactured by Siemens and Vestas have onshore versions but next generation offshore turbines manufactured by all suppliers are likely only to be used commercially offshore.

LCOE reduction due to technology development

The introduction of next generation turbines is the most significant element in achieving LCOE reductions. Although there is scope for further logistical efficiencies using existing turbines, most developers are looking to next generation turbines for significant cost of energy reductions as a means of increasing yields and lowering balance of plant, installation and operational costs.

Increased reliability is a central part of technology development. If achieved, it not only lowers the LCOE for a wind farm, but higher yields will reduce the capital investment in wind farms needed to meet emissions targets.

There is a strong focus on LCOE by turbine manufacturers. Industry feedback is that turbine manufacturers are facilitating reductions in LCOE, both with the 4MW class machines by increasing yields and with next generation models through larger turbines with more optimal sized-rotors and greater reliability. The past two years has seen a number of turbine platforms developed with up-rated capacities or larger rotors, stretching existing products:

- Areva M5000-116: Rotor increased to 135m
- REpower 5M: Capacity up-rated to 6.15MW, with larger rotor anticipated, and
- Siemens 3.6-107: Rotor increased to 120m; capacity up-rated to 4MW; rotor increased to 130m.

Increases in rotor size cannot be achieved simply by increasing blade length. Unless the turbine was initially designed to accommodate a larger rotor, the increased loads on the drive train and structure require further design modifications.

New offshore products are operating or close to demonstration. Turbine manufacturers have considerable investments in new turbine designs and prototypes and many are well advanced with demonstration turbines installed for several new products by the end of 2014.

Table 6.2 Status of turbines in development (examples only).

Manufacturer	Product	Status
Alstom	Haliade (6MW-150)	Onshore prototype installed 2012 Offshore demonstrator installed 2013
Gamesa	G128-5.0	Onshore prototype installed 2013
Goldwind	GW 6.0	Onshore demonstrator installed 2013
Ming Yang Windpower	SCD 6.5MW	Onshore demonstrator installed 2013
Mitsubishi Heavy Industries	Sea Angel (7MW-167)	Onshore demonstrator expected 2014
Samsung Heavy Industries	7MW-171	Offshore demonstrator installed 2013
Siemens	SWT6.0-154	Onshore demonstrator with 154m rotor installed 2012 Offshore demonstrators with 120m rotor installed 2013
Vestas	V164-8.0 MW	Onshore demonstrator expected 2014

Although some Asian suppliers report continued development of turbines greater than 10MW, feedback suggests that turbines larger than 8MW are unlikely to be installed on European commercial projects until after 2020.

The availability of test sites and facilities required in the development of large turbines is considered in Section 10.1.

Technology shift

The increased emphasis on reliability and maintainability is particularly important for projects located far from shore. Next generation turbines have been designed exclusively for the offshore market, rather than being marinised versions of onshore turbines. Increased reliability and maintainability to reduce turbine downtime and operational costs are high priorities and this will be particularly important for projects further from shore.

LCOE reduction due to supply chain development

There has been ongoing attrition of potential offshore turbine suppliers. In many cases, progress has been slowed or the development abandoned. This was inevitable given that the offshore wind market is unlikely to be viable for a player unless it has sales of 100 turbines or more a year. A market leader could aspire to manufacture three times this figure, perhaps leaving room for only four to six suppliers out of the 20-30 players seeking to enter the market 18 months ago.

The balance is tilting towards major industrial companies over wind market specialists. Industry feedback shows that developers increasingly recognise the need for turbine manufacturers to be financially strong. Some turbine manufacturers that began turbine development withdrew, having concluded that they did not have the financial strength or risk appetite to enter the offshore market. Pure-play wind industry companies are expected to find it hard to compete on this basis in the long-run.

There is currently limited competition for the supply of next generation offshore turbines. Figure 6.2 shows the number of next generation turbine models anticipated to be proven in a given year, based on known timelines for commercialisation. For manufacturers such as Vestas and Siemens with an existing northern European manufacturing capability, investment in new facilities for the manufacture of their next generation turbines is not urgent as they can meet short term demand from existing factories. For the remaining suppliers of next generation turbines, entry to the market is dependent on investment in new facilities and only Alstom has made a commitment to invest. Figure 6.2 shows that it will be 20178 before there are more than three suppliers. Feedback from industry indicates that, for cost reductions from competition, four or more suppliers would be needed, but that the market may not support more than four.

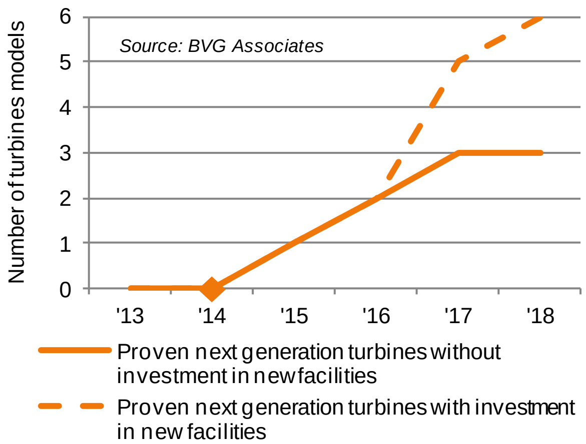

Figure 6.2 Forecast number of offshore wind turbine models in the market with and without investment in new manufacturing facilities. ◆ indicates the point at which the first investment decision is needed to achieve the increase in the number of suppliers shown.

***There is some evidence of partnership building*.** Relationships between developers and turbine manufacturers have not been a significant feature of UK and German projects, with the exception of Siemens, which has a stake in Gwynt y Môr and the Smart Wind consortium developing the Hornsea Zone through Siemens Project Ventures. Siemens also has a framework agreement and memorandum of understanding with DONG and SSE respectively. In 2009, RWE signed a framework agreement with REpower for 250 turbines, and the French development zones include either Alstom or Areva as a consortium member. Feedback from industry indicates that further frameworks are unlikely when the turbine supply market becomes more competitive.

The creation of the joint venture between Mitsubishi Heavy Industries (MHI) and Vestas for the offshore wind sector is a highly significant development.

There are signs of greater openness by turbine manufacturers. The relationship between developers and turbine manufacturers has been an uneasy one; however, manufacturers recognise that more openness will be necessary to win orders in a more competitive environment. Turbine manufacturers report that they need to build trust with developers and openness is a significant part of this strategy.

Volumes are too small to gain significant benefit from low-cost country supply. Most turbine manufacturers will have production volumes of 100-200 units a year and offshore turbines generally have different components and systems to smaller onshore turbines. Turbine manufacturers fed back that they generally do not intend sourcing components manufactured in low cost countries, focussing instead on quality and innovation.

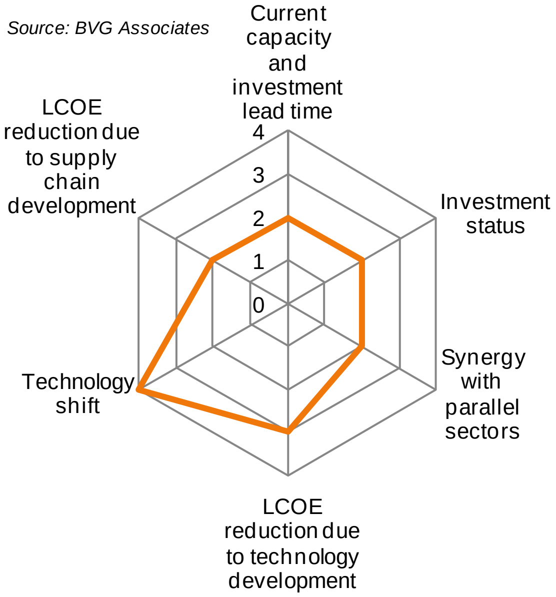

Figure 6.3 Summary of issues concerning offshore wind turbine supply.

Conclusion

R

This subelement has been graded red because the cost of energy reductions from next generation turbines are likely to be delayed until there is greater competition from financially strong manufacturers with proven products accepted by the market.

Actions

There is a need to establish timely, economically viable demonstration sites for next generation turbines. Some onshore and offshore sites have been made available for prototypes but a key additional step is demonstrating installation and operation of a number of turbines on preferred foundation solutions together in the offshore environment before use far from shore on a commercial-scale project. This may be on designated demonstration sites such as Blyth and Aberdeen Bay or attached to commercial wind farms. Activity on some demonstration sites has been delayed due to the lack of economic viability of such sites in an environment where many developers are reluctant to invest significantly in bringing forward future turbine technology due to uncertainties in eventual deployment.

Mechanisms are needed for lowering the risk of first commercial deployment of a turbine. The total investment in a commercial project is likely to exceed £2 billion. This represents a significant risk for a developer based on the performance of a small number of demonstration turbines. An option could be to provide incentives for developers to have two turbine designs in a wind farm, thereby reducing risk relating to new technology.

Gain greater assurance of next generation turbine reliability. Next generation turbines offer the potential for significant reduction in LCOE but much depends on turbine reliability and the customer pull for new products will depend on developers' confidence in certainty of reduced OPEX. This would be benefitted by measures to increase confidence in (or assurance of) reliability and drive turbine manufacturer practical focus on reliability right from the start of product development.

6.2. Blades

Approximately 60% of blades for the global wind industry are manufactured in-house by turbine manufacturers and this fraction is higher still for offshore wind. All blades used on Areva, Siemens and Vestas turbines offshore have been manufactured in-house by the wind turbine manufacturer. Of the players with offshore pedigree, only REpower has purchased blades from an external supplier, the global market leader, LM Wind Power and it now also has in-house capacity through its PowerBlades subsidiary.

This trend for in-house supply will change with the new entrants to the offshore wind turbine market. Alstom has an agreement with LM Wind Power to manufacture blades at Cherbourg, in France. Euros has supplied blades for the Mitsubishi Sea Angel prototype and plans to build series production facilities at Rostock and SSP has supplied early blades for Samsung. Gamesa may also outsource at least some of its blade supply. There are a growing number of independent blade manufacturers, though only market leader LM Wind Power has significant experience with the largest blades for offshore wind.

Current capacity and investment lead time

Capacity is sufficient to meet demand for turbine supply. There were no indications concerns expressed during our engagement with industry that supply of turbine blades will constrain the delivery of offshore wind. Feedback is that the current capacity for the supply to 4MW-class turbines is about 2.5GW/year, which is sufficient to meet the current market size, but there is scope for some manufacturers to increase supply by using facilities currently supplying the onshore market or to use the capability of R&D facilities ahead of investment in new coastal manufacturing factories.

The investment lead time for a blade factory is no longer than a nacelle production facility. As a result, in-house production can be expanded following a decision regarding nacelle assembly investment and external suppliers can invest with a clear sight of demand. Even more so than for nacelles, there is a strong requirement for any new manufacturing capacity to be coastal for logistics reasons.

Investment status

Investment in blade capacity may be the first new investment in local manufacturing facilities for some turbine manufacturers. Blade manufacture does not share the complex supply chain of nacelle components and the size of offshore blades in development all but prohibits land transport of finished blades in any volume. Preparations for LM Wind Power's blade factory at Cherbourg for Alstom are underway.

Synergy with parallel sectors

Manufacturing facilities can also serve the onshore wind market. While blades for the onshore market will not reach the lengths for next generation offshore turbines, the onshore market in Europe has seen recent increases in rotor diameter with increased yields with a view to developing previously uneconomic low wind sites. For example, the onshore Vestas V126 turbine, scheduled to be installed commercially onshore by the end of 2013, has a rotor as large as any currently installed at commercial offshore projects in Europe.

LCOE reduction due to technology development

Technology has extended the practical limits of blade length. The development of blade technology has been undertaken in parallel with that of the rest of the turbine and relates to materials, processes and aerodynamic developments. All suppliers continue to use fibreglass as a structural element. Vestas currently incorporates a carbon fibre spar and Samsung Heavy Industries' 83.5m prototype blade, produced by SSP, also has carbon fibre structural elements.[16] Obstacles to the greater use of carbon are not only the high cost and cost volatility on the global market but also increased technical and quality challenges for those using it.

Although the cube-square relationship between mass and swept area provides a theoretical, eventual soft constraint on blade length, in introducing new technology, manufacturers have managed to ensure that the cost and weight per MW or metre has not increased as much as one might expect.

Innovations in materials, manufacturing, aerodynamics and control are all making progress. In order to meet the requirements of increased quality and decreased capital and operating costs at significantly larger sizes, there is much room for process and materials development. In addition, work on new methods of aerodynamic control becomes more attractive as blade size increases. Modular designs assembled from separately manufactured parts

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[16] "World's longest rotor blade for wind turbine - core materials", *SSP Technology*, May 2013, available online at http://www.ssptech.dk/nyheder.aspx?Action=1&NewsId=116&PID=357&World's+longest+rotor+blade+for+wind+turbine+-+core+materials#, last accessed August 2013.

are also being developed that offer advantages at a larger scale.

Technology shift

All innovation is focused on reductions in LCOE. There is no particular need to change technology due to the demands of future projects. Although increased reliability and maintainability to reduce turbine downtime and operational costs will be particularly important for projects further from shore, these are already high on the agenda for blade design and manufacturing teams.

LCOE reduction due to supply chain development

There are increased opportunities for independent blade manufacturers. Potential wind turbine suppliers to the offshore sector have little in-house blade capacity with the result that the trend may be towards greater independent supply or the acquisition of independents.

There is potential for shared blade facilities to lower costs. Feedback is that turbine manufacturers would consider sharing blade factories to produce multiple products, and this is most likely if market growth is less than that projected for this analysis.

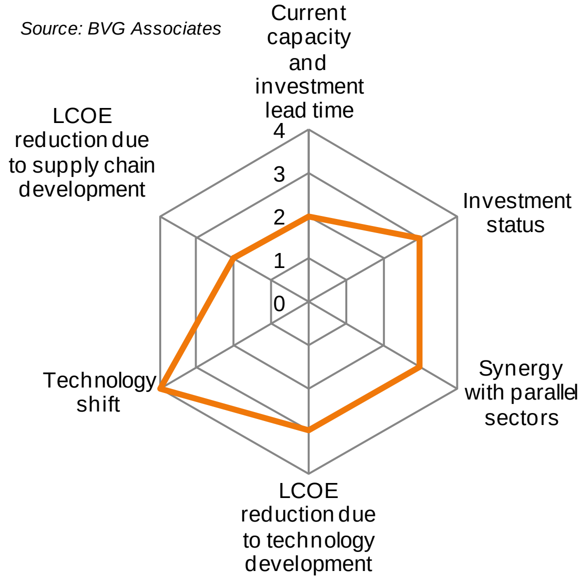

Figure 6.4 Summary of issues concerning offshore wind turbine blade supply.

Conclusion

G

Blade supply has been graded green. The development of blades for new turbines is being undertaken in parallel with other turbine development activities. New investments in new blade factories will be considered in parallel to investment in nacelle assembly facilities with the result that blade manufacturing capacity is likely to remain in step with turbine manufacturing capacity.

Larger rotors are an integral part of next generation turbine supply and by our calculation, new blades under development have close to optimal diameters for the given turbine power rating.

6.3. Castings and forgings

Spheroidal graphite iron castings are used for the following components:

- Hub
- Nacelle bedplate (some suppliers; others use steel fabrications)
- Main bearing housing (if present), and
- Gearbox housings and support components (if present).

Steel forgings have greater strength and ductility than cast iron and can be reliably welded. They are used in the following components:

- Bearings, both slewing rings (blade and yaw bearings), and main shaft and gearbox bearings
- Shafts
- Gear wheels, and
- Tower section flanges.

Current capacity and investment lead time

There are a limited number of European suppliers of iron castings over 20t. Castings are normally produced by large foundries which serve customers in a number of different industries. There are few companies able to supply the large castings needed for offshore wind and there are still fewer suppliers with facilities close to the point of use or with efficient transport options. In order to secure supply, wind turbine manufacturers have generally entered into long-term framework agreements and, in some cases, have acquired suppliers or established their own facilities in order to be able to ensure quality and cost of supply. Feedback from wind turbine manufacturers is that they have secured sufficient supply for anticipated projects in the next few years. The sale by Vestas of its casting facilities to VTC Partners in 2013 should lead to greater flexibility in casting supply.

Any shortfall in European supply can be met by Asian supply. New Asian companies, especially in India and China, have entered the market to fulfil local demand, but they also have the capability to export and therefore can meet any peaks in demand from the European offshore wind market. A number of options exist for cost-effective Asian supply, however, these have risks relating to quality, as long transit times means that any faults are difficult to address within the project timetable and are extremely costly.

There may in future be a shortage of steel forgings for main bearings. With a move towards integrated drive trains with larger diameter bearings, there are fewer players that are able to supply large steel forgings cost-effectively in quantity. This is not anticipated to become critical because capacity is still sufficient, but the situation could change.

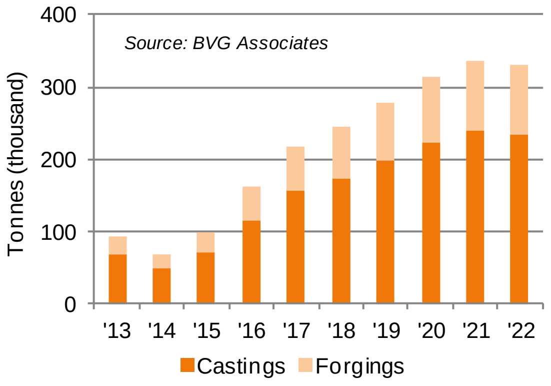

Figure 6.5 Projected demand for castings and forgings for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by one year).

Investment status

Investments in new capacity for offshore wind are likely to require agreements with more than one turbine manufacturer and serve other markets. Both supplier and turbine manufacturer prefer a situation in which the supplier has two or more customers in wind, as well as customers in other sectors. It enables the supplier to produce in higher volumes and thus provide economies of scale. It also reduces risk for both parties.

Synergy with parallel sectors

Other applications often require smaller quantities of large components. Although other industries have demand for large castings and forgings similar in mass to those needed for offshore wind, typically these are supplied in smaller quantities, so production and logistical inefficiencies are less important than for wind. Sectors that require large volumes of castings only require castings of low mass than that needed in the wind industry, but a range of sizes can be delivered reasonably efficiently from the same facility.

LCOE reduction due to technology development

There are opportunities for improved materials and quality. Cast iron properties can be significantly affected by manufacturing process and quality. Some are moving away from long-established international standards in order to obtain a more optimal balance between fatigue and ultimate strength and cost.

There is also early R&D activity underway in composite alternatives to cast iron for applications where mass is particularly important, but this is unlikely to impact until after 2020.

Technology shift

All innovation is focused on reducing LCOE. There is no need to change technology due to the demands of future projects.

LCOE reduction due to supply chain development

Castings are globally sourced by some manufacturers. There is a global supply chain for large castings and forgings and turbine manufacturers fed back that they were sourcing widely.

Dual sourcing may not be cost effective. Turbine manufacturers typically prefer dual sourcing to create competition between suppliers and lower the risk of being reliant on a single supplier. For annual production rates of less than 100, however, economies of scale may not be realised and manufacturers may opt for single source supply due to the cost of tooling required by each supplier.

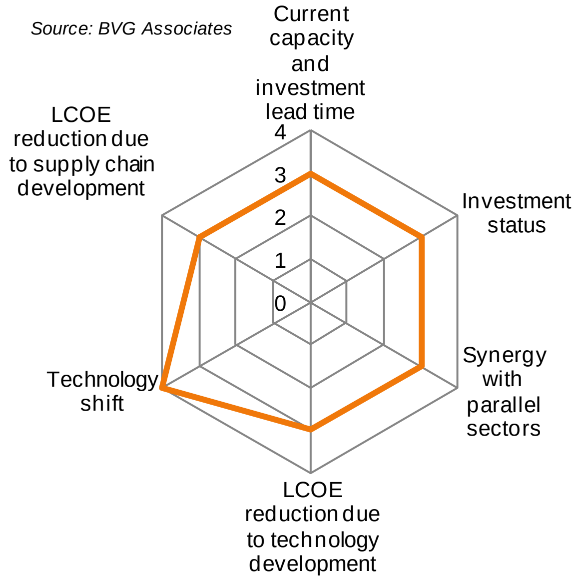

Figure 6.6 Summary of issues concerning castings and forgings supply.

Conclusion

G

Castings and forgings have been graded green because supply is unlikely to constrain projects and global sourcing can ensure competitive supply.

Table 6.3 Summary of supply chain status and conclusions on offshore wind turbines and blades.

Criterion	Offshore wind turbines	Blades
Proven capability	Areva, REpower, Siemens, Sinovel, Vestas	Areva, LM Wind Power, REpower, Siemens, Vestas
Additional future capability	Alstom, Gamesa, Goldwind, Mitsubishi Power Systems Europe, Samsung Heavy Industries, XEMC Darwind	Eurus, Blade Dynamics, Sinoi, SSP Technology In-house or JV supply by new entrants
Current capacity and investment lead time	There is sufficient capacity until 2017	Capacity is sufficient to meet the demand for turbine supply The investment lead time for a blade factory is no longer than a nacelle production facility
Investment status	Beyond 2017, demand will require investment in new manufacturing capacity	Investment in blade capacity may be the first new investment in local manufacturing facilities for some turbine manufacturers
Synergy with parallel sectors	Investment risks can be partially offset by the onshore market	Manufacturing facilities can also serve the onshore wind market
LCOE reduction due to technology development	The introduction of next generation turbines is the most significant element in achieving LCOE reductions There is a strong focus on LCOE by turbine manufacturers New offshore products are operating or close to demonstration	Technology has extended the practical limits of blade length Innovations in materials, manufacturing, aerodynamics and control are all making progress
Technology shift	The increased emphasis on reliability and maintainability is particularly important for projects located far from shore	All innovation is focused on reductions in LCOE
LCOE reduction due to supply chain development	There has been ongoing attrition of potential offshore turbine suppliers The balance is tilting towards major industrial companies over wind market specialists There is currently limited competition for the supply of next generation offshore turbines There is some evidence of partnership building There are signs of greater openness by turbine manufacturers Volumes are too small to gain significant benefit from low-cost country supply	There are increased opportunities for independent blade manufacturers There is potential for shared blade facilities to lower costs
Conclusion[1]	R	G
Actions	There is a need to establish timely, economically viable demonstration sites for next generation	

Criterion	Offshore wind turbines	Blades
	turbines Mechanisms are needed for lowering the risk of first commercial deployment of a turbine. Gain greater assurance of next generation turbine reliability	

Table 6.4 Summary of supply chain status and conclusions on castings and forgings.

Criterion	Castings and forgings
Proven capability	Castings: Felguera Melt, Fonderia Vigevanese, Metso, MeuselWitz, Rolls Royce, Sakana, Siempelkamp, Torgelow, VTC
Additional future capability	Various potential UK and EU suppliers
Current capacity and investment lead time	There are a limited number of European suppliers of iron castings over 20t Any shortfall in European supply can be met by Asian supply There may in future be a shortage of steel forgings for main bearings
Investment status	Investments in new capacity for offshore wind are likely to require agreements with more than one turbine manufacturer and serve other markets
Synergy with parallel sectors	Other applications often require smaller quantities of large components
LCOE reduction due to technology development	There are opportunities for improved materials and quality
Technology shift	All innovation is focused on reducing LCOE
LCOE reduction due to supply chain development	Castings are globally sourced by some manufacturers Dual sourcing may not be cost effective
Conclusion[1]	G ↑

6.4. Gearboxes, large bearings and next generation generators

Almost all of the next generation offshore turbines under development have drive trains that are either mid speed or direct drive. These replace the largely standard drive trains used in most turbines commercially deployed, onshore and offshore, which typically have a three-stage gearbox and a doubly-fed induction generator (DFIG) running at a nominal 1,500rpm.

This change in approach has been taken to improve reliability and maintainability for offshore turbines, where turbine downtime and vessel costs can exceed the cost of replacement or repair work. Gearbox failures in particular have been high profile and, although faults occur less frequently than for many other turbine components, any main drive train component failure requires significant external intervention. Technical trends have focused on reducing the number of drive train components and driving up reliability through holistic system design and thorough verification. A further innovation is the development of hydraulic drive trains, for example, by the Mitsubishi acquisition of Artemis.

The diversity of approaches means that drive train technology is increasingly product specific, which has implications for the availability of supply since it takes a long time to establish a new supplier for a bespoke component.

Large bearings have also been an area of concern, including gearbox, generator, main shaft and yaw bearings in the nacelle and blade bearings. The constraint arises from the small number of companies capable of supplying these large diameter bearings.

Work is underway to improve bearing lifetime, especially with respect to steel quality, the optimisation of bearing internal geometry and the development of oils and greases that better protect bearings over the whole range of conditions seen during the lifetime of a wind turbine, sometimes quite different from more conventional industrial applications. For generator bearings, work continues to improve to minimise the impact of local electrical effects on bearings.

A significant trend in new drive train concepts is the use of permanent magnets in generators, primarily for direct drive models, which can contain several tonnes of magnetic material. Permanent magnets are manufactured from rare earth elements. While these are found worldwide, productive mines are currently almost exclusively in China, although others are now being established in the United States of America (USA) and Australia.

Current capacity and investment lead time

Gearbox supply is sufficient. The supply of gearboxes has been an area of concern in the past but, with a slowing of the onshore market, there is currently overcapacity in Europe.

Supply from existing facilities can continue until the volume of large components reaches a critical point. Gearboxes, large bearings and generators can be moved by road but, if volumes exceed more than three or four units a week, the logistical advantages of supply local to the nacelle assembly facility become significant.

Supply of permanent magnets remains a concern. Permanent magnets are used in both direct drive and mid speed concepts. Turbine manufacturers have reported that they have secured sufficient supply, but feedback from developers is that they believe that there may be restrictions in the future supply from China, although new supply options have become available. An additional concern for the industry has been the volatility of permanent magnet prices.

Investment decisions will be made in parallel with turbine assembly. In some cases, the new investment will be in a component final assembly facility rather than a full manufacturing facility. This reduces the logistical challenge of moving large, fully assembled components by road, reduces the cost of the investment and avoids dilution of a supplier’s technical team.

Investment status

A number of investment plans are well developed. FIDs will be made in parallel with nacelle assembly factory investments. Some investment is committed, for example, GE Power Conversion’s generator facility at St Nazaire in France to supply Alstom’s nacelle assembly facility on the same site.

Synergy with parallel sectors

There is demand for factory capacity from other industries. With sufficient demand from offshore wind, manufacturers may choose to invest in dedicated facilities. Where this does not take place, offshore wind customers will compete for capacity at existing gearbox and generator factories with industries such as mining and ship building.

LCOE reduction due to technology development

New drive train technologies are still in development. New drive train concepts are at the heart of the development of next generation offshore turbines. A key element of this development is increasing reliability and maintainability and this has involved a divergence from traditional drive trains used in onshore turbines. Feedback from developers is that they will reserve judgement on improvements in reliability and they are concerned that the benefits of new drive trains will not be realised before there had been several years of operation.

Technology shift

All innovation is focused on reductions in LCOE. Technology development in next generation drive trains anticipates the value of increased reliability for offshore machines located a long way from operations bases.

LCOE reduction due to supply chain development

For low production volumes, dual sourcing may not be cost effective. Turbine manufacturers typically source drive train components from more than one supplier to lower risk and stimulate competition. Feedback is that they wish to continue this approach but, for production rates of less than 100 per year, it may not be a practical option as volumes would be insufficient for economies of scale. For this same reason and the requirement for increased quality to drive reliability, supply from low-cost countries is unlikely to be viable in the short term.

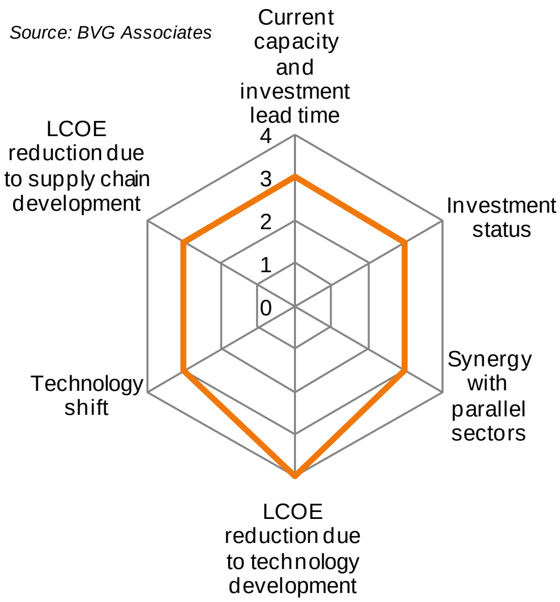

Figure 6.7 Summary of issues concerning gearbox, large bearings and next generation generator supply.

Conclusion

G

Gearboxes, large bearings and generators have been graded green as developers and turbine manufacturers are generally comfortable about component supply, although cost reductions from new drive train technology may not be realised until the next generation turbines have had several years of operation and production volumes deliver economies of scale and encourage dual sourcing.

6.5. Towers

All offshore turbines installed to date have used a tapered tubular steel tower as traditionally used onshore. These are manufactured by rolling sheet steel into tapered cylindrical cans, which are welded together to form tube sections of length typically 30m to 40m. Flanges are welded to each end of these before they are shot-blasted and surface-finished inside and out and internal components are installed. Towers, consisting of two or three sections, are then generally pre-assembled at the construction port before installation.

For 3-4MW turbines, towers have a diameter of 3 to 5m. Larger turbines require longer and larger diameter towers with thicker sections to carry the increased loads. Towers for the next generation of turbines will have a base diameter of between 5m and 7.5m. Such an increase in scale means inland production that requires the use of public roads for delivery will not be possible and the towers will need to be manufactured at a waterside facility and loaded directly onto a vessel.

In UK, safety regulations require that turbine towers are scaled so that the minimum clearance between blade tip and sea level (mean high water springs) is 22m, but offshore wind speed characteristics mean there is little incentive for hub heights above 100m.[17] This means that towers for offshore use are relatively short relative to rotor diameter, compared with onshore designs, especially those for flat, low wind or forested sites.

As well as fulfilling its main structural role, the tower also houses electrical switchgear, control panels, personnel access systems and lifting equipment to facilitate maintenance and allow components and tooling to be taken to the nacelle. In some designs, the transformer and power take-off system may also be in the tower.

Current capacity and investment lead time

There are a limited number of European suppliers. Tower supply for offshore turbines is mostly from independent suppliers, rather than from in-house facilities owned by the wind turbine manufacturer. New capacity will be needed for offshore wind but the barriers to entry are relatively low and lead times shorter than for many other components. The lead time for a tower manufacturing facility is shorter than a nacelle manufacturing facility.

Investment status

Investment decisions can be made in parallel with turbine assembly. A commitment to build a tower facility is likely to follow a commitment to build nacelle assembly facilities, even if not formally linked. For example, it has been reported that Korean supplier CS Wind may commit to a site downstream of the proposed Siemens factory in Humberside.[18]

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[17] *Offshore Renewable Energy Installations (OREIs): Guidance to Mariners Operating in the Vicinity of UK OREIs*, Maritime and Coastguard Agency, September 2008, available online at http://www.dft.gov.uk/mca/mgn372.pdf, last accessed August 2013.

[18] 'Korean firm in talks to join Siemens in Green Port Hull revolution', *This is Hull and East Riding*, 5 June 2012, available

Synergy with parallel sectors

Any new coastal facilities will also be able to serve the onshore wind market. A tower manufacturer can supply both onshore and offshore markets, subject to any constraints on logistics. A factory for the onshore market would ideally have unrestricted access to the motorway network.

LCOE reduction due to technology development

Cost reductions from the holistic design of towers with foundations have not been fully explored. While tower design is product specific, foundation design is largely project specific. The *Offshore Wind Cost Reduction Pathways Study: Technology work stream* concluded that a holistic design of the tower and foundation could reduce the mass of the combined structure by 15%. Feedback indicates that developers have started to investigate the benefits but these have yet to be fully explored. Critical is to establish open dialogue between the wind turbine manufacturer (designer of the tower), foundation designer, installers and developer in order to arrive at optimal solutions which may increase tower manufacturing costs, but with greater benefits elsewhere. Conventionally, there have been significant discontinuities in structural stiffness at the interface between tower and foundation, which highlights the inefficiency of design.

There has been no visible progress on single section towers. The *Offshore Wind Cost Reduction Pathways Study: Technology work stream* concluded that the tower cost could be reduced by 10% by manufacturing the tower as a single section, rather than having bolted, flanged joints between sections. Progress in this innovation is not visible and investment in suitable manufacturing facilities and new tooling may deter progress without increased market confidence.

Technology shift

All innovation is focused on reducing LCOE. Increases in rotor diameter will lead to longer towers but future projects have no inherent new demands on tower technology.

LCOE reduction due to supply chain development

Tower supply is likely to continue to be outsourced by turbine manufacturers. No turbine manufacturers that are active in the European offshore market produce towers in-house. Turbine suppliers may build long term relationships with suppliers who may co-invest on the same coastal manufacturing site. Feedback is that some turbine manufacturers expect to continue to source steel and free issue to tower suppliers or insist on approved suppliers.

There is limited use of Asian tower suppliers for the offshore market. The cost of tower manufacture is dominated by steel price and welding is automated where possible. As a result, the gains from sourcing from countries with low labour costs may not be significant unless volumes are high.

There is a potential move from turbine manufacturer's scope of supply. As in onshore wind, the tower is currently part of the scope of design and supply of the turbine manufacturer, although the manufacturing activity is subcontracted. Offshore towers are typically designed for a given turbine model and only in some cases are tailored to the requirements of a specific project. This is in contrast to the technology choice and design of the foundation which is made after the turbine supplier has been selected, and procured by the developer. Feedback indicates that some turbine manufacturers may be flexible about excluding the tower from their scope of supply. The demand from developers for this will come particularly if they want an integrated tower and foundation design, which has the potential to reduce the steel mass in the combined support structure. Despite this, some developers report that they would not want to manage the tower-turbine interface and the turbine manufacturer would still need to be involved with tower design and also in tuning control system design to the dynamics of the complete structural support system.

There are reasonable levels of automation and efficiency already present in the industry because much of the welding is relatively simple, although the conical nature of the tower does present challenges.

online at www.thisishullandeastriding.co.uk/Korean-firm-talks-join-Siemens-Green-Port-Hull/story-16282658-detail/story.html#axzz2b6ZrcESt, last accessed August 2013.

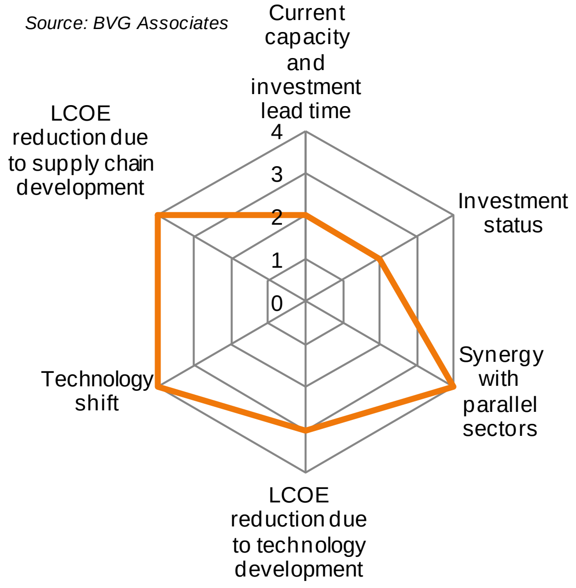

Figure 6.8 Summary of issues concerning tower supply.

Conclusion

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Tower supply has been graded green because there is an established supply base and investment decisions made in parallel to turbine nacelle assembly investment will be able to deliver additional capacity within the required timescales. Incentives to stimulate investment are still likely to be required if new sources of supply are to be established and ongoing work is needed to communicate the opportunity and promote suitable sites to potential investors.

Table 6.5 Summary of supply chain status and conclusions on gearboxes, large bearings and next generation generators, and towers.

Criterion	Gearboxes, large bearings and generators	Towers
Proven capability	Gearboxes: Bosch Rexroth, Eickhoff, Hansen (Suzlon), Moventas, RENK, Winergy (Siemens) Generators: ABB, Elin, Ingeteam, Leroy Somer, VEM	Ambau, Marsh Wind, SIAG, Titan Towers, Welcon
Additional future capability	Gearboxes: David Brown, Mitsubishi (Artemis hydraulic equivalent) Generators: GE Power Conversion	CS Wind, DS SM, Gestamp Wind Steel, TAG Energy Solutions, Wind Towers Scotland
Current capacity and investment lead time	Gearbox supply is sufficient Supply from existing facilities can continue until the volume of large components reaches a critical point Supply of permanent magnets remains a concern Investment decisions will be made in parallel with turbine assembly	There are a limited number of European suppliers
Investment status	A number of investment plans are well developed	Investment decisions can be made in parallel with turbine assembly
Synergy with parallel sectors	There is demand for factory capacity from other industries	Any new coastal facilities will also be able to serve the onshore wind market
LCOE reduction due to technology development	New drive train technologies are still in development	Cost reductions from holistic design of tower with foundations have not been fully explored There has been no visible progress on single section towers
Technology shift	All innovation is focused on reductions in LCOE	All innovation is focused on reducing LCOE
LCOE reduction due to supply chain development	For low production volumes dual sourcing may not be cost effective	Tower supply is likely to continue to be outsourced by turbine manufacturers There is limited use of Asian tower suppliers for the offshore market There is a potential move from turbine manufacturer's scope of supply
Conclusion[1]	G	G

7. Balance of plant supply

Balance of plant includes cables, turbine foundations, offshore and onshore substations and other wind farm infrastructure. Of these, this section will focus on the following, most significant areas:

Subsea cables. Export cables connect offshore substations to shore and between collector stations and transformer substations. These can be alternating current (AC) or direct current (DC) and operate at high voltage (HV). Array cables connect turbines to local offshore substations generally at medium voltage (MV). The supply of export cables (especially DC) is more specialised, so there are fewer suppliers in that market. The three cable types are considered separately. Definitions of high and medium voltage vary. For this study, high voltage (HV) is defined as greater than 69kV while MV is defined as 1kV to 69kV. An offshore wind farm may have significant onshore cable routes depending on the location of a suitable onshore grid connection. These typically use multiple buried single core cables for both AC and DC systems. While the onshore cable route is a challenging part of wind farm design and consenting, there are no significant supply issues concerning the cables themselves.

AC and DC substation electrical systems. Depending on the specific design used, AC systems may incorporate HV transformers, reactors, switchgear and associated power electronics, control and auxiliary systems. DC systems also incorporate HVDC converters. Although a number of major suppliers of HV electric components produce both AC and DC equipment, the HVDC market has some distinct supply issues and is considered separately. For larger wind farms, an HVDC converter platform may be associated with AC collector platforms.

Offshore substation electrical systems are mounted on platforms. The fabrication capability for platform topsides exists in the oil and gas sector and foundations are usually similar to those of turbines. Few of these are required compared with the number of turbine foundations, so steelwork fabrication for offshore substations is not considered a concern. As projects get larger the size and weight of the offshore substations and platforms will also increase, and this may mean that fewer fabricators can supply, especially for the larger HVDC units. Foundation technologies will also develop to meet the need for larger platforms, including self-installing designs to avoid the use of expensive vessels and concrete gravity bases.

Steel and concrete foundations. Foundations support the turbine above the sea bed. Designs are driven by a combination of wind and wave loading, and structural dynamic requirements. Steel monopile foundations currently dominate the market but, as larger turbines are used in deeper water, non-monopile steel foundations such as jackets are increasingly likely to be used. Another key material for offshore foundations is concrete. As the supply issues for these three types of foundation are distinct, they are considered separately here.

There is uncertainty about future foundation technology choices. By 2020, the greater mass and rotor diameters of the next generation of larger turbines, combined with the development of projects in greater water depths, could mean that cost and logistics considerations will preclude the use of monopiles for many projects. It is likely that braced, space frame jackets (in one form or another) will be the preferred alternative to monopiles, at least in the short term until other solutions are demonstrated. In the medium and long term, jackets are likely to retain a significant market share for a number of years, but may face much greater competition from other designs including alternative space frame designs, next generation monopiles, concrete designs and also floating foundations as these technologies are proven.

Our projections assume that, as well as the projects that are likely to use smaller monopiles or jackets, there is a wider, long term “open opportunity” space for which all designs will compete. The significance of this is considered in Sections 7.6-7.8 which consider monopile foundations, non-monopile steel foundations and concrete foundations separately.

7.1. Subsea array cables

Subsea array cables connect turbines to offshore substations. Almost all array cables used to date have been three-core XLPE (cross-linked polyethylene) AC MV designs rated at 33kV and using copper cores.

The underlying technology is well established and proven in many industries such as oil and gas and power transmission and distribution. Eight MV cable suppliers have served the offshore wind market to date. While most of these also supply HV cables some companies, such as JDR Cable Systems and Parker Scanrope, currently only manufacture MV cable.

Current capacity and investment lead time

Array cable supply is likely to meet demand. Although demand for array cable almost triples over the period shown in Figure 7.1, this growth is less challenging than might otherwise be expected because the length of cable required for any given size wind farm drops as turbine capacities increase. New investment will be needed to meet future demand but industry feedback is that most suppliers have the ability to increase capacity relatively easily at their existing facilities.

Current order lead times are quoted at about nine months for 33kV array cable and the ramp-up time to increase factory capacity is six to eight months, assuming no planning restrictions. Array cables are lighter and can be made in shorter lengths than export cables (see Sections 7.2 and 7.3), which provides more flexibility at both the manufacturing and storage stage, meaning that the additional plant required for increasing array cable capacity can be smaller, less costly and more flexible.

There is a risk that suppliers will move into supplying higher voltage products (for both array and export cables) due to the higher margins, which will divert capacity away from manufacturing array cables at lower voltages and therefore possibly decrease competition and increase costs, without actually risking insufficiency of supply.

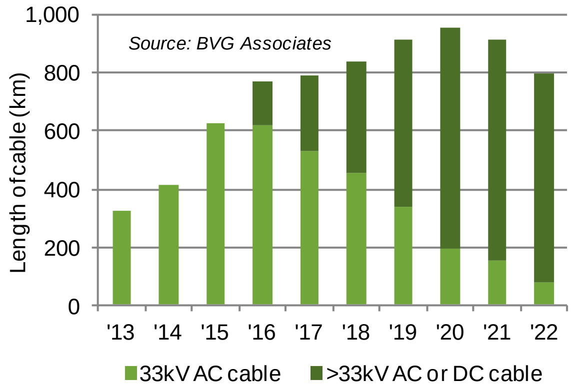

Figure 7.1 Projected demand for subsea array cable for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by two years).

Investment status

Incremental investments are ongoing. There are investment plans in development for a number of suppliers, both to increase supply and flexibility in supply.

Synergy with parallel sectors

Array cable factories can also be used to supply the oil and gas market. Feedback from industry is that production capacity used for offshore wind array cables can be diverted to serve other sectors, such as umbilical and power cables for oil and gas applications. The higher profit margins in this parallel sector mean that there is a risk that production capacity could be diverted away from offshore wind. Likewise, should supply for offshore wind become limited, possibilities exist for investment by oil and gas suppliers to meet demand.

LCOE reduction due to technology development

Large scale adoption of higher voltage array cables is expected. Increasing the voltage of array cables from 33kV has the potential to reduce electrical losses and preserve the number of turbines connected in each “string” connected to the substation as turbine ratings increase.

In some circumstances, this innovation also means it becomes cost effective to install turbines on ring circuits from the offshore substation, rather than in a radial circuit as generally used today. This adds upfront costs but allows the turbines to continue generating electricity in the event of a single cable or switchgear fault. The introduction of higher voltage array cables was identified as the most significant innovation in array cables in the *Offshore Wind Cost Reduction Pathways Study: Technology work stream*, potentially reducing LCOE by up to 0.4%.

Cables at up to 66kV should be available in 2015. Higher voltage array cable designs at up to 66kV with a dry-type design are fully developed but developers are seeking wet-type 66kV cables which are seen to be more cost effective. Designs exist for wet-type 66kV cables but feedback from industry is that it will take at least two years to commercialise these.

Evidence that the introduction of 66kV is an important milestone is the launch by the Carbon Trust-led Offshore Wind Accelerator (OWA) of a 66kV cable qualification competition in May 2013. Funding of up to £300 thousand will be awarded to at least two cable suppliers to deliver a certificated 66kV product to be installed offshore by 2015.

In deploying higher voltage cables, it is necessary to have not only a certificated cable product but also the switchgear and transformers developed for higher voltage. Based on industry feedback, Figure 7.1 shows that higher-voltage array cable could be first used by 2016 and then account for a rapidly increasing market share.

Widespread adoption of higher voltage array cables is expected. The advantages of higher voltage cables, particularly following the introduction of next generation turbines is such that they will become widely used subject to availability. Most turbines in development will offer options for 33kV or 66kV array distribution.

DC array cabling is expected to offer significant potential cost benefits. Looking beyond the introduction of high voltage AC array cables, analysis in the *Offshore Wind Cost Reduction Pathways Study: Technology work stream* indicated that the introduction of DC power take-off could reduce the LCOE significantly.

DC circuit protection technology is being developed by (at least) ABB, Alstom Grid and GE Power Systems and has applications for interconnected transmission systems as well as DC turbine arrays. Standards and certification will need to be developed for both applications. It is unlikely that such a solution will be available for use on a commercial scale wind farm until after 2020.

Technology shift

All innovation is focused on reducing LCOE. There are no additional requirements for array cable design for larger projects further shore.

LCOE reduction due to supply chain development

Supply of 66kV cable may be initially constrained. Only a subset of suppliers has a wet cable in development. This may mean that early supply of 66kV cables is constrained with cost reductions not maximised until more suppliers have certificated products in the market.

There is likely to be a consolidation of cable supply and install packages. Cable installation has interfaces with cable supply and foundation supply and installation. For UK projects in particular, developers have so far preferred to award separate contracts but feedback from industry is that developers are now increasingly looking to combine the supply and install packages to reduce the number of contractual interfaces. This is likely to drive acquisitions and cooperation agreements. Cable manufacturers such as Nexans and NKT Cables have some in-house cable-laying capacity and Prysmian strengthened its capability in 2012 with the acquisition of cable installed Global Marine Energy. ABB has also developed long term relationships with installers EMAS AMC and Canyon Offshore.

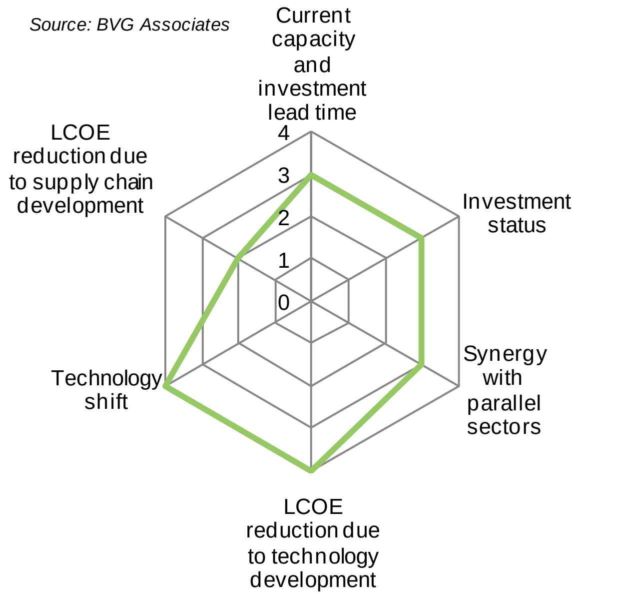

Figure 7.2 Summary of issues concerning subsea array cable supply.

Conclusion

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Array cable supply has been graded green because there are sufficient experienced suppliers with adequate capacity to facilitate good competition in the market. Incremental investments can be made to meet demand and a cost reduction from the introduction of 66kV cables should start to be realised within the next three years.

7.2. Subsea AC export cables

For the purposes of this analysis, subsea AC export cables have been defined as high voltage cables that connect the offshore and onshore substations. These cables will also be required on projects using HVDC transmission to connect AC collector platforms and the main DC converter platforms.

High voltage AC export cables have typically been three-core 132kV, 150kV, 155kV, 220kV or 245kV extruded XLPE cable. With only a few exceptions, offshore wind export cables have had copper cores.

The capacity of a factory may be constrained by either core extrusion capacity, laying up machine capacity or turntable capacity. A typical factory can produce about 80km of 220kV cable a year. In general, 220kV cables take longer to manufacture than 132kV cables.

Current capacity and investment lead time

There has been investment in new capacity but supply is still constrained. The supply of HVAC export cables to offshore wind farms has been expressed as a concern in previous gap analyses both in terms of the number of suppliers and the overall capacity available. Overall, the picture has improved since 2009 with the three established players in the global market (ABB, Nexans and Prysmian) joined by LS Cable & System, NKT Cables and NSW General Cable, and several investments have been made (see Table 7.1).

Figure 7.4 shows that, despite this progress, demand in 2016 is close to maximum supply and there are likely to be delays as factory output is unlikely to be aligned to project schedules because supply will not always meet demand even if over a period factory capacity is sufficient. The increase in the supply shown in Figure 7.4 in part reflects the investment that has been made but also shows the effect of greater demand for DC export cables. With two cores per link rather than three for AC cables, the capacity for a DC production line is about 50% higher than for AC, although this will depend on the cable voltage and the power rating.

Table 7.1 Publicly stated European investments in subsea export cable since 2010.

Manufacturer	Investment since 2010
ABB	Doubling of capacity at Karlskrona, Sweden by 2015
JDR Cable Systems	Research and development in higher voltage MV cables HV cables
NKT Cables	New factory in Cologne, Germany opened 2010 New logistics facility in Rotterdam, Netherlands opened 2013
Prysmian Cables and Systems	Additional capacity added at Arco Felice, Italy and Pikkala, Finland

The lead time for an export cable can be up to two years, depending on the length and the voltage required. Manufacturers report that a number of developers have issued tenders during 2013 and that supply for these is likely to be constrained without new investment. Export cable supply is particularly challenging for the industry as installation typically takes place early in the construction schedule, about two years ahead of works completion.

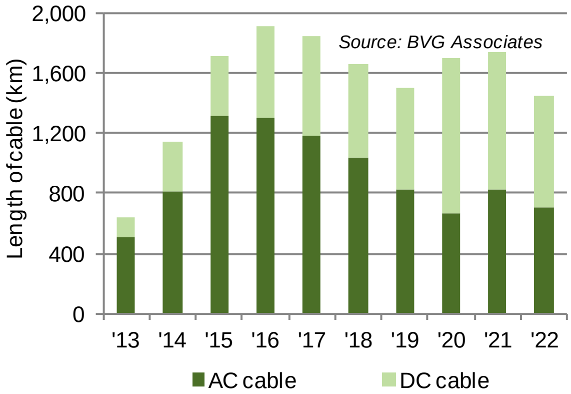

Figure 7.3 Projected demand for subsea export cable for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by two years).

There is a long lead time for new export cable investment. The investment lead time for a new factory by an existing supplier is about four years and for an extension to an existing facility about two years. Figure 7.4 shows that, even with three investments already made in existing facilities, cable supply will constrain projects requiring cables in 2015. To meet the demand shown, further investment needs to be committed in 2013.

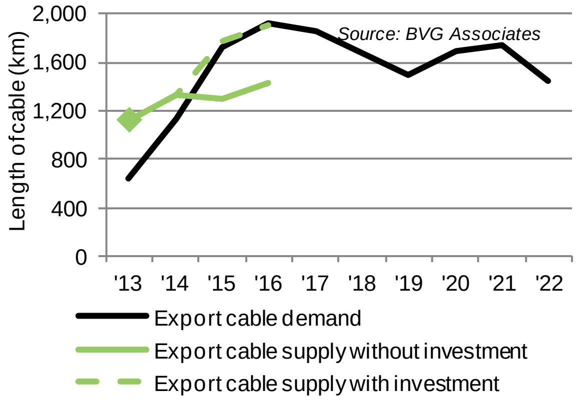

Figure 7.4 Supply and projected demand for subsea export cable for European offshore wind to 2022 (demand by year of manufacture, offset from turbine installation by two years).◆ indicates the point at which a first investment decision is needed to achieve the increase in the supply shown.

Investment status

Some new capacity is already committed at existing facilities. ABB announced in 2011 the doubling of its high voltage capacity at its Swedish factory at Karlskrona. This is scheduled to reach full capacity in 2015.

Cable manufacturers are cautious about investing at new sites as this risks diluting technical and management capability at existing facilities. Despite this, Nexans is reported to be considering a new facility in Asia or the USA to meet the global demand for submarine power cables.[19]

Most investments in submarine cable manufacturing facilities have been made to fulfil contracts to supply interconnector projects.

Synergy with parallel sectors

High voltage AC subsea cables can be used for short interconnectors. Manufacturing facilities will also supply the HVAC interconnector market but demand is lower than for offshore wind.

LCOE reduction due to technology development

Higher voltage cables have the potential to reduce costs. An increase in transmission voltage has the potential to increase power carrying capability for the same conductor size. This explains the current trend towards 220kV cables for offshore wind. The available voltage rating for XLPE cable is likely to increase and industry

[19] Francois de Beaupuy 'Nexans Mulls U.S. Subsea Cable Plant for $3.9 Billion Market', *Bloomberg*, 16 July 2013, available online at www.bloomberg.com/news/2013-07-16/nexans-mulls-u-s-submarine-cable-plant-for-3-9-billion-market.html, last accessed July 2013.

feedback is that 320kV cable is likely to be available by 2020.

Technology shift

Higher voltage or lower frequency AC cables may provide an alternative to DC systems. For some projects, the decision between an AC or DC system may be a marginal one. Higher voltage or lower frequency AC cables can have a higher capacity and may overcome some of the supply issues for DC cables and converter stations discussed below.

LCOE reduction due to supply chain development

New Asian players are likely to enter the market. LS Cable & System is the first Asian cable supplier to a European offshore wind farm but there is further potential for new entrants, particularly from Japan. Feedback from industry is that HVAC submarine cable suppliers currently tend to have higher margins than MV cable suppliers because of reduced competition. These new entrants are likely to drive lower margins and reduce costs, as long as they have proven capability in other sectors.

Framework agreements are not favoured by all suppliers. These can provide suppliers with greater confidence to invest in new capacity but one leading cable supplier fed back that frameworks do not necessarily benefit suppliers; frequently they are conditional so do not provide certainty of orders and for those with full order books, there is limited incentive to enter such agreements.

There is likely to be a consolidation of cable supply and install packages. As discussed in Section 7.1, cable supply and install packages are likely to be consolidated for export cables as well as array cables. Even if separate packages are awarded, developers advise that they will make it a contractual obligation on suppliers to work together.

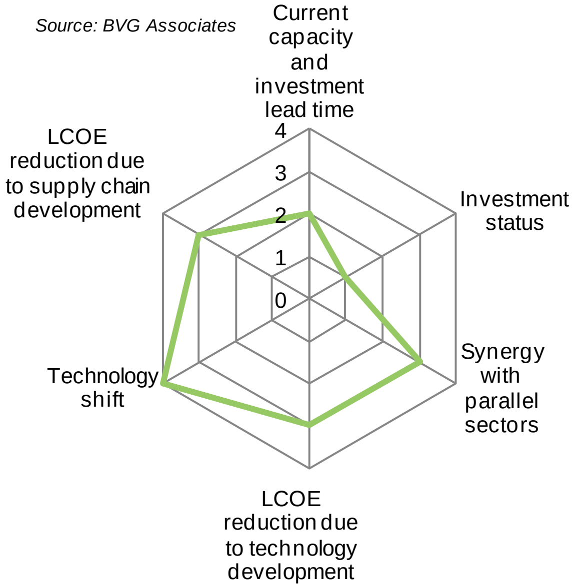

Figure 7.5 Summary of issues concerning subsea AC export cable supply.

Conclusion

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Subsea AC export cable supply has been graded amber. Although there has been investment in new capacity, the projected demand will exceed supply in 2016 without new investment. The long lead times for investment mean that this investment is urgently required.

Actions

De-risk new investment in manufacturing capacity by tendering for more than one project. There are options to achieve this through strategic action by one developer with a portfolio of projects or collaboration between multiple offshore wind developers.

Take benefit from synergies with subsea interconnectors. Contracts for these interconnectors tend to be larger than for offshore wind farms and are therefore more likely to trigger investment if the lead time permits. There are opportunities to de-risk investment in manufacturing capacity or smooth demand through dialogue with investors in subsea interconnectors such as National Grid Electricity Transmission or Scottish Power Transmission, or their overseas counterparts.

In particular, there may be synergies between UK-Irish interconnectors and offshore wind. There is interest in importing power from Irish onshore wind farms, which would require an additional interconnector to be laid. Since new HV cable investments have historically been associated with interconnector projects, an award of an interconnector supply contract four or more years ahead of installation may enable a manufacturer to make an investment that could also help meet the demand from offshore wind.

7.3. Subsea DC export cables

HVDC cables can be either extruded XLPE or mass impregnated (MI) designs although all the offshore wind HVDC cables installed to date have been the former. MI cables are currently preferred over extruded cables for interconnectors because higher voltages are achievable which allows more power to be transmitted for the same conductor size. MI cables have a higher requirement for factory space than extruded cables because of the need to immerse the cables in large tanks for several months. Industry feedback suggests that the voltages available using XLPE cables are rising and that demand for MI cables may ultimately disappear.

Where capability exists, XLPE DC or AC cables can be manufactured at the same facility, so export cable suppliers will follow the market and manufacture to meet demand.

To date, HVDC cables for offshore wind have only been installed for the German converter stations at Borwin 1 (±150kV) and Helwin 1 (±320kV). The first UK project to use HVDC is likely to be installed in 2017 or 2018.

Current capacity and investment lead time

There is limited capacity at suppliers with a track record. Only two manufacturers have supplied extruded HVDC cables for offshore wind application.

A single line for an HVDC cable manufacturer will produce about 400km of cable core a year, of which two are needed for each circuit. Figure 7.6 shows that, in 2016, about 600km of paired cable (1,200km of single core cable) will be required, and this demand can only be met if the equivalent of three lines are used for the production of HVDC cable. Given the projected high demand for HVAC cables for offshore wind at this time, it is likely that new investment will be needed.

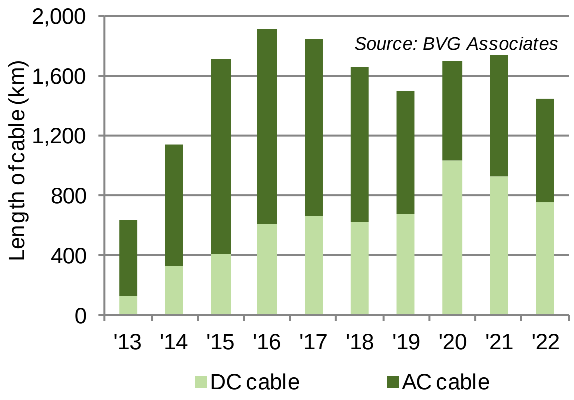

Figure 7.6 Projected demand for subsea export cable for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by two years).

There is a long lead time for new export cable investment. The investment lead time for a new factory by an existing supplier is about four years and, for an extension to an existing facility, about two years. Figure 7.8 shows that, even with three investments already made in existing facilities, cable supply will constrain projects requiring cable in 2015. To meet the demand shown, further investment needs to be committed in 2013.

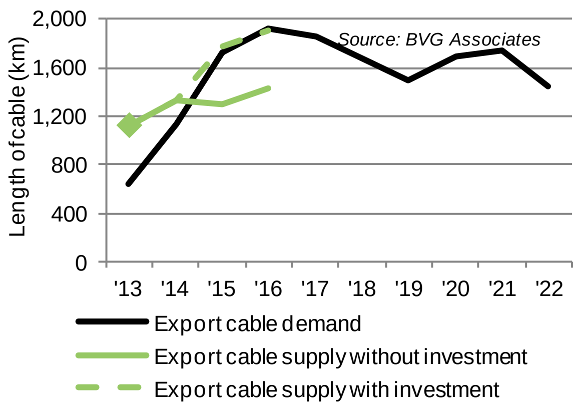

Figure 7.7 Supply and projected demand for subsea export cable for European offshore wind to 2022 (demand by year of manufacture, offset from turbine installation by two years).◆ indicates the point at which the first investment decision is needed to achieve the increase in the supply shown. (Figure is duplicate of Figure 7.4.)

Investment status

Some new capacity is committed at existing facilities. ABB's investment at Karlskrona, described in Section 7.2, can be used to supply extruded HVDC cable.

Uncertain economics for far-offshore projects may weaken demand and deter investment. Although projects further from shore that require HVDC systems typically have higher wind speeds, the CAPEX is inherently higher because of the cost of the converter platforms and the increased weather risk during construction. This may delay such projects relative to others.

MV cable suppliers are likely to make the first step into the HV market with AC cables. Our projection in Figure 7.8 shows that the market for HVAC cables will exceed the HVDC market until 2019 and a new entrant is likely to prioritise the development of an HVAC product in order to de-risk activity for all.

Synergy with parallel sectors

The availability of extruded cables at higher voltages may lower the risk of new investment. The emergence of extruded cables at voltages comparable to MI cables would create a demand for extruded cable from the interconnector market. This would lower the risk of investment in new capacity as lines can be used to supply both the wind farm and interconnector markets and the removal of MI cable manufacturing capacity would make more efficient use of factory space.

HVDC cable suppliers meet demand from a global market. Offshore wind projects compete with other energy sectors and, in some cases, projects also against each other.

LCOE reduction due to technology development

Cost reductions are possible beyond 2020 through extruded cables at higher voltages. Extruded HVDC cables currently have a capacity of 800MW, which means that larger projects will require a second cable pair. In practice, the cost reduction from this development may be limited if the developer decides that it will still prefer a second cable to give redundancy in case of failure.

Technology shift

The decision to use HVDC transmission is driven by the distance of the wind farm to the onshore grid connection. This is considered in Section 7.5.

LCOE reduction due to supply chain development

There is limited competition in supply of extruded HVDC cable. Although the HVDC market is available to any supplier with HV cable capability, only ABB and Prysmian have supplied HVDC cables to the offshore wind industry to date (see Table 7.2). NSW General had been awarded the contract for the BorWin Alpha converter platform link but the cable was ultimately manufactured by ABB. There is no technical reason why MI cables cannot be used for offshore wind farms, and their use would enable three further suppliers to be considered. Of these, only Nexans has additional European manufacturing capacity at present and transport from Korea or Japan would add a significant cost.

Table 7.2 Capability of HV cable suppliers to produce DC cable.

Company	XLPE HVDC	MI HVDC	Supplied HVDC to offshore wind
ABB	✓	✓	✓
J-Power	✓	×	×
LS Cable & Systems	×	✓	×
Nexans	×	✓	×
NKT Cables	×	×	×
NSW General Cable	✓	×	×
Prysmian Cables and Systems	✓	✓	✓
Viscas	✓	×	×

Source: Cable Consulting International[20]

There are potential new entrants from Asia. The economic growth in China, for example, has been concentrated in the east of the country, a long way from some of its energy sources. It therefore has a high demand for HVDC transmission and China has been building domestic capacity to meet that demand. There has been no export of HVDC cables from Asia so far and, should this happen, Europe may not be the first market.[21]

[20] *Cable Manufacturing Capability Study,* Cable Consulting International for The Crown Estate, July 2012, available online at http://www.thecrownestate.co.uk/media/341885/Windfarm%20export%20cable%20market%20study.pdf, last accessed August 2013.

[21] "China takes HVDC to new level", *Power Engineering International*, Volume 21 (6), 20 June 2013, available online at, www.powerengineeringint.com/articles/print/volume-21/issue-6/special-focus-hvdc/china-takes-hvdc-to-new-level.html, last accessed July 2013.

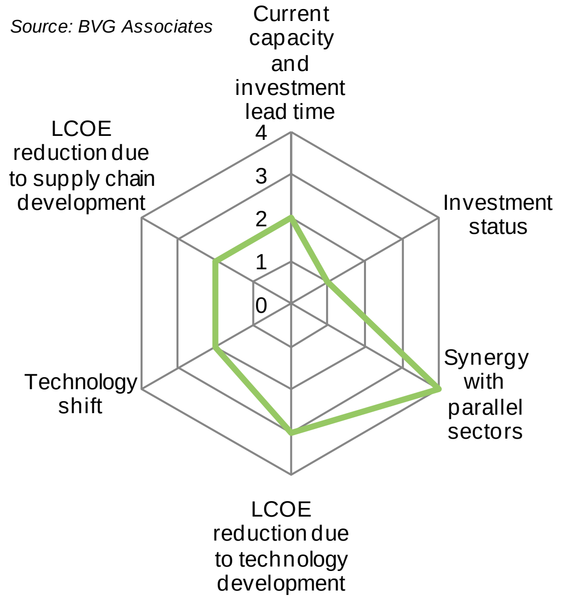

Figure 7.8 Summary of issues concerning subsea DC export cable supply.

Conclusion

R

Subsea DC export cable supply has been graded red. It shares the same issues with HVAC cable supply but the problem is compounded by the limited number of suppliers with the capability to produce extruded HVDC cable.

Actions

De-risk new investment in manufacturing capacity by tendering for more than one project. There are options to achieve this through strategic action by one developer with a portfolio of projects or collaboration between multiple offshore wind developers.

Take benefit from synergies with subsea interconnectors. Contracts for these interconnectors tend to be larger than for offshore wind farms and many of the interconnectors have relevance to offshore wind. There are opportunities to de-risk investment in manufacturing capacity or smooth demand through dialogue with investors in subsea interconnectors such as National Grid Electricity Transmission or Scottish Power Transmission, or their overseas counterparts.

In particular, there may be synergies between UK-Irish interconnectors and offshore wind. There is interest in importing power from Irish onshore wind farms, which would require an additional interconnector to be laid. Since new HV cable investments have historically been associated with interconnector projects, an award of an interconnector supply contract four or more years ahead of installation may enable a manufacturer to make an investment that could also help meet the demand from offshore wind.

Establish confidence in pan-European HVDC super grid plans. As plans for international interconnects become firmer, then this will help support investment decisions in new capacity.

Table 7.3 Summary of supply chain status and conclusions on subsea array cables and subsea AC export cables.

Criterion	Subsea array cables	Subsea AC export cables
Proven capability	ABB, JDR Cables, Nexans, NKT, NSW General Cable, Parker Scanrope, Prysmian	ABB, Nexans, NKT, Prysmian
Additional future capability	Hellenic Cables, J-Power, LS Cable, Twentsche Kabelfabriek, Viscas	JDR Cable Systems, J-Power, LS Cable, NSW General Cable, Viscas
Current capacity and investment lead time	Array cable supply is likely to meet demand	There has been investment in new capacity but supply is still constrained There is a long lead time for new export cable investment
Investment status	Incremental investments are ongoing	Some new capacity is already committed at existing facilities
Synergy with parallel sectors	Array cable factories can also be used to supply the oil and gas market	High voltage AC subsea cables can be used for short interconnectors
LCOE reduction due to technology development	Large scale adoption of higher voltage array cables is expected Cables at up to 66kV should be available in 2015 Widespread adoption of higher voltage array cables is expected DC array cabling is expected to offer significant potential cost benefits	Higher voltage cables have the potential to reduce costs
Technology shift	All innovation is focused on reducing LCOE	Higher voltage or lower frequency AC cables may provide an alternative to DC systems
LCOE reduction due to supply chain development	Supply of 66kV cable may be initially constrained There is likely to be a consolidation of cable supply and install packages	New Asian players are likely to enter the market Framework agreements are not favoured by all suppliers There is likely to be a consolidation of cable supply and install packages
Conclusion	G	A
Actions		De-risk new investment in manufacturing capacity by tendering for more than one project Take benefit from synergies with subsea interconnectors

Table 7.4 Summary of supply chain status and conclusions on subsea DC export cables.

Criterion	Subsea DC export cables
Proven capability	ABB, Prysmian
Additional future capability	J-Power, LS Cable, NKT, NSW General Cable, Nexans, Viscas
Current capacity and investment lead time	There is limited capacity at suppliers with a track record
Investment status	Some new capacity is committed at existing facilities Uncertain economics for far-offshore projects may weaken demand and deter investment MV cable suppliers are likely to make the first step into the HV market with AC cables
Synergy with parallel sectors	The availability of extruded cables at higher voltages may lower the risk of new investment
LCOE reduction due to technology development	Cost reductions are possible beyond 2020 through extruded cables at higher voltages
Technology shift	The decision to use HVDC transmission is driven by the distance of the wind farm to the onshore grid connection
LCOE reduction due to supply chain development	There is limited competition in supply of extruded HVDC cable There are potential new entrants from Asia
Conclusion	R
Actions	De-risk new investment in manufacturing capacity by tendering for more than one project Establish confidence in pan-European HVDC super grid plans Take benefit from synergies with subsea interconnectors

7.4. AC substation electrical systems

AC electrical systems, onshore and offshore, comprise transformers, reactors, switchgear, associated power electronics, and control and auxiliary systems.

With the exception of a small number of early projects that were connected to the grid without offshore substations, all the UK offshore wind projects completed to date have incorporated one or more HVAC substations and a new, or extended, onshore substation.

AC infrastructure may also be needed for HVDC grid connections for large projects or zones. If needed, HVAC collector substations would be located across a wind farm to minimise the transmission distances from turbines at lower voltages, and hence reduce electrical transmission losses. These collector stations will include transformers to step up the voltage from a typical 33kV or 66kV to 220kV for input to the HVDC substation.

Not considered here are the substation topsides and foundations which can be supplied by fabricators of oil and gas platforms and turbine foundations respectively.

Current capacity and investment lead time

***Design and build is difficult within wind farm construction timetables*.** The substation topside and foundation cannot be designed until the substation's electrical requirements have been established, which in turn require the turbine choice to have been made. With the substations installed early in the construction phase, developers often need to schedule their construction programmes around the lead time for the substations.

Current levels of demand are lower than they have been for several years, with the result that there is spare capacity. There remains a danger that, if a number of projects are taken forward simultaneously, there will be insufficient capacity as there are few suppliers of key components.

There has been an increase in Asian manufacturers for gas insulated switchgear and transformers supplying the European market.

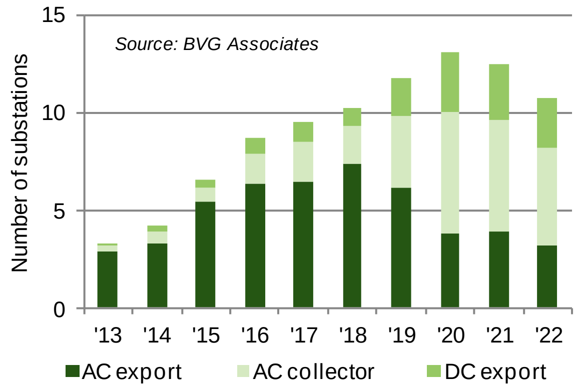

Figure 7.9 Projected demand for AC and DC substation electrical systems for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by two years). Figures are derived from projected generating capacity and hence are not integers.

Investment status

Significant investment is not required. The electrical suppliers need to grow design teams for offshore wind projects but this can be achieved through organic growth. Little additional manufacturing capacity is required from suppliers' global supply chains.

Synergy with parallel sectors

There is competition for components from other power and generation sectors. Offshore substation HV transformers have previously been an area of significant concern. Although lead times for transformers have been up to two and a half years, they are now below 18 months. While there are a small number of HV system integrators, they have a worldwide supply chain. The supply of large electrical components is therefore driven by the global requirement for new electrical infrastructure at the time of order, rather than the specific requirements from the offshore wind industry. One developer reported concerns that the growth in electricity generation using shale gas may have an adverse impact on the availability of transformers for the wind industry. Although these parallel sectors enable suppliers to invest in the capability to supply offshore wind projects, there is a risk that suppliers may ultimately find these sectors more attractive than offshore wind.

The conventional onshore substation market can sustain design and project teams during low levels of offshore wind activity. Suppliers have been able to keep their offshore teams during the current lull in the market. Without this, they would have lost much of the expertise built up so far.

LCOE reduction due to technology development

The rating of the transmission system lower than the total nameplate turbine rating can reduce cost. The RenewableUK report to The Crown Estate on the *Potential* *for offshore transmission cost reductions* concluded that transmission assets rated lower than the total rated capacity of the turbines could save 2-3% on CAPEX with little penalty on energy production.[22] Wind farms rarely generate at their nameplate capacity, either because the wind is below rated speed or because of turbine unavailability. As a result, the savings from lower capital costs are likely to outweigh any potential reduction in output through any required curtailment.

Progress for new concepts is slow. New design concepts are in development but, with low levels of demand in 2013, progress has been slow. The situation will improve with an upturn in the market.

The design of offshore substations is still in its infancy. There are still fewer than 30 offshore wind substations in the world and there is still significant scope for reducing costs through learning.

Technology shift

AC substation technology is well established but platforms further offshore raise some new technical challenges. For further offshore AC substations and collector stations for DC transmission systems, there will be a demand for new cooling systems and fire suppression systems because the response time for maintenance will be longer and the platforms may also be used for accommodation. HVDC systems for wind farms with long grid connections are considered in Section 7.5 below.

LCOE reduction due to supply chain development

A new entrant has increased competition in the market. Since 2012, CG Power has entered the UK market with its contract to supply the Humber Gateway substation. Further entrants are likely as developers seek lower cost sources of supply. We understand that developers are undertaking global searches for potential suppliers, and this may include breaking down the electrical package further and sourcing key components for free issue to tier 1 suppliers. The lack of orders in 2013 has reduced the appetite for investment by further new entrants.

The market is insufficient to incentivise new supply chain partnerships. To form partnerships, there needs to be a pipeline of more than one project. Industry feedback indicates that there are numerous discussions taking place between suppliers, but it may be 2015 before future levels of demand are clearer and partnerships are finalised.

Progress is underway in standardising substation design. There is a significant degree of variation in substation design. There are inevitable differences between projects that reflect the choice and number of turbines, and the location of the wind farm. Attention among suppliers is on developing a core product that can be adapted to meet the needs of individual projects. If achieved, the project lead times discussed above will fall. A large area of cost and risk is the layout and mass of the offshore substation and the design of the topside. Simplifying the topside design may reduce costs more than innovations in the electrical system itself.

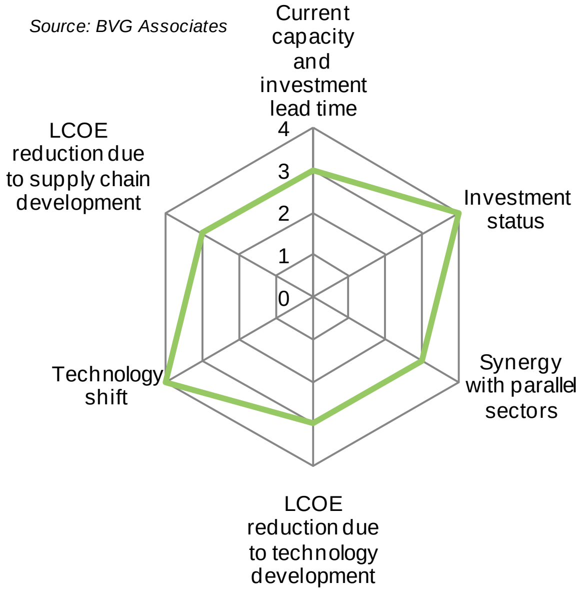

Figure 7.10 Summary of issues concerning AC substation electrical system supply.

Conclusion

G

AC substation electrical systems have been graded green as they should not constrain the delivery of projects and the increasing emphasis on standardisation should enable progress in achieving cost reduction and further improved delivery timescales.

7.5. DC substation electrical systems

HVDC systems allow more power to be carried by less cable at higher voltages, with lower electrical losses over long distances compared with HVAC systems.

HVDC systems have been in commercial use since the 1950s but the most widely used designs use current source converters (CSC). CSC systems, like HVAC systems, require reactive compensation components. These account for over 40% of the footprint, making it expensive to

[22] *Potential for offshore transmission cost reductions: A report to The Crown Estate*, RenewableUK, February 2012, available online at www.thecrownestate.co.uk/media/305106/RenewableUK%20Potential%20for%20offshore%20transmission%20cost%20reductions.pdf, last accessed August 2013.

accommodate on an offshore platform. Offshore wind farms therefore use voltage source converter (VSC) technology, developed in the early 1990s by ABB. VSC systems are lower mass and require a smaller footprint than CSC systems. There are currently three suppliers: ABB, Alstom Grid and Siemens Energy.

Not considered here in detail are the converter topside and foundations. Designs for housing and installing offshore DC systems are still evolving. Topside fabrication can be undertaken by the suppliers of oil and gas platforms, provided they have the space at their facilities to build units that are significantly larger than AC platforms.

The size and mass of HVDC topsides presents challenges for installation as only the largest semisubmersible crane vessels will have the capacity to lift them.

Current capacity and investment lead time

Design and build is difficult within wind farm construction timetables. As for AC substations, the substation topside and foundation cannot be designed until the substation's electrical requirements have been established, which in turn require the turbine choice to have been made. The engineering challenges for DC substations mean that lead times are longer than for AC substations. With the substations installed early in the construction phase, developers often need to schedule their construction programmes around the lead time for the substations.

There is no constraint on electrical component supply. The individual components of HVDC systems are standard electronic products and converter assembly facilities do not require significant capital investment. Suppliers report that a doubling of current production could be accommodated at existing sites. As for AC substations, the lead time is dependent on the required wind farm design and turbine choice before the electrical system is designed and the topside subsequently designed and manufactured. The current lead time for supply is four years, which may impact on project schedules as feedback from suppliers is that some developers underestimate this. The challenge has been housing and installing the equipment offshore rather than the supply of the electrical systems themselves, which often have shorter lead times.

Investment status

Investment plans being implemented. Alstom Grid has begun investment in its Stafford facility and Siemens Energy Transmission is growing its capacity at its new Renewable Energy Engineering Centre in Manchester.

Synergy with parallel sectors

HVDC systems are essential for the construction of offshore interconnectors. HVDC has been used for a number of interconnector projects and this is a growing market and feedback is that there is greater certainty than for offshore wind. Interconnectors are not necessarily dependent on VSC technology as there is no need for offshore infrastructure, although there may be onshore space constraints. The development of the European Supergrid would need VSC HVDC technology.

Components are sourced globally. The electronic components for HVDC systems are sourced from companies all over the world supplying a number of sectors.

LCOE reduction due to technology development

There has been recent progress in DC hub technology. All commercial HVDC links have been point-to-point connections. The development of an integrated offshore grid requires the further development of DC circuit breakers. These have been used for many years but DC grids require a shorter breaking time than has been available. ABB, Alstom Grid and GE Power Conversion have all reported solutions.

DC array cabling offers theoretical cost reductions. MVDC technology would enable DC connections directly from turbines. This technology is still under development but it could mean that certain projects up to 70km from shore could be connected directly to an onshore substation without an offshore substation, or that projects using HVDC systems may not require collector stations, as well as offering simplifications to turbine power take-off arrangements. There is uncertainty about when such solutions will be first implemented.

Technology shift

The decision to use HVDC transmission is driven by the distance of the wind farm to the onshore grid connection. As mentioned, HVDC systems are preferred for longer grid connections. HVDC systems using VSC technology do not require separate reactive power components to compensate for the cable capacitance. HVDC systems also have a reduced cable material demand because they only require two, smaller conductors compared with three for HVAC, and fewer HVDC circuits are needed for transmitting the equivalent power compared with HVAC. Onshore cable corridors can therefore be narrower which reduces land take and makes more direct routes possible in some cases and therefore reduces cost.

HVDC substation infrastructure is currently more expensive than that of HVAC systems due to the use of high power semiconductor devices and related equipment, and the use of a more specialist supply chain compared with conventional HVAC transmission equipment. HVDC substations are also heavier, which increases the installation cost, and larger, which limits the number of yards that can build them.

These benefits and disadvantages mean there is a tipping point when the additional cost of HVDC substations is outweighed by the savings in cable costs and the increased revenue generated through reduced electrical losses. Industry assessments of this tipping point currently range from 80km to 100km, including the onshore cable route. In the short term, developers may consider using HVAC even where it is marginally less cost effective due to the longer lead time of HVDC systems. In the long term, it is expected that the distance at which HVDC systems become cost effective, compared with HVAC systems, will reduce as standardisation and more efficient manufacturing processes reduce the lead time, cost and risk associated with HVDC systems faster than for HVAC systems.

Technical challenges will be addressed on German projects first. The first HVDC transmission systems for offshore wind farms are already operational in Germany as discussed in Section 7.3. By the time the first UK project to use HVDC transmission, which is likely to be East Anglia One, is scheduled to start construction in 2017, Germany plans to have seven HVDC substations operating.

The technical challenges for HVDC transmission are mainly the design and cost of the platform rather than technical challenges for the electrical system. VSC HVDC technology currently has an upper limit of 1,200MW and if there is demand for capacities greater than this and/or interconnected grids then further development and innovation will be required for converters and cables.

LCOE reduction due to supply chain development

A new entrant to market has partially eased competition concerns. Since 2012, Alstom Grid has won its first subsea HVDC contract with the award of the German DolWin3 project and this has eased concerns among wind farm developers, although the engineering capacity of suppliers may limit the number of projects that can be taken forward simultaneously.

The demand for HVDC systems in China is likely to lead to the emergence of further competition. Although Chinese supply might be perceived as high risk, any new entrant is likely to be a major industrial conglomerate.

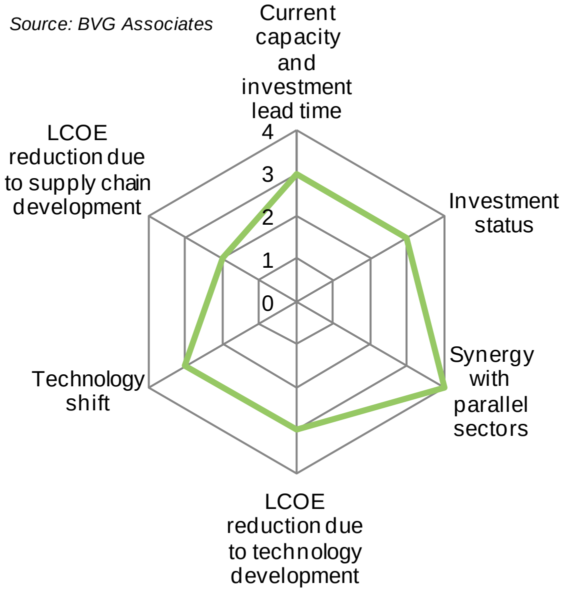

Figure 7.11 Summary of issues concerning DC substation electrical system supply.

Conclusion

A

DC substation electrical systems have been graded amber as there is still uncertainty over their large-scale deployment for offshore wind, the long supply lead times and the limited engineering capacity of suppliers for developing the bespoke solutions currently required for each project.

Action

A joint industry project could usefully establish best practice in housing solutions for DC converter platforms and in standardising HVDC systems. We understand that the Carbon Trust plans to fund an HVDC optimisation study to support standardisation and reduce lead times. A challenge is that VSC technology is still developing and there is a competitive advantage for the company that can increase the VSC power rating most. This may limit the opportunities for standardisation in the short term.

Table 7.5 Summary of supply chain status and conclusions on AC substation electrical systems and DC substation electrical systems.

Criterion	AC substation electrical systems	DC substation electrical systems
Proven capability	ABB, Alstom Grid, CG Power, Siemens Energy Transmission	ABB, Alstom Grid, Siemens Energy Transmission
Additional future capability	Mitsubishi Heavy Industries	Possible Asian supply
Current capacity and investment lead time	Design and build is difficult within wind farm construction timetables	Design and build is difficult within wind farm construction timetables There is no constraint on electrical component supply
Investment status	Significant investment is not required	Investment plans are being implemented
Synergy with parallel sectors	There is competition for components from other power generation sectors The conventional onshore substation market can sustain design and project teams during low levels of offshore wind activity	HVDC systems are essential for the construction of offshore interconnectors Components are sourced globally
LCOE reduction due to technology development	The rating of the transmission system lower than the total nameplate turbine rating can reduce cost Progress for new concepts is slow The design of offshore substations is still in its infancy	There has been recent progress in DC hub technology DC array cabling offers theoretical cost reductions
Technology shift	AC substation technology is well established but platforms further offshore raise some new technical challenges	The decision to use HVDC transmission is driven by the distance of the wind farm to the onshore grid connection Technical challenges will be addressed on German projects first
LCOE reduction due to supply chain development	A new entrant has increased competition in the market The market is insufficient to incentivise new supply chain partnerships Progress is underway in standardising substation design	A new entrant to market has partially eased competition concerns The demand for HVDC systems in China is likely to lead to the emergence of further competition
Conclusion	G	A
Actions		A joint industry project could usefully establish best practice in housing solutions for DC converter platforms and in standardising HVDC systems

7.6. Monopile foundations

More than three quarters of all installed European offshore wind projects to date have used steel monopile foundations, with most of the remainder using concrete gravity base designs. Monopile technology is tried and tested for 3MW to 4MW turbines and there is existing manufacturing and installation capacity in the market.

For larger turbines, the cost of monopile supply increases significantly because of the increased steel demand in order to give sufficient stiffness to provide reasonable dynamic response to wind and wave loading, especially with heavier nacelles and heavier, slow-rotating rotors. Together with the increased installation costs of larger monopiles (see Section 7.8), there is a point at which the total installed cost of using monopiles outweighs the cost of other designs. Previous industry feedback has been that that this tipping point is 30m to 35m water depth for projects using turbines with a rated capacity of 4MW or less and 20m for turbines with a rated capacity of around 6MW. In the last two years, however, effort has been made to stretch the envelope of monopile use to larger turbines in deeper water, recognising that there will still be practical, supply chain and economic limits for projects in water much deeper that 35m using, for example, 6MW turbines. These large monopiles (frequently referred to as XL (eXtra Large) monopiles) have a diameter greater than 7.5m.

Current capacity and investment lead time

There is sufficient supply of monopiles with a diameter of 7.5m or less. Annual demand for monopiles of this size is projected to peak at about 330 in 2015 and few will be needed beyond 2017 due predominantly to the move to larger turbines. There is sufficient capacity from proven suppliers to meet this demand (see Figure 7.12).

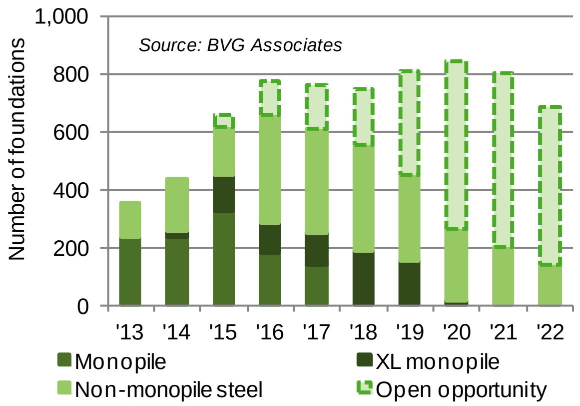

Figure 7.12 Projected demand for foundations for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by two years). Open opportunity indicates the demand for foundations for which the technology choice is uncertain.

There is limited production capacity for monopiles with a diameter greater than 7.5m. It is understood that only Dillinger Hütte, supplier of steel plate to a number of fabricators, and EEW have the capacity to produce monopiles greater than 7.5m in diameter in any quantity today. Annual demand is not likely to exceed 200 until 2018. With a lead time for investment in appropriate tooling at one year, supply is unlikely to be constrained despite uncertainty over the longer term market for XL monopiles.

Investment status

There are well developed plans under consideration. Steel plate supplier Dillinger Hütte has invested in its own manufacturing facilities and TAG Energy Solutions has made investments that have enabled it to enter the market for the supply of monopiles to the UK Humber Gateway wind farm.

Synergy with parallel sectors

Monopile fabrication facilities can also supply pin piles for jackets and tripod foundations. Pin piles for jackets are up to 3.5m in diameter and the production facilities for standard monopiles can be used efficiently to manufacture pin piles.

Thick steel plate is also manufactured for other sectors. For example, there is competition for thick steel plate from shipbuilding and pressure vessel manufacturing for the gas industry.

LCOE reduction due to technology development

Progress is underway in developing new design standards and improved design processes. There is opportunity to improve the way that the pile-soil interaction is modelled. Existing standards reference the p-y approach which is highly empirical and relies on ‘old’ test data from piles of less than 20 per cent of the diameter of those being installed today. Work is underway to develop a more relevant data set. Another opportunity, relevant also to jackets, is to take advantage of improved fatigue properties of current materials compared with those used when the routinely used standards were developed, and to revise partial safety factors for loads and materials based on inspection regimes and consequences of failure.

There has been slow progress in addressing the issue of piling noise. Concerns over the impact of piling noise, particularly on sea mammals, have already had an impact on projects in Germany. This issue is likely to become much more important across all national markets due to the cumulative impact of increasing levels of activity with project construction activity being sustained over several years. If unresolved, industry feedback is that this issue could lead to rapidly escalating costs for developers.

This requires rapid development of improved mitigation measures but also more real-life evidence on the impact of cumulative activity of piling to understand what are the appropriate levels of precautionary measures that should be put in place.

Technology shift

Deeper water constrains the cost effective application of monopiles. As discussed above, industry is extending the window for monopile foundations which will benefit from new manufacturing and installation technology.

Mitigation of piling noise may be required due to cumulative impacts of large projects. There is a risk that the collective effect of piling for prolonged periods over a large area will have a detrimental effect on the health and behaviour of sea mammals.

LCOE reduction due to supply chain development

There are few suppliers of monopiles with a diameter greater than 7.5m. There is limited competition in the market for XL monopiles. If uncertainty in the market persists, further investment may be deterred, and the price advantage over jackets or tripods may be eroded.

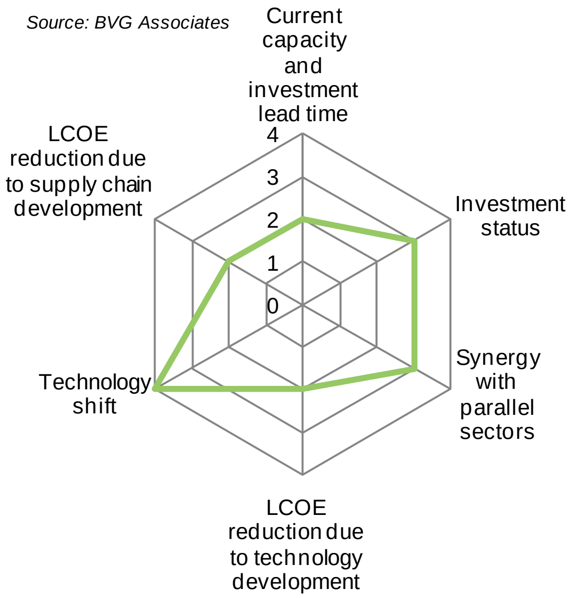

Figure 7.13 Summary of issues concerning monopile foundation supply.

Conclusion

G

This subelement has been graded green because there is sufficient competition in the market from proven suppliers. A potential area of concern is the competition in the market for XL monopiles. Although investment will be needed to provide the tooling and factory space to produce XL monopiles, it is likely that suppliers will respond to meet industry demand. Incentives to stimulate investment are still likely to be required, however, and ongoing work is needed to communicate the opportunity and promote suitable sites to potential investors.

7.7. Non-monopile steel foundations

There is a range of steel foundation designs currently being proposed for projects in which monopiles are not a feasible option. There is uncertainty, however, about which designs are likely to dominate in the long term.

Industry feedback is that the most common “deeper water, larger turbine” design will be the four-legged steel jacket (a cross-braced, welded, space-frame structure) but other steel designs, such as tripods and tri-piles, have also been used on some Continental projects. Furthermore, other steel designs have been proposed, such as braced monopiles, monopods that use suction buckets to provide the sea bed connection, and jacket variants with designs of three or six legs and with “twisted” structures.

These space frame designs have been grouped together as many of the issues faced by potential suppliers and customers are similar.

Current capacity and investment lead time

There is sufficient capacity at the moment but proposed investment plans need to be realised. There are a number of existing suppliers on the Continent and in the UK that have invested in production facilities and now have a track record of delivery. The demand for non-monopile steel foundations is not projected to exceed 250 units per year until 2016 (see Figure 7.12) and it is expected that this can be met by these existing facilities.

If much of the open opportunity is filled by XL monopile demand, industry feedback is that non-monopile steel foundation supply is not likely to be a serious bottleneck as there are companies in France, Germany, Poland and the UK with advanced propositions in place that could meet demand if orders are placed.

Some suppliers have faced financial difficulties or have withdrawn from the market which has reduced capacity. This includes the announcement by Kvaerner that it was withdrawing from offshore wind to focus on the oil and gas sector, the closure of Cuxhaven Steel Construction and the financial restructuring of Smulders and SIAG after they both filed for administration in 2012.

In part, these problems have been blamed on the contractual arrangements currently being used by many developers (see below).

Early commitment by developers may be needed if production capacity is going to be ready to meet demand. Assuming the availability of a suitable site with planning consent, industry feedback is that the lead time for a new production facility from FID is about 18 months with a further 12 months to ramp up to full production. This could represent a challenge for developers who are unlikely to be able to give full commitment to suppliers before their own FID for a given project. This issue may be addressed by some form of alliancing or framework agreement to give suppliers the opportunity to make some progress before receiving an order.

Investment status

It is proving difficult for companies to invest based on the uncertain market opportunity available. The high investment required for a foundation production facility means it is unlikely that a prospective supplier will be able to invest without two or more firm orders.

There is currently uncertainty over which projects will progress, which makes it difficult for any investor to forecast the scale of the market for their foundation concept with any certainty. This is further complicated by the increased industry expectation of using XL monopile designs on sites that would have previously been regarded as too deep.

Synergy with parallel sectors

The design and fabrication technology has been derived from other sectors. All of the foundation types that are being used or considered in offshore wind have been used at some scale in the oil and gas industry already, though generally under quite different loading patterns. Many of the companies currently producing jackets and tripods are also active in these sectors.

The critical difference compared with oil and gas that is becoming more pronounced is the need to refine the design and fabrication of offshore wind structures to enable efficient serial manufacturing.

Technology may also be adapted from parallel industries that have developed serial- or mass-production technologies such as the automotive, ship building or pipeline sectors. In this case, the major obstacle is to justify capital intensive equipment on relatively low volumes in an uncertain market (both in terms of scale and technology choice), especially due to the large size of components to be handled.

LCOE reduction due to technology development

Innovations in manufacturing to reduce costs are well understood. Several fabricators have well advanced plans to invest in serial manufacturing facilities. The high cost and uncertain market means that the investment has not been forthcoming and there is a danger that the LCOE benefits do not materialise through lack of competition between players that have invested.

Cost reduction is currently focused on achieving marginal gains through more streamlined manufacturing. Although there has been a strong focus in the industry on developing new and innovative foundation designs to achieve cost reductions, the gains that have been made so far have been through investment in facilities that have allowed easier handling of foundation designs and more streamlined production flow between production stages.

The lack of demonstration sites for deep water foundations has the potential to restrict the introduction of new designs. With much of the effort of the offshore wind industry being focused on the demonstration and commercialisation of “next generation” turbines, there is a risk that novel foundation concepts are overlooked and are subsequently unavailable when market demand increases.

The two flagship demonstration projects in the UK (the European Offshore Wind Deployment Centre at Aberdeen Bay and the Blyth Offshore Wind Demonstration Project) are both delayed, and plans unveiled by The Crown Estate for a demonstration licensing round are unlikely to be realised in time for demonstration to be completed in time for early Round 3 projects. This is also the case for demonstration projects in France, the Netherlands and Germany.

Through its Scottish Innovative Foundation Technologies (SIFT) Fund, Scottish Enterprise is funding foundation projects for water depths of greater than 30m, which may open up opportunities for demonstrating novel designs at commercial projects. Two foundation designs supported through the Carbon Trust's OWA are being demonstrated as met mast foundations, although further demonstration with a turbine will be necessary before large-scale commercial use. Through a Department of Energy competition in the USA, three out of seven combinations of offshore turbines and foundations are also likely to be demonstrated, but probably not before 2017.

There has been slow progress in solving the problem of piling noise. This is discussed in Section 7.6.

Technology shift

The number of units required for larger projects means new manufacturing processes are required. As well as the industry drive to reduce costs in jacket and tripod production, the trend towards larger projects with 80 or more units means that suppliers are going to need to set up more advanced factory production lines to achieve the required throughput.

This requires a change from bespoke manufacture to production-line culture for companies with a background in oil and gas one-off fabrication, and will require investment in tooling and jigs and more detailed planning to ensure that bottlenecks in the production process do not cause costly overruns in project schedules.

LCOE reduction due to supply chain development

The standardisation of tube sizes enables lower cost manufacture. A number of jacket designs under development use standard tubes. This potentially lowers the cost of steel although the steel mass may be greater.

There is slow progress in updating design standards that could reduce costs. Current standards are more relevant to the oil and gas industry and relate to permanently manned structures. Standards set at a level appropriate to unmanned structures are anticipated to have benefits for offshore wind.

Contractual arrangements have exposed suppliers to risk. The value of 100 jacket or tripod foundations is likely to be about £300 million and contracts have had strong penalty clauses, for example, for late delivery. Competitive bidding in an industry with intermittent demand can lead to narrow margins. The risk that this places on manufacturers has been a factor in the difficulties faced by some companies in recent years. Industry feedback is that this relatively confrontational approach is not seen so much in some other sectors where alliances and collaboration are used as ways to reduce cost by better managing risk.

There is increasing interest in supply from low cost countries. Jackets and tripod fabrication have a higher labour content than monopiles, which makes supply from low cost countries more attractive. This is particularly likely where there are strong heavy engineering sectors such as shipbuilding. Despite this, the amount of deck space needed to transport space frames may result in little cost benefit and there is a higher risk to project schedules if any problems arise. Solutions may include the transport of partially assembled sections or designs that enable more efficient use of deck space.

The market may be too small to support the competitive supply of low cost jackets. If fewer than three or four fabricators invest in serial manufacturing capacity, the resulting cost reductions will not be fully passed onto their customers unless other technologies are competitive.

Production capacity constraints are likely to mean that split sourcing will be required for larger projects. The largest project that has not used monopiles so far is Global Tech 1 in Germany.[23] In this case, the developer split the contract of 80 tripods between three fabricators. The largest single contract for non-monopile foundations to date is 48 jackets with Kvaerner supplying the German Nordsee Ost wind farm.

We may see that developers with projects requiring more than 50 non-monopile foundations will use two or more suppliers, with related additional contracting resource and quality management resource required. For larger projects, industry feedback is that this may be an opportunity for developers to stimulate competition by split-sourcing a proportion of the project and retaining a fraction that will be awarded to the best performing supplier.

[23] The Bard Offshore 1 project used 80 tripiles which were sourced internally by Bard as part of its vertical integration strategy.

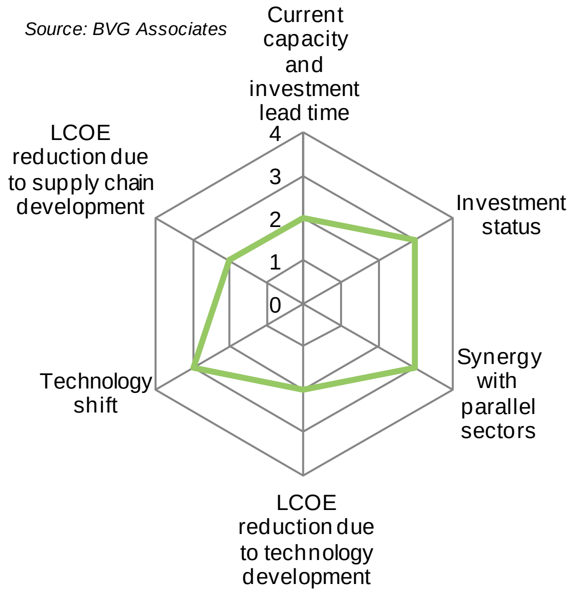

Figure 7.14 Summary of issues concerning non-monopile steel foundation supply.

Conclusion

A

This subelement has been graded amber because there is uncertainty about when the market for non-monopile foundations will reach the critical mass to justify investment in serial manufacturing facilities. Without it, manufacturing costs will remain high and developers are more likely to look to extend the use of monopiles as a solution with lower installed cost, where possible.

Actions

Increase certainty about future technology choices. Uncertainty about what foundation technology will be used is a key barrier to investment in new manufacturing facilities (as well as installation vessels, see Section 8.2). Industry-wide activity and information sharing to increase understanding of installed foundation cost for different solutions in different conditions will help narrow the current diverse range of solutions under consideration.

Provide fabricators with an early view of future demand to enable better planning. In the UK, the commitment of developers to participate in share fairs provides an opportunity to give the supply chain advance notice of their technology needs.

7.8. Concrete foundations

Concrete gravity base foundations have been used extensively in shallow, generally calm water sites in the Baltic Sea, most recently at Kårehamn. This approach has benefits, including reducing exposure to relatively volatile steel prices and removing the need for sea bed piling, which is likely to be a major planning constraint for some projects.

The design and installation method used in the Baltic Sea cannot be applied cost effectively for deeper water and harsher North Sea conditions. In order to address this issue, “next generation” concrete or concrete-steel hybrid designs have been developed. These new designs do not need the costly heavy lift crane vessels required for existing concrete foundations and for piled steel foundations.

There are two main approaches: non-buoyant designs that use a bespoke vessel to transport them to site, and buoyant designs that are towed to site with conventional tugs and ballasted to sink them to the sea bed. The non-buoyant designs have typically been designed to allow the complete installation of the turbine on the foundation at the quayside before it is delivered to site, a solution likely to take longer to commercialise but offering the prospect of greater cost savings. Neither approach has yet been applied at full scale in offshore wind.

Current capacity and investment lead time

There has been limited use of concrete foundations for offshore wind in the North Sea. Most concrete foundations have been produced for Baltic Sea projects with the only North Sea project being the first phase of the Belgian Thornton Bank wind farm. For the second phase, it was decided to change to jacket foundations due to the high cost of transport and installation of the concrete solutions using a heavy-lift vessel.

Figure 7.15 shows the demand for foundations where the technology choice is uncertain, much of which is likely to be met by the supply of steel foundations. Looking forward, no project developers have made a firm choice to use concrete foundations, but a number are examining possibilities thoroughly.

There is no operational manufacturing capacity for deep water concrete foundations. There are no facilities operational that are set up to supply suitable foundations in sufficient volume for a commercial wind farm. For the North Sea, in the absence of demonstrated concrete technologies, the main opportunity for concrete foundation suppliers is for projects for which monopiles are not an option, which is likely to be in water depths over 35m.

A manufacturing facility can be built quickly. Concrete foundation manufacturing facilities can be operational 12 months after FID and are not capital intensive unless investment is needed to strengthen quaysides and dredge channels. Although the land requirements of manufacturing facilities are high, a number of sites are being considered by prospective suppliers of concrete foundations. In addition, Acciona has a mobile ’floating factory’ concept for the manufacture of such structures, successfully used in other sectors.

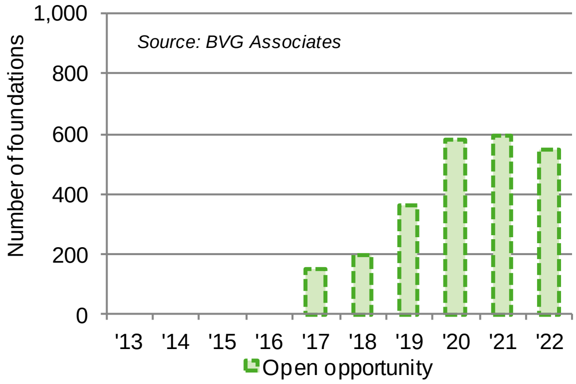

Figure 7.15 Projected demand for foundations for which the technology choice is uncertain and could be met by concrete technologies for European offshore wind to 2022 (by year of manufacture, offset from turbine installation by two years).

Investment status

Greater access to demonstration sites is needed. Investment will not be forthcoming without greater confidence that concrete provides a practical and cost effective alternative to steel designs. Industry feedback indicates that, while developers need assurance about the manufacturing and installation processes, unlike other novel technologies, there is confidence in the long term performance of concrete structures in offshore applications from other sectors.

Currently there are few dedicated offshore test sites available and efforts are focused on identifying forthcoming or operational commercial projects which could host test locations. The Crown Estate announced a leasing round in June 2013 for this purpose.

Through its SIFT Fund, Scottish Enterprise is funding foundation projects for water depths of greater than 30m, which may open up opportunities for demonstrating novel concrete designs at commercial projects.

Non-buoyant designs have a high investment hurdle for demonstration. Concepts such as those developed by Gravity Base Foundations and Strabag involve a bespoke vessel for installation. For a commercial wind farm the costs can be borne by the project but the investment for a one-off demonstration project would be high.

Synergy with parallel sectors

The technology is derived from other sectors but the ongoing benefit is uncertain. Prospective suppliers have benefitted from the technology development and supply chain logistics of concrete structures in the oil and gas industry and marine bridge building sector.

LCOE reduction due to technology development

Developments in design are ongoing. Areas of innovation include steel skirts to improve geotechnical performance and hybrid steel designs. Without opportunities for demonstration, however, these will be unavailable to the market.

Technology shift

New design and install concepts are needed for larger projects in deeper water. As discussed previously, the application of proven shallow water concrete designs to water depths over 35m for far offshore projects is not practical because of the high cost of the heavy lift vessels needed for their installation.

LCOE reduction due to supply chain development

Consortia contain large marine and civil engineering contractors. Potential concrete foundation suppliers have formed joint ventures with large marine and civil engineering contractors to allow them to offer a complete EPC solution to developers and maximise the learning from different sectors; for example, BAM Nuttall with Van Oord, Hochtief with Costain and Arup (to form Gravitas), Seatower with MT Højgaard, and Skanska with SMIT Marine Projects.

Competition between design concepts is unlikely to extend to manufacturing. If concrete concepts enter the market, it is possible that only one or two consortia deliver these. Competition is likely to come as much from steel foundations as from other concrete players and this is likely to be sufficient to reduce cost.

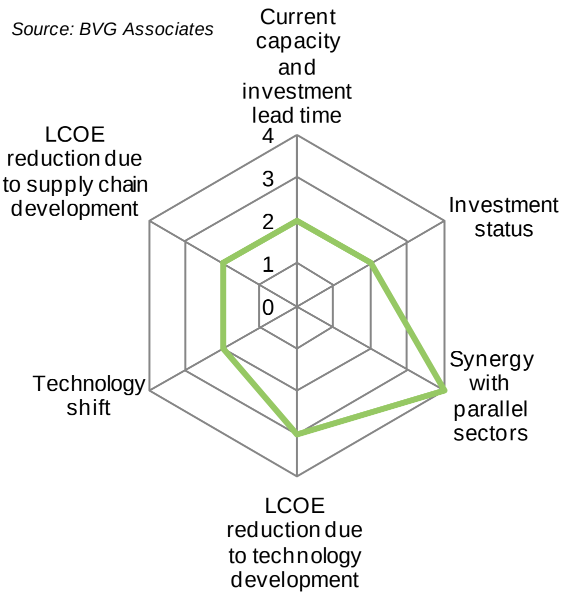

Figure 7.16 Summary of issues concerning concrete foundation supply.

Conclusion

A

This subelement has been graded amber because the slow progress in demonstrating concrete foundation concepts means that it is likely that they will not be available to be installed in quantity before 2020. Developers that prefer concrete foundations for their projects before this date, for example, because of soil conditions or constraints on piling, may have to delay the project or choose a non-optimal solution.

Actions

Early site characterisation and preliminary foundation design could give fabricators clear indicators of future demand. This action is described in Section 7.7.

More demonstration sites for deep water foundations are needed. Public sector supported programmes should prioritise deep water demonstration to enable concrete foundation suppliers to not only demonstrate the technology but also the manufacturing and installation logistics. This is particularly important for concepts that involve integrated foundation and turbine installation ("float-out-and-sink").

Table 7.6 Summary of supply chain status and conclusions on monopile foundations and non-monopile steel foundations.

Criterion	Monopile foundations	Non-monopile steel foundations
Proven capability	Ambau, Bladt, EEW, SIAG, Sif, Smulders Group	Aker Verdal, BiFab, Bladt, SIAG Nordseewerke, Smulders Group, WeserWind
Additional future capability	Dillinger Hütte, TAG Energy Solutions	Aquind (OGN Group), Crist/Bilfinger Berger, Global Energy Group, Harland & Wolff (Universal Foundation), Jade Werke, Navantia, OGN Group, Samsung Heavy Industries, Steel Engineering, STX Europe, TAG Energy Solutions, ThyssenKrupp Mannex
Current capacity and investment lead time	There is sufficient supply of monopiles with a diameter of 7.5m or less There is limited production capacity for monopiles with a diameter greater than 7.5m	There is sufficient capacity at the moment but proposed investment plans need to be realised Some suppliers have faced financial difficulties or have withdrawn from the market which has reduced capacity Early commitment by developers may be needed if production capacity is going to be ready to meet demand
Investment status	There are well developed plans under consideration	It is proving difficult for companies to invest based on the uncertain market opportunity available
Synergy with parallel sectors	Monopile fabrication facilities can also supply pin piles for jackets and tripod foundations Thick steel plate is also manufactured for other sectors	The design and fabrication technology has been derived from other sectors
LCOE reduction due to technology development	Progress is underway in developing new design standards and improved design processes There has been slow progress in addressing the issue of piling noise	Innovations in manufacturing to reduce costs are well understood Cost reduction is currently focused on achieving marginal gains through more streamlined manufacturing The lack of demonstration sites for deep water foundations has the potential to restrict introduction of new designs There has been slow progress in solving the problem of piling noise
Technology shift	Deeper water constrains the cost effective application of monopiles Mitigation of piling noise may be required due to cumulative impacts of large projects	The number of units required for larger projects means new manufacturing processes are required
LCOE reduction due to supply chain development	There are few suppliers of monopiles with a diameter greater than 7.5m	The standardisation of tube sizes enables lower cost manufacture There is slow progress in updating design standards that could reduce costs

Criterion	Monopile foundations	Non-monopile steel foundations
		Contractual arrangements have exposed suppliers to risk There is increasing interest in supply from low cost countries The market may be too small to support the competitive supply of low cost jackets Production capacity constraints are likely to mean that split sourcing will be required for larger projects
Conclusion[1]	G	A
Actions		Increase certainty about future technology choices Provide fabricators with early view of future demand to enable better planning

Table 7.7 Summary of supply chain status and conclusions on concrete foundations.

Criterion	Concrete foundations
Proven capability	None for water depths greater than 25m
Additional future capability	BAM/Van Oord, Concrete Marine Solutions, Gravitas, MT Højgaard/Seatower, Skanska/SMIT/Grontmij, Strabag, Vici Ventus, Vinci, Xanthus
Current capacity and investment lead time	There has been limited use of concrete foundations for offshore wind in the North Sea There is no operational manufacturing capacity for deep water concrete foundations A manufacturing facility can be built quickly
Investment status	Greater access to demonstration sites is needed Non-buoyant designs have a high investment hurdle for demonstration
Synergy with parallel sectors	The technology is derived from other sectors but the ongoing benefit is uncertain
LCOE reduction due to technology development	Developments in design are ongoing
Technology shift	New design and install concepts are needed for larger projects in deeper water
LCOE reduction due to supply chain development	Consortia contain large marine and civil engineering contractors Competition between design concepts is unlikely to extend to manufacturing
Conclusion[1]	A
Actions	Early site characterisation and preliminary foundation design could give fabricators clear indicators of future demand. More demonstration sites for deep water foundations are needed

8. Installation and commissioning

Installation and commissioning covers work on all balance of plant as well as turbines. It can be broken down into the following areas: transport of completed assemblies from manufacturing facilities; port construction facilities; foundation installation; turbine installation and commissioning; array and export cable installation; offshore substation installation; and sea-based support. Of these, this section will focus on the following, most significant areas:

Installation ports. While a number of ports have been used to date for offshore construction, the scale of Round 3 developments will in some cases require more ports with larger lay-down areas.

Foundation installation. This includes transport to the wind farm site and installation, including any piling, scour protection, transition piece installation and grouting. The section focuses on steel foundations as it is likely that future concrete foundations will be installed either with standard tugs or with bespoke vessels supplied by the foundation manufacturer.

Turbine installation. This includes transport to the wind farm site and the installation and commissioning of turbines. It includes the work of the turbine manufacturer during installation.

Subsea cable installation. This includes transport and laying of both array and export cables and their termination in turbine electrical panels and at the offshore substation.

8.1. Installation ports

The availability of waterside (port) infrastructure is a prerequisite for much of the necessary new coastal manufacturing, assembly and installation infrastructure to deliver the European demand projection in Section 3. Facilities may either be developed for manufacturing and installation activities or as standalone installation facilities. The term installation port is used here to describe the location where the main wind farm components are consolidated and pre-assembly completed before being loaded onto an installation vessel. The reason for setting up an installation port (as opposed to taking components straight from their manufacturing location to site) is to lower the logistical risks (and in some cases, costs) of a project by storing components closer to the wind farm site. Since the UK's supply of finished wind farm components is still relatively low, there is a greater need for construction ports in UK than in Germany, Denmark and France.

Previous gap analyses have been primarily concerned with the availability of UK ports. They have also highlighted the fact that most UK ports are operated privately whereas many Continental ports are in public ownership so that their investment decisions often consider the wider local economic benefits of a project, as well as the direct port revenue. This analysis will take a broader view, considering whether the availability of construction ports across Europe will constrain the delivery of offshore wind projects.

Current capacity and investment lead time

There is sufficient capacity in Europe as a whole. A number of offshore wind companies have signed agreements with ports. In the UK, there has been progress in developing installation capacity at Belfast, Great Yarmouth, Harwich, Hull, Merseyside, Mostyn and Teesside. There have also been developments in Belgium at Ostend, in Denmark at Esbjerg and in the Netherlands at Eemshaven and Vlissingen. Additional capacity from integrated manufacturing facilities will be forthcoming if the market grows in line with the projected installed capacity used for this analysis.

Logistics will be inefficient without investment in integrated port facilities for turbine assembly and installation. The use of a standalone installation port is a pragmatic decision based on the risks and costs associated with the transport of components from manufacturing facilities to the wind farm site. Project logistics are most efficient if these risks and costs are lowered by the use of an installation port as near as possible to the wind farm. In Europe there are currently no manufacturing locations from which components can be transported directly to site for North Sea projects. German North Sea projects using REpower and Areva turbines have either used port space elsewhere in Bremerhaven or at Eemshaven for final assembly activities.

Investment status

Investment in coastal facilities is underway. There are no known plans outstanding for new standalone installation ports. Alstom's integrated facility at St Nazaire is due to be operational from 2015. Other investments by turbine manufacturers are pending FID, which will follow from a sufficient pipeline of orders or sufficient confidence in the growth of the market.

There is a weak business case for investment for a single project. The cost of upgrading a port to be suitable as an offshore wind farm installation facility is often significant. For example, the investment in DONG's facility in Belfast was reported to be £50 million. A business case based on a single project is therefore likely to be untenable without co-investment by a public body, developer or turbine manufacturer. A stronger business case can be made if the port will be used for a number of projects or if the case considers the wider economic impacts or synergies with other applications.

Investment cannot be made within project timescales. The benefit of an installation port may only be established once the turbine has been chosen. If the selected turbine manufacturer has an integrated manufacturing and installation port that is well positioned to supply the wind farm site directly, there is no benefit from a dedicated construction port. By the time the turbine is chosen, however, the lead time for consenting, investment decision and construction is likely to be too long to be accommodated with the project schedule.

Synergy with parallel sectors

There is significant demand from other port-related sectors. Waterside infrastructure is in demand from a number of sectors. For ports with long quaysides and sufficient draft for large vessels, competition is strong from traditional port traffic, which may generate higher revenue from relatively small areas of land by vessel movements, bringing cargo across the quays, storing it temporarily in the port and then moving it away as soon as possible. Housing, leisure and other applications also compete strongly at some locations.

LCOE reduction due to technology development

Developments in port logistics have been incorporated into plans for integrated manufacturing and installation facilities. As discussed above, efficient logistics can best be achieved by the development of integrated manufacturing and construction facilities. The concept is well developed and available to the market, though there are likely to be further innovations to improve the use of limited port space during construction.

Technology shift

Future projects may need more land for installation. For projects further from shore in harsh conditions, larger lay-down areas may be required to mitigate weather risk, by being able to better utilise good weather conditions by having sufficient stock.

The minimum size for a Round 3 project is likely to be 500MW. Although 5-7MW turbines require less space per MW than 3-4MW turbines, depending on the installation strategy, the demand for port space may be higher for Round 3 projects than for Round 2 projects.

LCOE reduction due to supply chain development

Offshore wind clusters offer cost reductions. Large sites offer benefits in terms of reduced logistics costs and generate a "gravity" which attracts more suppliers and supports training and public investment.

Competition between ports would also reduce costs, but there is a relatively small demand and it is hard to sustain multiple players that end up with empty space due to loss of orders.

Source: BVG Associates

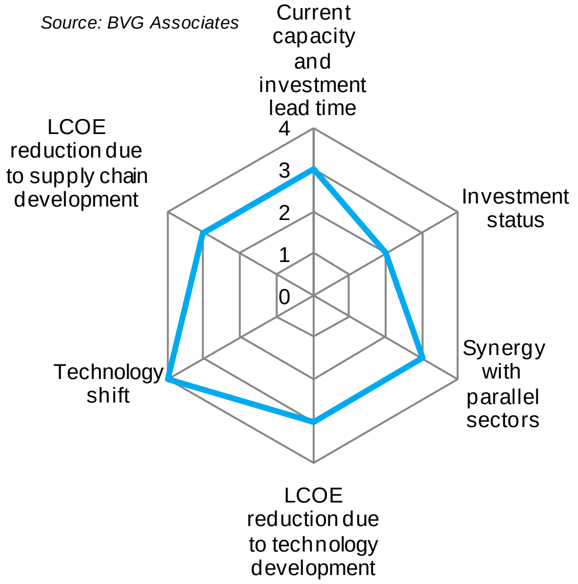

Figure 8.1 Summary of issues concerning installation port supply.

Conclusion

G

Installation ports have been graded green because project delivery is unlikely to be constrained by a lack of availability and, if the market grows as projected, investment in integrated manufacturing and installation facilities is likely. For projects a long distance from manufacturing locations, the experience has been that the industry has been able to secure the port space it needs. Ongoing work is needed to communicate the opportunity to ports and promote suitable sites to wind industry customers.

8.2. Foundation installation

There are two main vessel options for steel foundation installation: a jack-up vessel, most of which are also used for turbine installation; or a floating vessel, often with foundations fed by a separate floating vessel. In establishing the sufficiency of supply of steel foundation installation vessels, it is useful to divide the foundations into three groups:

- Standard monopiles
- XL monopiles, and
- Jackets or tripods (space frames).

In Section 7.6, an XL monopile is defined as having a diameter greater than or equal to 7.5m. For installation, the key parameter is the monopile mass which determines whether the crane capacity of an installation vessel is sufficient to lift the monopile. For a given turbine, monopile diameter, thickness and length varies according to the water depth and sea bed conditions and there is therefore no simple correlation between monopile diameter and mass.

The lifting capacity of a crane diminishes as the lifting radius increases so we will assume for this study that a crane with a 1,200t capacity will be unable to install a monopile with a mass greater than 1,000t. For the purpose of this section of the analysis, an XL monopile is defined as requiring a crane with a lifting capacity greater than a 1,200t.

For a jack-up vessel, its efficiency for space frame installation depends on the number of foundations it can fit on its deck as this will affect the time that the vessel spends in transit. This is because the use of a feeder vessel is unlikely to be economic because the charter rate of a jack-up feeder vessel would be higher and the component transfer longer because of the jacking up time. The transfer of turbine components from a floating feeder vessel to a jack-up is generally considered impractical.

An optimal jack-up for space frame installation is considered to be one that has a crane with a 1,000t capacity or higher and can carry at least five foundations. The optimal number of foundations for a vessel to carry will depend not only on the cost of the vessel but also the time needed to move a number of foundations into place ready for loading at the quayside in the period while the installation vessel is offshore.

A floating vessel has less need for deck space as foundations can be readily transferred from a floating feeder vessel or floated out with tugs. Space frames have been installed using the sheerleg crane vessel Rambiz but its sensitivity to weather (maximum significant wave height for installation is 0.75m) means that it cannot be considered to be an optimal solution unless it is brought in for short projects or to complement other vessels during the summer months on benign sites. It is assumed that monopiles are not installed from a sheerleg crane vessel.

Suction buckets are an alternative method of sea bed connection to piles. These can be used for both space frames and monopods. Similar vessels can be used for both piling and suction buckets.

Concrete foundations for shallow water projects have also been installed using a sheerleg crane vessel. Next generation concrete foundations have a mass that exceeds the capacity of sheerleg cranes and will either be floated out using standard tugs or a bespoke vessel provided by the manufacturer. There are therefore no distinct issues surrounding vessel supply for concrete foundations.

Section 7.6 presented an uncertain demand for different foundation technology and that there was an “open opportunity” which could be XL monopiles, space frames or concrete foundations. The analysis presented here mirrors this approach.

Current capacity and investment lead time

There is sufficient capacity for standard monopile installation vessels. Future demand for standard monopile installation can easily be met as over 15 suitable vessels are currently operating, though many are also used for turbine installation.

The capacity to install XL monopiles is limited. There are four proven offshore wind installation vessels with sufficient crane capacity, with one new build vessel ordered. Figure 8.2 shows that seven vessels would be needed in 2022 if the open opportunity for foundations is met fully by XL monopiles. The lead time for a new vessel is about three years from investment decision. Figure 8.3 shows that FID may be needed for two such vessels in 2016 should the open foundation opportunity be fully met by XL monopiles, given that these vessels may also be used for turbine installation.

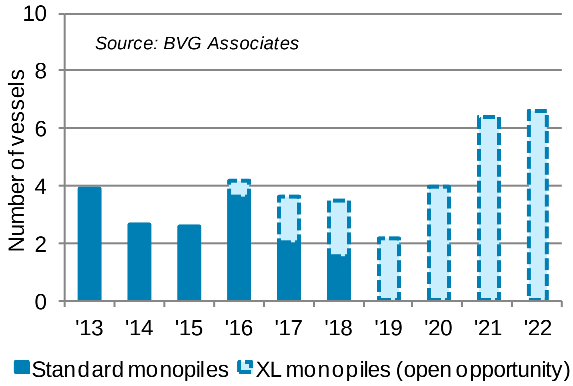

Figure 8.2 Projected demand for monopile foundation installation vessels for European offshore wind to 2022 (by year of foundation installation, offset from turbine installation by one year). This assumes that open foundation opportunity is fully met by XL monopiles.

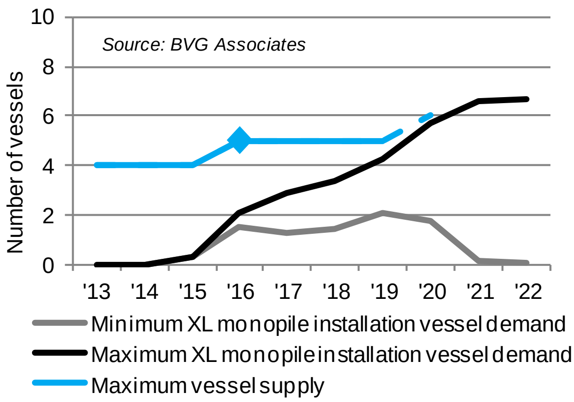

Figure 8.3 Supply and projected demand for installation vessels that can install XL monopiles for European offshore wind to 2022 (by year of foundation installation, offset from turbine installation by one year). This assumes that open foundation opportunity is fully met by XL monopiles.◆ indicates the point at which investment decision is needed to achieve the increase in the number of vessels shown.

There is insufficient capacity for optimised space frame installation vessels. The peak annual demand for non-monopile installation vessels between now and 2022 is between two and nine, depending on how much of the foundation open opportunity is met by space frames (see Figure 8.4). Considering space frame foundations specifically, there are currently 13 vessels capable of installing, with a further two under construction. Only two of these vessels meet the criteria for an optimal vessel, however, and neither of these are jack-ups. The largest jack-up vessel can carry only three space frames and therefore does not meet the criterion for an optimal vessel. Figure 8.5 presents the same demand data as Figure 8.4 but models the demand for vessels that can optimally install space frames (assuming that the optimal vessels can install at 75% of the overall fleet average time). It shows that the two vessels, those of Seaway Heavy Lifting, are sufficient until 2015 provided they are not used for monopile installation or in other sectors. The analysis shows that without investment in 2014 in three optimal space frame installation vessels, supply will be constrained.

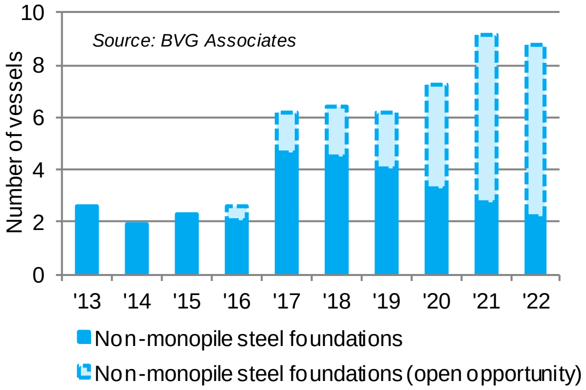

Figure 8.4 Projected demand for non-monopile steel frame foundation installation vessels for European offshore wind to 2022 (by year of foundation installation, offset from turbine installation by one year). This assumes that open foundation opportunity is fully met by steel space frames.

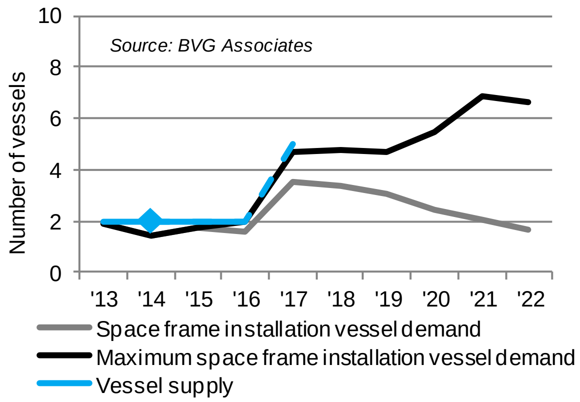

Figure 8.5 Supply and projected demand for vessels that can optimally install space frames for European offshore wind to 2022 (by year of foundation installation, offset from turbine installation by one year). This assumes that open foundation opportunity is fully met by space frames and that they are installed using an optimal vessel. ◆ indicates the point at which investment decision is needed to achieve the increase in the number of vessels shown.

It should be noted that all space frame installations for commercial projects to date has been undertaken with the sheerleg *Rambiz* or a jack-up vessel. These may have been the least costly option for developers at the time of contracting but are not seen as optimal looking forward.

Investment status

Investment continues in dual purpose installation vessels. Seajacks has recently commissioned the construction of the jack-up vessel *Scylla*, which could be used for turbine, monopile and space frame installation.

Investment in foundation installation vessels depends on overall market certainty as well as increased certainty about foundation technology trends. Although our analysis indicates a deficit in specialist foundation installation vessels, overall uncertainty in the market is compounded by uncertainty in foundation technology trends. There are well-developed installation vessel concepts, which could still be ordered in 2013.

Synergy with parallel sectors

Floating heavy lift vessels have few applications in other sectors. The heavy lift vessels in the global fleet are used primarily in the container and oil and gas industries. Typically, they have higher lifting capacities than those needed in offshore wind and any heavy lift vessels built with crane capacities at about 1,500t may have a limited market outside offshore wind. This weakens the investment case for optimal offshore wind foundation installation vessels.

Vessels suitable for XL monopile installation may also be used for turbine installation. Figure 8.3 shows that the potential supply of vessels for XL monopile installation is sufficient until 2019 if none are used for other operations. Although these vessels represent a quarter of the fleet available for turbine installation, they are among the largest vessels in the available fleet and could be in demand in particular for turbine installation projects with long transit distances.

LCOE reduction due to technology development

There is progress in developing new concepts for the efficient installation of space frames. There are a number of well-developed specialist space frame installation concepts but no consensus on the optimal approach. MPI Offshore has developed a jack-up that enables five to seven space frames to be loaded on a skidding system with a large deck area that allows the movement of the foundations. Jumbo Offshore has designed a floating vessel, also with a skidding system. A partnership between A2SEA and Teekay has also developed a design for floating installation vessel that can carry five to seven space frames. New concepts have largely focused on space frame installation. An exception is a monopile installation vessel designed by naval architects Dutch Offshore Innovators.

There is a limited trend towards floating vessels for foundation installation. Floating vessels offer the prospect of faster installation with less vessel downtime as they can operate at a significant wave height (Hs) up to 2.5m. The jacking up and down processes can take six and three hours respectively and is generally not possible at 1.5m Hs or above. The use of floating vessels also provides the option of using low cost feeder vessels. Suppliers have reported that their customers prefer the flexibility that jack-ups provide by being able to undertake foundation and turbine installation, which may be a factor in the lack of investment in floating vessels for foundation installation only.

Technology shift

New approaches to mitigate piling noise are under development. As discussed in Section 7.6, the mitigation of piling noise has been a significant obstacle for German projects. An increase in the size and number of developments in the North Sea has heightened concerns that the impact of piling noise on sea mammals will become an issue for UK projects. There is concern that the mitigation strategies trialled so far have failed to reduce noise sufficiently, that trials have been mostly undertaken in shallow water, and that the associated costs of mitigation are high. This issue is further discussed in Section 4.4.

LCOE reduction due to supply chain development

There are a significant number of suppliers in the market. There have been several new entrants to the offshore wind installation market over the past two years although not all are capable of installing XL monopiles or providing an optimal option for installing space frames. There is likely to be some consolidation of the market due to the oversupply of turbine installation vessels. This consolidation is likely to lead to operators with larger fleets which will drive efficiencies in delivery.

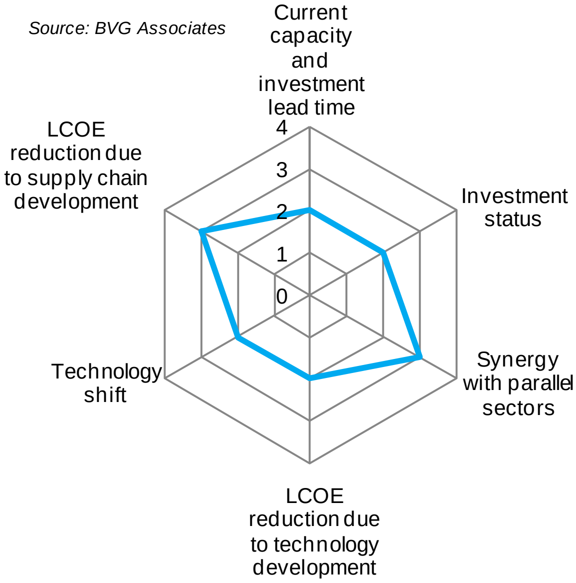

Figure 8.6 Summary of issues concerning foundation installation vessel supply.

Conclusion

R

This subelement has been graded red because a shortage of vessels is likely without new investment because the few vessels with the crane capacity are also likely to be used for either turbine installation or space frame installation. In addition, there has been little progress in developing specialist space frame installation vessels that provide the cost savings sought by the industry.

Actions

Earlier communication by developers with the supply chain about foundation technology choices would support the business case for the construction of new foundation installation vessels. Over the last few years, vessel operators have shown their willingness to invest to meet the needs of the offshore wind market when they have been given clear indications of future technical requirements.

A joint industry project could define the optimal foundation installation strategies for a range of sites. The work could include a holistic analysis of foundation supply and installation costs and in the UK would support the supply chain plans now required for the FID-enabling programme and CfD applications.

Table 8.1 Summary of supply chain status and conclusions on installation ports and foundation installation.

Criteria	Installation ports	Foundation installation
Proven capability	Belfast, Bremerhaven, Dunquerque, Esbjerg, Eemshaven, Great Yarmouth, Grenaa, Harwich, Mostyn, Ostend, Ramsgate, Vlissingen	A2SEA, Ballast Nedam, Geosea, HGO Infrasea Solutions, MPI Offshore, RWE OLC, Scaldis, Seajacks, Seaway Heavy Lifting (Subsea7), Swire Blue Ocean, Workfox
Additional future capability	Cherbourg, Dundee, Holyhead, Hull, Killingholme, Le Havre, Leith. Sheerness	Jumbo Offshore, Saipem, Technip, Van Oord, Wolker Vessels
Current capacity and investment lead time	Logistics will be inefficient without investment in integrated facilities for turbine manufacture and installation Logistics will be inefficient without investment in integrated port facilities for turbine assembly and installation	There is sufficient capacity for standard monopile installation vessels The capacity to install XL monopiles is limited There is insufficient capacity for optimised space frame installation vessels
Investment status	Investment in coastal facilities is underway There is a weak business case for investment for a single project Investment cannot be made within project timescales	Investment continues in dual purpose installation vessels Investment in foundation installation vessels depends on overall market certainty as well as increased certainty about foundation technology trends
Synergy with parallel sectors	There is significant demand from other port-related sectors	Floating heavy lift vessels have few applications in other sectors Vessels suitable for XL monopile installation may also be used for turbine installation
LCOE reduction due to technology development	Developments in port logistics have been incorporated into plans for integrated manufacturing and installation facilities	There is progress in developing new concepts for the efficient installation of space frames There is a limited trend towards floating vessels for foundation installation
Technology shift	Future projects may need more land for installation	New approaches to mitigate piling noise are under development
LCOE reduction due to supply chain development	Offshore wind clusters offer cost reductions	There are a significant number of suppliers in the market
Conclusion[1]	G	R ↓
Actions		Earlier communication by developers with the supply chain about foundation technology choices would support the business case for the construction of new foundation installation vessels. A joint industry project could define the optimal foundation installation strategies for a range of sites.

8.3. Subsea cable installation

Cable installation can be undertaken using either a single lay and burial process with a plough or a separate surface lay with subsequent burial, using a jetting tool operated from a remotely operated vehicle (ROV). Cable installation contractors say that both approaches have their advantages, depending on site conditions. Feedback from industry is that the sea bed for many Round 3 projects will be too hard to bury using a jetting tool.

Array cable laying is considered a more technically challenging process than export cable-laying due to the large number of operations that are involved and the cable pull-in interface at each foundation. Export cable-laying vessels tend to be larger with cable carousels with a higher capacity to enable a single length of cable to be laid where possible.

Cable installation has long been an area of concern for the industry due to the number of problems that have been encountered, and developers have cited the lack of credible suppliers as the greatest source of problems. A constraint is the lack of availability of experienced crews to execute the works. Installation contractors report that many problems could have been avoided with their early engagement in a project and that inadequate sea bed surveys and inflexible burial requirements have added risks to projects.

Both anchored barges and specialist dynamic positioning (DP) vessels have been used for offshore wind projects to date. The latter are more costly but they can work faster and have a shorter mobilisation and demobilisation time.

Pairs of single core cable HVDC cables can be laid simultaneously or separately. For simultaneous burial using a plough, the cables need to be bundled and this is understood to increase risk of damage to the cable.

Current capacity and investment lead time

For array cables, there is no constraint on vessel availability but few vessels have been optimised for offshore wind. Vessel availability is not critical as, in practice, there are a large number of vessels that could be used for array cable installation. The choice of vessel is often a compromise between cost and availability.

There are enough vessels if developers can be flexible over the timing. There is often an overlap in the schedules of projects, so it may appear to a developer that there is a shortage.

For export cables, there are few ocean-going vessels but supply is unlikely to constrain project delivery. Export cable installation vessels are typically larger than array cable laying vessels, with carousels that can carry 70-100km of cable. Many of these were built for the construction of interconnectors. As Figure 8.7 shows, only three vessels will be needed for the next decade using the projected capacity from Section 3. This demand should be met without difficulty although some vessels of the interconnector fleet that could be used in offshore wind are reaching the end of their life and may need replacement or significant refurbishment in the next decade.

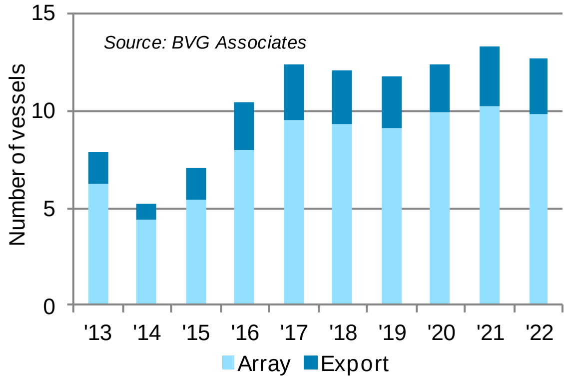

Figure 8.7 Projected demand for subsea cable installation vessels for European offshore wind to 2022 (by year of cable installation, offset from turbine installation by one year).

Investment status

There is little known interest in specialist new build capacity solely for the offshore wind industry. New investments have been made in trenching and burial equipment but new-build cable-laying vessels, such as Jan de Nul's *Willem de Vlamingh* built in 2011 and Van Oord's new build vessel due to enter service in 2014, have been designed to meet the needs of multiple sectors.

Synergy with parallel sectors

Cable-laying vessels can also be used in oil and gas, telecoms, interconnector, pipeline and umbilical markets. This has the positive effect of ensuring that the available fleet is potentially large but also means that the vessels to do not closely match the needs of the offshore wind industry as the optimal vessel specification for each sector varies.

It also means that there is competition from other sectors. Vessels suitable for offshore wind can be engaged in the oil and gas industry and, if so, their vessel rates will increase if there is demand from that sector.

Capacity for export cable installation may be affected demand for interconnector projects.

LCOE reduction due to technology development

There has been progress in optimising array cable installation. Problems in installing array cables persist where the work has critical interfaces with cable supply and foundation design. There is joint industry work to address this issue: DNV KEMA is leading a joint industry project scheduled for completion in December 2014; and the Carbon Trust has held a series of workshops to explore and promote best practice.[24] Work is also being taken forward by the Carbon Trust OWA into J-tube-less entry systems.[25]

There has been some progress in reducing weather downtime in array cable installation. A frequent limiting step is crew access to the transition piece to perform tests and complete terminations. Any technologies that improve access or reduce the need to access the transition piece will benefit projects. Innovations supported by the Carbon Trust's OWA are expected to reduce array cable installation downtime due to weather.

At the Dan Tysk, project, the contractor Van Oord chose to use an accommodation vessel fitted with a motion compensated bridge to provide access to the transition piece. For any project a balance must be struck between the cost of the access system, which can be £10,000 a day, and the risk of downtime using conventional access using a crew transfer vessel.

Some developers are adopting a risk-based approach to cable burial. Installation contractors have reported that developers historically have been unwilling to be flexible about cable burial depths until they are faced with cost and programme overruns. As project managers have become more experienced, there is evidence they are becoming more pragmatic in seeking minimum lifetime cost solutions.

Technology shift

Sites further offshore will preclude the use of cable barges other than for inshore export cable laying and storage. Cable-laying companies report that anchored barges are considered unsuitable for working on Round 3 sites due to their slower transit times, lower freeboard (the height of the deck above the water level), lack of manoeuvrability, the time needed to shift anchors during the laying process and the increased distances to sheltered water. Barge operations are also more sensitive to the weather and there are more safety considerations using barges further offshore.[26]

Far offshore projects need different personnel transfer systems. Conventional access from crew transfer vessels will not be suitable for future projects further from shore due to increased probability of severe sea states.

LCOE reduction due to supply chain development

There is a trend away from small operators. Offshore cable installation has been associated with a number of insolvencies, with Subocean the most recent high profile casualty in 2011. Developers have been concerned that installation contractors have typically been small companies that took on too much risk. The situation here has improved. Global Marine Energy was acquired by Prysmian in 2012 and larger companies such as Technip and Reef Subsea have now also entered the market.

There is likely to be a trend towards consolidated supply and install packages. Industry feedback indicates that, because a number of contractors specialise in array or export cable-laying and some undertake burial only, a widespread shift to supply and install packages may risk lower competition in the market to balance improvements in reducing the number of across-contract interfaces.

The industry shows signs of maturity and price is less commonly the dominant factor in contracting. Despite concerns from some installers that price still solely determines the choice of contractor, developers have learnt from previous projects and there is an increased focus on performance which should subsequently reduce risks and therefore overall costs.

[24] *Subsea cable risks in offshore Windfarms: Joint Industry Project (JIP) CableRISK*, www.dnvkema.com/innovations/wind-energy/cablerisk.aspx, last accessed July 2013 and *Offshore Wind Accelerator: Driving down the cost of offshore*, Carbon Trust, available online at www.carbontrust.com/media/105326/cable_presentation-jm-28march2012-v2.pdf, last accessed July 2013.

[25] *Wood Group Kenny awarded carbon trust offshore wind turbine contract*, 28 February 2013, available online at www.woodgroupkenny.com/press-releases/Wood-Group-Kenny-Carbon-Trust-280213.pdf, last accessed July 2013.

[26] *Submarine cables and offshore renewable energy installations*, RedPenguin for The Crown Estate, April 2012, available online at www.thecrownestate.co.uk/media/313713/submarine_cables_and_offshore_renewable_energy_installations_proximity_study.pdf, last accessed July 2013.

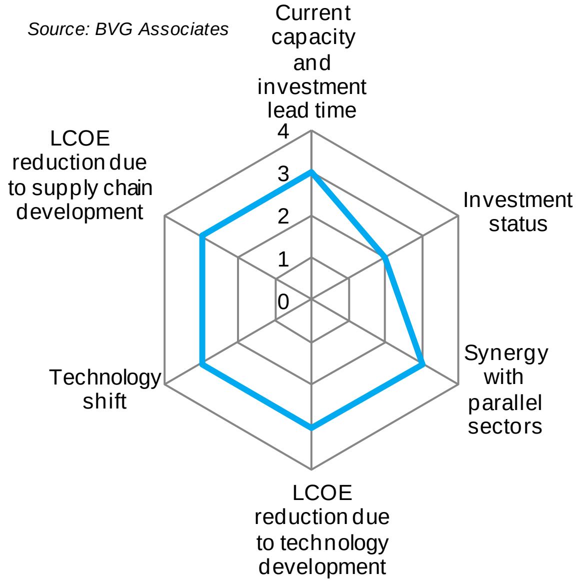

Figure 8.8 Summary of issues concerning subsea cable installation vessel supply.

Conclusion

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This subelement has been graded green because the problems faced by the industry are understood and being collectively addressed. Greater experience within developers means they are becoming more pragmatic on burial depths and there is an increased focus on through-life cost. While investment in specialist offshore wind subsea cable installation vessels has not been forthcoming, sufficient vessels are likely to be available from other sectors. The market at its projected size is likely to remain too small to make a strong business case for specialist offshore wind vessels.

8.4. Turbine installation

Turbine installation on all existing commercial-scale projects to date has been undertaken with a jack-up. In early projects, a number of self-propelled jack-ups, leg-suspended vessels (such as A2SEA's *Sea Power*) and general purpose jack-up barges were employed. These vessels are generally unable to operate in water depths greater than 25m and only have deck capacities for a small number of turbine component sets. For projects built since 2010, most developers have used vessels purpose built for offshore wind.

There is an operational balance to be achieved between assembling as much as possible onshore and having fewer but more complex offshore operations, and continuing with offshore operations but with simpler lifts. Current practice for Siemens and Vestas is to assemble the tower onshore and fix the hub to the nacelle. These items are transported along with individual blades in a rack for final assembly offshore. Other turbines from Areva, Bard and REpower have had rotors fully assembled and then installed in a single lift offshore. The Siemens and Vestas solution is likely to become the norm provided that a solution can be found to the problem of rotating a direct-drive or mid-speed turbine offshore in order to be able to easily mount blades.

Current capacity and investment lead time

There is a short term overcapacity in the turbine installation vessel market. The availability of specialist jack-up vessels for turbine installation was identified in the 2009 gap analysis as one of the most serious potential bottlenecks in the supply chain.[4] Since then, there has been significant investment in new vessels, with 16 entering the fleet and it is unlikely that many new vessels will be ordered in the next few years to meet the demand for turbine installation alone.

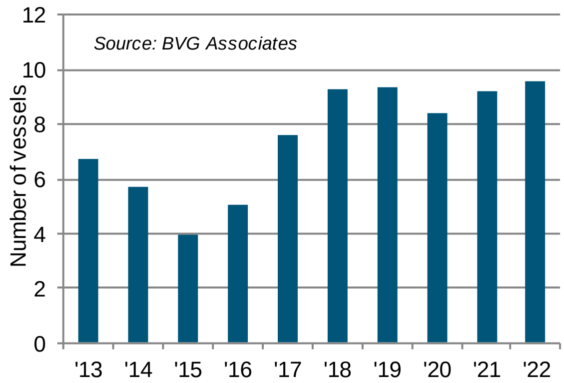

Figure 8.9 Projected demand for turbine installation vessels for European offshore wind to 2022 (by year of turbine installation).

Investment in integrated port facilities drives demand for larger vessels. As discussed in Section 6.1**Error! eference source not found.**, most investment in turbine manufacturing facilities is likely to be part of an integrated manufacturing and installation facility. Where this occurs, there will be demand for the largest jack-up vessels since transit distances will generally be longer than if a dedicated construction facility is established. These vessels will be faster (over 12 knots maximum) and be capable of carrying six or more turbines of size 6MW or larger. Currently there are four such vessels, not all of which have a track record for turbine installation as some have been deployed for foundation installation initially. A further two large vessels of this type are under construction.

Investment status

There has been significant new build in the last two years and some new capacity in construction. The investment needed for 2020 and beyond has been made or committed. Three vessels are under construction and another was commissioned in June 2013. Any further investments are likely to be made in vessels that can perform turbine installation and the installation of foundations of mass greater than 1,200t.

Synergy with parallel sectors

The potential use of installation vessels in other offshore sectors lowers investment risk. Investment in new turbine installation vessels has occurred more rapidly than other elements of the offshore wind supply chain. This reflects not only the appetite for investment in new vessels for offshore wind use but also their application globally in the oil and gas industry as accommodation vessels or offshore operations bases. For example, Master Marine commissioned two similar jack-ups, of which one was originally contracted to work at Sheringham Shoal. The vessels are now being used exclusively in the oil and gas industry.

Demand for vessels with high capacity cranes for foundation installation may limit their availability for turbine installation. Despite the higher day rates for the largest vessels, there is likely to be significant competition for these vessels, which will be intensified with demand from the offshore wind foundation installation market.

LCOE reduction due to technology development

There has been progress in increasing the maximum wind speed for blade lifts. Turbine installation with single blade lifts is considered optimal by many in the industry, with 12 hours for each turbine regularly achieved (excluding loading, transit and jacking time). The main limiting step is the blade lift, which is sensitive to wind speed and has to date often been limited to less than 8-10m/s for single blade lifts and 6m/s for the full rotor ('star') lift. A further challenge for mid-speed and direct-drive turbines is the rotation of the hub to install each blade in the three o'clock position. So far the only commercially deployed turbine of this type is the Areva M5000 but by 2017 most turbines will be mid-speed or direct drive. A significant innovation is one that can enable blade lifts in a wider range of rotor positions and ideally at wind speeds of 12m/s or above. Liftra's *Blade Dragon*, developed with Areva, has been designed with this purpose but it has not yet been certificated for offshore use. Other tools are being introduced now and industry feedback is that, within two years, lifts at 12m/s will be routine.

There is no medium-term prospect of floating vessels for turbine installation. Solutions that enable turbine installation using a floating vessel have been proposed but with separate tower, nacelle and blade lifts, this is not practical given the amplified effects of vessel movements at 100m height. Instead, the emphasis has been on installing turbines, fully assembled, possibly on a foundation, at the quayside. Feedback from industry is that, while this has theoretical benefits, it is unlikely to be commercially deployed this decade.

Technology shift

There is a greater need for vessels that can operate in deeper water. In the 2011 gap analysis, we found that there was concern among developers with projects in water depths of about 40m that there would be too few vessels that could operate at this depth. Many of the new vessels that have become operational in the past two years have longer legs than their predecessors to reflect the trend towards deeper water projects. The data sheets for many of these vessels indicate that they can work in up to 45m depth, but only five can work at 50m, and only three at 70m. It is likely, however, that there will be sufficient capacity for deeper water projects if suitable vessels are secured early for these projects.

LCOE reduction due to supply chain development

There is scope for further optimisation of the installation process. Significant improvements have been made in the logistics of turbine installation. The Siemens 3.6MW turbine has now been used on 15 projects and installation cycle times (the average time to install one turbine over the installation campaign) have steadily decreased. Industry feedback is that there could be scope for further optimisation. While installation times have fallen overall, installers of Areva and REpower turbines have not made the transition from "rotor star" installation to offshore single blade installation and a single tower lift, both of which are considered by most in the industry as more efficient.

Consolidation of the vessel operator market may increase fleet efficiencies and sustain learning rates. Recent investment has meant that competition in the market is healthy. Some vessels are likely to be under-utilised and this is likely to lead to acquisitions, either of assets or operators. Consolidation in vessel ownership will to drive efficiencies, enable more flexible use of vessels and avoid dilution of expertise by enabling suppliers to sustain experienced teams.

Source: BVG Associates

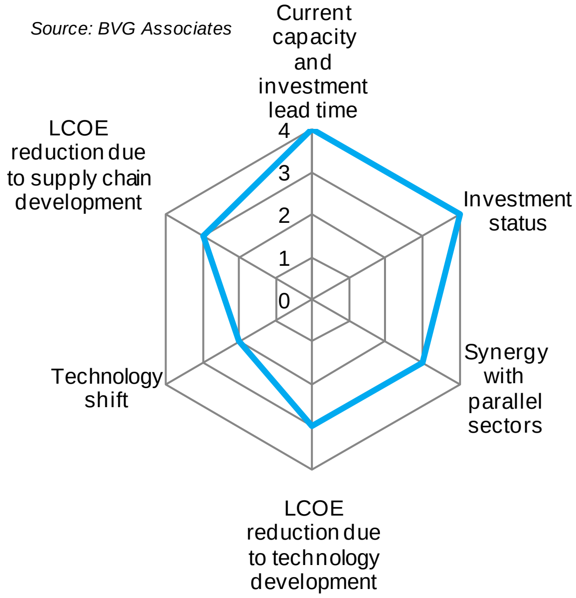

Figure 8.10 Summary of issues concerning turbine installation vessel supply.

Conclusion

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In the past, turbine installation vessels have been a significant concern for developers, especially those with deep water projects. It is now graded green because significant investment means that most projects will be able to secure vessels that are optimal or close to optimal for turbine installation.

Table 8.2 Summary of supply chain status and conclusions on subsea cable installation and turbine installation.

Criteria	Subsea cable installation	Turbine installation
Proven capability	Canyon Offshore (trenching), CT Offshore, DeepOcean, EMAS AMC, Nexans, Prysmian Powerlink Services (Global Marine Energy), Reef Subsea, Technip Offshore Wind, Van Oord, Visser & Smit Marine Contracting	A2SEA, Geosea, MPI Offshore, Seajacks, Swire Blue Ocean
Additional future capability	Jan de Nul, Siem Offshore, Tideway	Fred Olsen Windcarrier, HGO Infrasea Solutions, RWE OLC, Subsea7, Van Oord, Workfox
Current capacity and investment lead time	For array cables, there is no constraint on vessel availability but few vessels have been optimised for offshore wind For export cables, there are few ocean-going vessels but supply is unlikely to constrain project delivery	There is a short term overcapacity in the turbine installation vessel market Investment in integrated port facilities drives demand for larger vessels
Investment status	The availability of general-purpose cable-laying vessels is sufficient There is little known interest in specialist new build capacity for the offshore wind industry	There has been significant new build in the last two years and some new capacity in construction
Synergy with parallel sectors	Cable-laying vessels can also be used in oil and gas, telecoms, interconnector, pipeline and umbilical markets	The potential use of installation vessels in other offshore sectors lowers investment risk Demand for vessels with high capacity cranes for foundation installation may limit their availability for turbine installation
LCOE reduction due to technology development	There has been progress in optimising array cable installation There has been some progress in reducing weather downtime in array cable installation Some developers are adopting a risk-based approach to cable burial	There has been progress in increasing the maximum wind speed for blade lifts There is no medium-term prospect of floating vessels for turbine installation
Technology shift	Sites further offshore will preclude the use of cable barges other than for inshore export cable laying and storage Far offshore projects need different personnel transfer systems	There is a greater need for vessels that can operate in deeper water
LCOE reduction due to supply chain development	There is a trend away from small operators There is likely to be a trend towards consolidated supply and install packages The industry shows signs of maturity and price is less commonly the dominant factor in contracting	There is scope for further optimisation of the installation process Consolidation of the vessel operator market may increase fleet efficiencies and sustain learning rates
Conclusion[1]	G ↑	G

9. Operation, maintenance and service

Currently, almost all commercial offshore wind turbines are either in warranty or maintained under a long-term service agreement by the wind turbine manufacturer. UK asset managers are starting to consider the issues raised by increasing numbers of onshore turbines coming out of warranty by developing maintenance and support strategies. The three main options for routine maintenance are:

- Continue to purchase from the turbine manufacturer;
- Move to using a third party service provider, or
- Establish in-house expertise.

A number of utilities advise a strategy of using in-house expertise, including from their other power generation support functions, for maintaining onshore wind turbines and using specialist third-party service providers (such as blade and gearbox specialists) where necessary. Fewer are seeking the same approach offshore at this stage and it is anticipated that most asset owners will continue to purchase offshore maintenance from the turbine manufacturer for some time, given the additional level of risk and sophistication associated with the latest technology in the offshore environment. Some, however, are preparing for takeover of turbines or are now already leading maintenance activities themselves.

Operation includes monitoring the performance of the wind farm, both onsite and remotely, planning maintenance schedules, responding to reliability issues, including via proactive and reactive service interventions, managing supplier interaction and addressing all other commercial obligations.

The operations base houses crew areas and spare parts as well as the transport vessels. Typically, wind farm operators will look to use the nearest port that meets its specification in order to minimise travelling time and make the best use of weather windows.

A 500MW wind farm may require the operation of up to around seven vessels at one time, depending on the distance to shore. Wind farms further offshore are likely to use hotel vessels and larger maintenance vessels. These will require berths over 100m long. Although these berths will not need to be dedicated, operators will want priority access and adjacent warehousing. A landing area for helicopters is also a likely requirement.

9.1. Routine maintenance vessels and equipment

Wind turbines and offshore substations incorporate a substantial number of technically complex systems that are expected to operate continuously for at least 20 years in particularly hostile conditions. As a result, an operator must undertake planned maintenance throughout the operational lifetime of a wind farm. Increasing reliability and greater levels of remote monitoring should reduce the amount of onsite activity but there will always be work that can only be carried out by a technician present in a turbine or substation. This creates the challenges of transporting, loading and unloading personnel and equipment in difficult sea and weather conditions while prioritising safety. There is a financial incentive for addressing issues that halt the production of electricity as quickly as possible.

There are three main types of maintenance vessel:

- Personnel transfer vessels
- Offshore support vessels, and
- Mother ships.

Personnel transfer vessels are used to undertake daily visits carrying up to 12 technicians at a time as well as basic spares and equipment. The size of the vessels varies between 14m and 24m. The upper limit is self-imposed by the industry in the UK as vessels 24m and above are classified as cargo ships and require additional certification. Vessels less than 24m in length are usually classified by the Marine Coastguard Agency as Category II, which limits their operating to range to 60nm from base.

Offshore support vessels will be semi-permanently stationed offshore and can therefore respond to issues more quickly. They are floating DP vessels that are typically designed to be equipped with advanced personnel access systems, cranes, workshops, and a helideck and accommodation for up to about 50 people.

Mother ships are variants of the offshore support vessels but are typically larger with accommodation for about 100 people and have the capability to launch and recover two or more “daughter” personnel transfer vessels. They have extensive catering and recreational facilities, office space and workshop areas.

Both offshore support vessels and mother ships will be able to transfer technicians onto a turbine in much more challenging sea conditions than a personnel transfer vessel. While the need for these vessels will be greatest for far-from-shore projects, it is expected that they will also be used on projects closer to shore as such a solution is developed and proven at sea.

Most of the maintenance vessels are owned and operated by specialist companies, although some wind farm owners have bought their own vessels.

Current capacity and investment lead time

There is significant new demand for personnel transfer vessels. Figure 9.1 shows that over 250 new personal transfer vessels will be needed by 2022, approximately 30 a year. Table 9.1 shows 13 examples of the boat builders that have supplied personnel transfer vessels to the offshore wind industry. One leading supplier indicated that it could manufacture over 20 vessels a year, so it is clear that demand can be met.

The delivery of maintenance vessels can be accommodated within project timescales. The construction and commissioning of the type of small personnel transfer vessels currently used takes around six months to complete, with sea trials lasting a further two weeks. These vessels tend to be based on a relatively standard design with only minor bespoke refinements made for each customer. This build time may increase by up to six months as this type of vessel gets larger to accommodate more people and equipment. Payment is typically on delivery and boat builders have suffered cash flow problems. Operators of such vessels have also reported difficulty in securing finance for new vessels. For offshore support vessels and mother ships, lead times are likely to be up to three years.

There is uncertain demand for offshore support vessels and mother ships. There are currently no such bespoke vessels used for offshore wind farm maintenance. A number of projects have used hotel vessels, often converted ferries, for accommodation during installation or large scale programmes of component replacement but it is unlikely that these will be suitable as offshore support vessels for most Round 3 projects. There is little consensus about what specific vessels, technology and access methodologies should be used. It is expected that demand for these vessels will not start until the second half of this decade as maintenance strategies evolve and far-from shore wind farms come on line.

Table 9.1 Suppliers of personnel transfer vessels to the offshore wind industry.

Company	Country
AF Theriault	Canada
Alnmaritec	UK
Alicat (including subsidiary South Boats)	UK
Austal	Philippines
Båtservice	Norway
CWind	UK
Damen	Netherlands
Danish Yachts	Denmark
Fjellstrand	Norway
Mercurio	Spain
Mobimar	Finland
Strategic Marine	Singapore
Topaz Engineering	United Arab Emirates

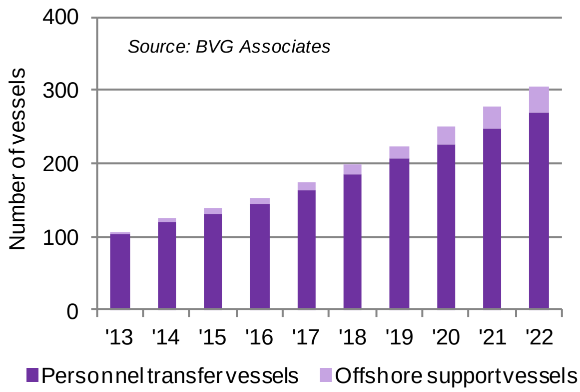

Figure 9.1 Projected demand for routine maintenance vessels for European offshore wind to 2022 (by year of operation).

There is uncertain demand for helicopters. Although this option does offer a significant reduction in transit time and the ability to access the wind farm in high sea states, the high cost of this approach, concerns about safety of so many transfers and limitations to the amount of equipment that helicopters can transfer, means it is unclear whether it will be widely used. Civil Aviation Authority regulations define the distance of vertical obstructions from the landing area, which is likely to preclude landing on the nacelle of a three-bladed turbine.[27] Technicians can therefore only be lowered to a cage mounted on the nacelle from a hovering helicopter. This results in high fuel consumption which in turn constrains the number of passengers that the helicopter can carry at one time. One solution is that the helicopter then returns to an accommodation platform or mothership, rather than to shore.

Investment status

Investment in capacity for offshore wind has been made. UK manufacturers Alnmaritec and South Boats/Alicat have made investments in new facilities.

Danish ship owner Esvagt announced in August 2013 that it has signed a long-term chartering agreement with Siemens for two 84m Havyard-built offshore support vessels for use at the Butendiek and Baltic 2 offshore wind farms.

Synergy with parallel sectors

Transit and access requirements are unique to offshore wind. Boatbuilders supplying the offshore wind industry may construct vessels for other sectors, although the high demand for offshore wind vessels may mean that boatbuilders use dedicated a production line to improve the utilisation of factory space.

Logistics planning tools can be adapted from other sectors. There are opportunities to adapt strategies using tools developed from the oil and gas and passenger aircraft industries.

LCOE reduction due to technology development

New access systems are being developed to increase the operational envelope. The transfer of technicians to a turbine using a personnel transfer vessel can currently only take place with a significant wave height (Hs) at 1.5m or lower, with acceptable swell and wind direction which means that about 30% of the annual working time of a technician is currently spent waiting for weather windows. Increasing the turbine access to a limit of 2.5m Hs would reduce this to about 10%. As a result, a number of access systems are under development and some have been trialled at operational wind farms. The limit then may become the viability of transfer between turbines, rather than accessing turbines.

[27] *Standards for Offshore Helicopter Landing Areas*, CAP 437, February 2013, Civil Aviation Authority, available online at www.caa.co.uk/docs/33/Cap437.pdf, last accessed August 2013.

Technology shift

As projects are developed further offshore, the sole use of personnel transfer vessels approach becomes increasingly impractical as technicians must spend a significant proportion of the working day being transported to, from, and around the site. Harsher sea conditions may also mean that a small vessel strategy means technicians are unfit to start complex maintenance work for some time after they have arrived. There are also health and safety implications of long, routine transfers as well as from transporting personnel back to shore should an incident occur.

There is greater demand for larger vessels for wind farms further from shore. Most turbine maintenance is currently undertaken using personnel transfer vessels. These vessels are used to undertake daily visits carrying technicians and basic spares and equipment. Current regulations restrict the number of passengers for crew transfer vessels to 12 but it is understood that the International Maritime Organisation is considering raising this limit. Larger crew transfer vessels are already being developed that will be able to carry more people and a greater variety of spares.

A variety of different designs and concepts of offshore support vessels and mother ships are currently in the market, with a number of designs having already been used in other offshore industries, such as oil and gas. A vessel that can accommodate approximately 60 personnel is likely to take similar time to manufacture as an installation vessel once account is taken of the procurement process, construction, sea trials and commissioning.

There will in future be a greater use of offshore operations bases. Fixed operations bases, similar to platforms used in the oil and gas sector, or floating operation bases may be used when wind farms are greater than about 40nm from the nearest suitable OMS port.[28]

LCOE reduction due to supply chain development

There is strong competition in the personnel transfer vessel market. As Table 9.1 shows, there are a number of personnel transfer vessel manufacturers. A number of vessel operators have also emerged with the growth of the offshore wind industry.

[28] *A Guide to UK Offshore Wind Operations and Maintenance*, Scottish Enterprise and The Crown Estate, June 2013, available online at http://www.scottish-enterprise.com/~/media/SE/Resources/Documents/MNO/Offshore-wind-guide-June-2013.pdf, last accessed August 2013.

Clustering of wind farm operations can bring economies of scale and investment to reduce logistics costs. There could be opportunities to share vessels and a critical mass can stimulate local investment in services. There are particular opportunities for small local companies who can offer flexibility and local skills and knowledge, such as workboat operators.

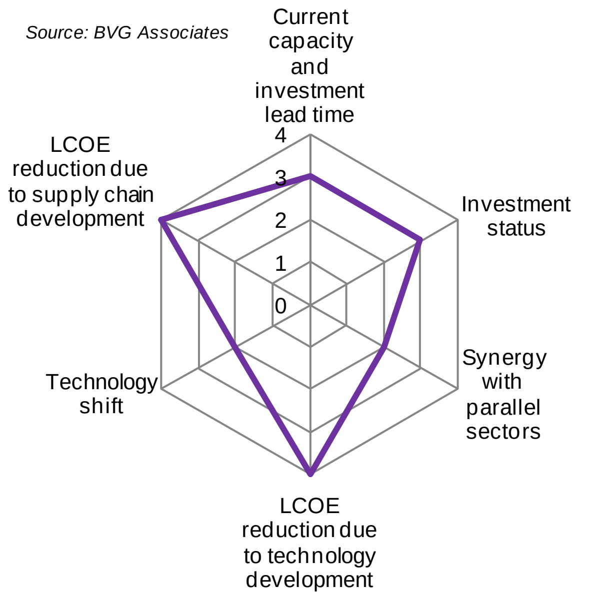

Figure 9.2 Summary of issues concerning routine maintenance vessel and equipment supply.

Conclusion

G

This subelement has been graded green because there is significant capacity for new build vessels globally. If demand is uneven, lead times may increase but this is unlikely to have an impact on turbine maintenance due to the timescales of project development and construction.

9.2. Large component replacement vessels

Large vessels are needed to undertake the removal and replacement of major components such as turbine blades or gearboxes during operation.

As for installation, the current practice is to use jack-up vessels to keep crane hook movement to acceptable levels at the tower top. To date, most of this work has been undertaken by the same vessels that have been used previously for installation. For installation, the demand is now for larger, self-propelled vessels with bigger cranes (see Section 7.8) and these are typically over-specified for large component removal and replacement, with larger cranes and deck area than is needed. This has created demand for dedicated OMS jack-up vessels, which may be older installation vessels or new purpose built vessels.

Current capacity and investment lead time

There are a significant number of jack-ups in limited demand for installation. There are about 20 jack-up barges and vessels that have been used in offshore installation but they will be considered unsuitable for this purpose in the second half of this decade. Feedback from industry is that these vessels will primarily be used for large component replacement and modification for this purpose can generally be achieved cost effectively. About half of these vessels cannot be used in water depths greater than 40m and hence unless modified would be unsuitable for projects built after 2015. There are also some newer vessels, such as Geosea's *Neptune* and Seajack's *Hydra*, which may be increasingly be devoted to maintenance work.

With a projected demand of about 15 such vessels across Europe in 2022, there is anticipated to be sufficient capacity in the market. At periods of high demand, operators are also likely to be able to secure larger installation vessels if these are between installation contracts.

Investment status

There has been some investment in specialist large component replacement vessels. DBB Jack-Up Services has ordered two purpose built OMS jack-up vessels, with the first due to enter service in 2013. In addition Celtic Design Consultants has developed a maintenance vessel concept with an elevated secondary working platform, which is being offered to the market. Further investment in specific new vessels may be inhibited by the lower risk option of installation vessel upgrades and the uncertain economic case for bespoke OMS vessels. The market will depend significantly on the reliability of the next generation of turbines.

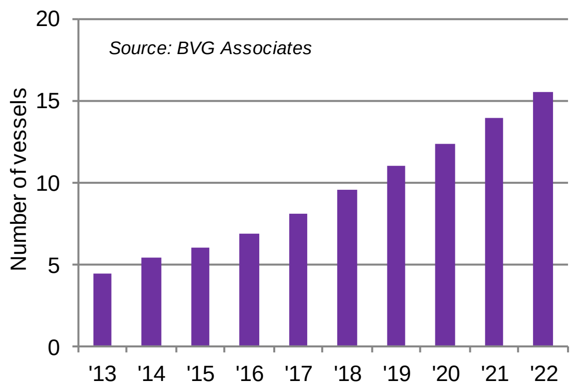

Figure 9.3 Projected demand for large component replacement vessels for European offshore wind to 2022.

Synergy with parallel sectors

There is significant demand for jack-ups in the oil and gas industry. Most of the vessels used for early offshore wind projects had been used previously used in oil and gas and a number will return to this sector as the specialist wind farm installation fleet grows.

LCOE reduction due to technology development

The choice of vessel will depend on sophisticated OMS modelling tools. Feedback from industry indicates that the choice of vessels as part of the OMS strategy depends on a number of complex factors, which will include the consideration of fuel prices as well as specific wind farm parameters and expectations about future turbine reliability. There has been progress by consultancies in developing tools and there is an increasingly sophisticated understanding of activity by asset owners.

Technology shift

The current fleet of maintenance jack-ups may not be suitable for future projects. Projects far offshore and in deeper water will need vessels that can jack-up in water depths greater than 40m and in more severe weather conditions.

LCOE reduction due to supply chain development

The supply chain strategies for large component replacement vessels are likely to evolve. Wind farm operators may address this demand in a number of ways:

- Chartering vessels on an ad hoc basis to address major faults as soon as they occur
- Waiting until a critical number of turbines have developed (or are predicted to develop) major faults and then chartering a vessel to address all of them in one campaign
- Chartering a vessel for a given period every few months on the assumption that some major faults will occur within a wind farm each period, or
- Chartering a vessel long term or purchasing a vessel. This could be attractive for developers that have a critical mass of operating turbines. For clusters of wind farms, feedback suggests that "owners clubs" could emerge, particularly if they are coordinated by a third party. Developers indicate that they do not consider operating a large vessel as their strength. They would be more likely to contract this to a company that can provide an operating service.

Progress in developing suitable strategies will likely be made only when developers have greater understanding of the reliability of next generation turbines.

Source: BVG Associates

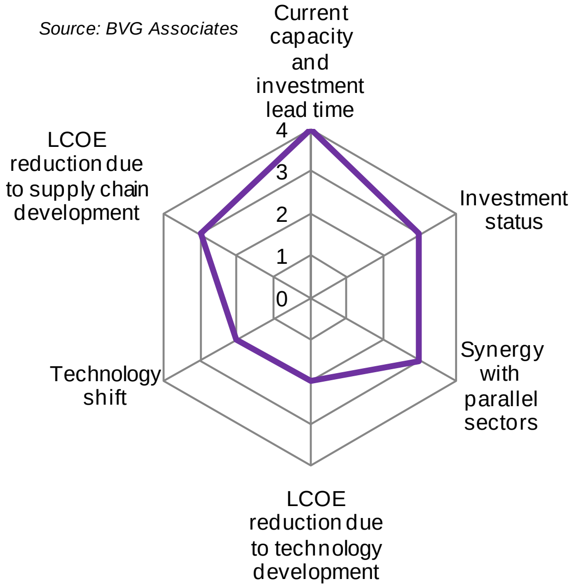

Figure 9.4 Summary of issues concerning large component replacement vessels.

Conclusion

G

This subelement has been graded green because there are a significant number of jack-up vessels previously used for installation that can be used. These are likely to be supplemented by purpose-designed vessels and larger installation vessels if available.

Table 9.2 Summary of supply chain status and conclusions on routine maintenance vessels and equipment, and large component replacement vessels.

Criteria	Routine maintenance vessels and equipment	Large component replacement vessels
Proven capability	Manufacturing: AF Theriault, Alicat/South Boats, Alnmaritec, Austral, CTruk, Damen Shipyards Operation: Various companies operating locally and nationally	A2SEA, Hochtief Solutions, Geosea, Jack-Up Barge, MPI Offshore, Seajacks, Swire Blue Ocean
Additional future capability	Investment by vessel fabricators and operators	DBB Jack-Up, Fred Olsen Windcarrier, RWE OLC, Subsea7, Van Oord, Wolker Vessels, Workfox
Current capacity and investment lead time	There is significant new demand for personnel transfer vessels The delivery of maintenance vessels can be accommodated within project timescales There is uncertain demand for offshore support vessels or mother ships There is uncertain demand for helicopters	There are a significant number of jack-ups in limited demand for installation
Investment status	Investment in capacity for offshore wind has been made	There has been some investment in specialist large component replacement vessels
Synergy with parallel sectors	Transit and access requirements are unique to offshore wind Logistics planning tools can be adapted from other sectors	There is significant demand for jack-ups in the oil and gas industry
LCOE reduction due to technology development	New access systems are being developed to increase the operational envelope	The choice of vessel will depend on sophisticated OMS modelling tools
Technology shift	There will in future be a greater use of offshore operations bases	The current fleet of maintenance jack-ups may not be suitable for future projects
LCOE reduction due to supply chain development	There is strong competition in the personnel transfer vessel market Clustering of wind farm operations can bring economies of scale and investment to reduce logistics costs	The supply chain strategies for large component replacement vessels are likely to evolve
Conclusion	G	G

10. Support services

A number of services are relevant to two or more areas of the supply chain or are independent of the wind farm development, construction and operating phases. These can be categorised under the following headings:

- RD&D, including full-scale test facilities
- Training, including technical, and health and safety
- Legal and financial services
- Enabling activities, including by public bodies and trade associations
- Supply of health and safety equipment, and
- Supply of tooling, consumables and materials.

We will focus on large component test facilities as we believe that there are few issues in the other areas that are not covered elsewhere in this report.

10.1. Full-scale test facilities

Considered within this section are whole turbine test sites as well as facilities for drive train and blade testing.

Current capacity and investment lead time

The trend towards larger turbines has stimulated investment in new fit-for-purpose test facilities. In Continental Europe there are a number of test facilities built over recent years to support the technology development of the onshore wind sector. Introducing next generation turbines demands the construction of new facilities to meet the increased power rating of drive trains and longer blades.

For whole turbine onshore test sites for very large turbines, there has been the additional challenge of securing planning consent. The only unallocated UK test site is at Hunterston, where two of the three sites have been awarded to MHI and Siemens.

There are few available offshore test sites. Those currently operating include Alpha Ventus (Areva, REpower) Beatrice (REpower), Gunfleet Sands (Siemens) and Hooksiel (Bard).

For larger demonstration sites, such as the European Offshore Wind Deployment Centre in Aberdeen Bay, consent may not be achieved any faster than for a commercial wind farm.

The UK has new state-of-the-art testing component facilities at Narec, including a 100m blade test facility and a drive train test rig for up to 10MW-rated turbines. In June 2013, Samsung announced that it would be the first to use the drive train test rig and these tests are now underway. Other European open access test facilities suitable for offshore wind testing are at Spain's National Renewable Energy Centre (CENER) (blade and drive train) and Germany's Fraunhofer Institute for Wind Energy and Energy System Technology (blade). Siemens and Vestas have in-house blade and drive train test facilities for large offshore turbines. LM Wind Power also has its own blade test facilities.

Investment status

The economics of dedicated test sites are uncertain. By its nature, a dedicated test site is small and uses unproven turbines. Even a developer with a significant pipeline of projects is unlikely to commit to a demonstration project in the current climate without confidence of some level of profit. Turbine manufacturers in general have been unwilling to sell at below commercial rates and the result has been that few such sites have been built, even with public sector funding. The most significant exception, Alpha Ventus, involved investment from three developers as well as public funders.

There is an additional hurdle for demonstration sites for novel foundation concepts in that ideally a turbine needs to be erected on the foundation, both to verify the solution in the medium-term and to help support the high cost, via a revenue stream. Scottish Enterprise announced the SIFT fund in April 2013 to demonstrate foundations, complementing the Prototyping for Offshore Wind Energy Renewables Scotland (POWERS) fund it has available for turbine demonstration.

There are plans for demonstration sites pending FID. In the UK there are two such projects. Vattenfall has been developing the Aberdeen Bay project with a 75% stake but announced in May 2013 that it was seeking a new investment partner. Narec has been developing the Blyth Offshore Wind Demonstration Site but progress has been slow in securing partners.

In June 2013, The Crown Estate announced a leasing round to accelerate the testing of emerging offshore wind technologies, including the use of floating foundations. The initiative aims to support the progress being made in lowering the LCOE and encourage investment.

Both the Fraunhofer Institute for Wind Energy and Energy System Technology in Germany and the Lindoe Offshore Renewables Center in Denmark have advanced plans for open-access drive train test rigs. The USA has a blade test rig in Massachusetts and a drive train rig soon to open in South Carolina. Facilities are also in development in China (blade and drive train).

Synergy with parallel sectors

Turbine component test facilities have a value in the onshore sector. While the offshore drive train test rigs are over specified for onshore turbines, the trend towards larger onshore rotors for low wind sites means that blade test facilities can service both markets.

LCOE reduction due to technology development

Test facilities are playing a significant role in commercialising next generation turbines. Offshore wind is considered a high risk investment and test facilities play a crucial role in increasing the bankability of turbines with the potential to make significant reductions in the cost of energy.

Blade and drive train test facilities offer the potential to improve reliability. With the high costs of component repair or replacement and the risk of weather downtime, turbine reliability and maintainability for the next generation offshore machines is an even higher priority than for onshore turbines. The reason for testing is to verify designs and design methodologies and hence help to improve reliability.

Wind turbine manufacturers are starting to specify wider component type testing. For some time, international standards have dictated a level of workshop type testing of gearboxes and blades. Larger and more experienced offshore players are now specifying more thorough type testing of a wider subset of components and systems in order to further improve turbine reliability.

Technology shift

Offshore test sites can be used to optimise maintenance systems for projects further from shore. Test sites can have a broader remit than complete turbine and component testing and, although most test sites are relatively close to shore, there are opportunities to develop new maintenance systems during testing.

LCOE reduction due to supply chain development

Competition is now starting for very large offshore blade and drive train type testing. Following a period of specification, design and construction, international competition in the supply of testing services has begun. This will assist in keeping costs reasonable as well as developing more efficient and effective test methods.

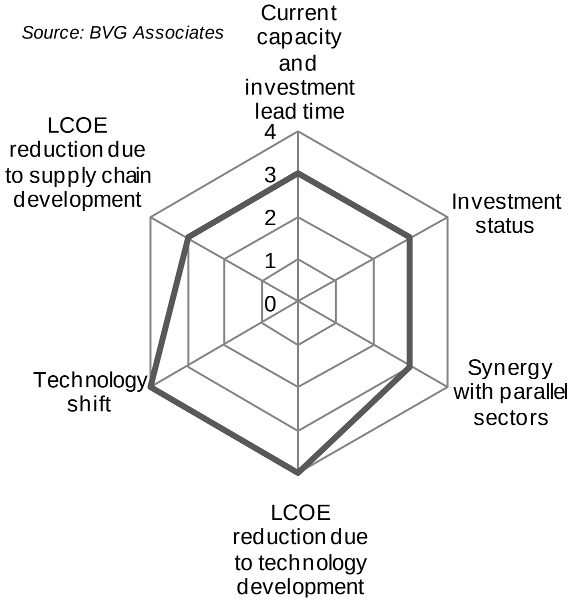

Figure 10.1 Summary of issues concerning the supply of full-scale test facilities.

Conclusion

A

Full-scale test facilities have been graded amber. The economics of test sites means that, despite initiatives by BIS, DECC, The Crown Estate and the Scottish Government, sites may not all be used. Uncertainty over the long-term offshore wind market means that developers will have a shorter term perspective on turbine and technology and will look for close to commercial returns on demonstration projects.

Action

Investment in demonstration projects needs to be more attractive. Although stand-alone offshore demonstration sites have received public funding, the benefits to investors have been insufficient. The Scottish POWERS and SIFT funds have been valuable in addressing this issue but additional action is needed, ideally coordinated at a European level, between countries with significant offshore wind ambitions.

The selection of test sites needs to reflect the range of conditions for commercial projects. Developers are more likely to invest if a test site has similar conditions. This is particularly important for the testing of novel foundation technologies.

Best practice in component testing should be shared. The benefits from testing can be accelerated with cooperation between facilities.

Table 10.1 Summary of supply chain status and conclusions on full-scale test facilities.

Criteria	Full-scale test facilities
Proven capability	Alpha Ventus, Cener, ECN, Frederikshavn, Hovsore, IWES, Osterild, Narec, Risø
Additional future capability	Aberdeen Bay, Belwind, Blyth, Hunterston
Current capacity and investment lead time	The trend towards larger turbines has stimulated investment in new fit-for-purpose test facilities
Investment status	The economics of dedicated test sites are uncertain There are plans for demonstration sites pending FID
Synergy with parallel sectors	Turbine component test facilities have a value in the onshore sector
LCOE reduction due to technology development	Test facilities are playing a significant role in commercialising next generation turbines Blade and drive train test facilities offer the potential to improve reliability Wind turbine manufacturers are starting to specify wider component type testing
Technology shift	Offshore test sites can be used to optimise maintenance systems for projects further from shore
LCOE reduction due to supply chain development	Competition is now starting for very large offshore blade and drive train type testing
Conclusion[1]	A
Actions	Investment in demonstration projects needs to be more attractive The selection of test sites needs to reflect the range of conditions for commercial projects Best practice in component testing should be shared

Appendix A: Summary of assessments

The methodology behind scoring of issues and traffic lights is explained in Section 2.5.

Supply chain element	Supply chain subelement	Traffic light[29]		Summary of issues (1 is strongly negative, 4 is strongly positive): Current capacity and investment lead time	Investment status	Synergy with parallel sectors	LCOE reduction due to technology development	Technology shift	LCOE reduction due to supply chain development
	Full-scale test facilities	A		3	3	3	4	4	3
OMS	Large component replacement vessels	G		4	3	3	2	2	3
OMS	Routine maintenance vessels and equipment	G		3	3	2	4	2	4
Installation and commissioning	Turbine installation	G		4	4	3	3	2	3
Installation and commissioning	Subsea cable installation	G	↑	3	2	3	3	3	3
Installation and commissioning	Foundation installation	R	↓	2	2	3	2	2	3
Installation and commissioning	Installation ports	G		3	2	3	3	4	3
Balance of plant supply	Concrete foundations	A		2	2	4	3	2	2
Balance of plant supply	Non-monopile steel foundations	A		2	3	3	2	3	2
Balance of plant supply	Monopile foundations	G		2	3	3	2	4	2
Balance of plant supply	DC substation electrical systems	A		3	3	4	3	3	2
Balance of plant supply	AC substation electrical systems	G		3	4	3	3	4	3
Balance of plant supply	Subsea DC export cables	R		2	1	4	3	2	2
Balance of plant supply	Subsea AC export cables	A		2	1	3	3	4	3
Balance of plant supply	Subsea array cables	G		3	3	3	4	4	2
Turbine supply	Towers	G		2	2	4	3	4	4
Turbine supply	Gearbox, large bearings and generators	G		3	3	3	4	3	3
Turbine supply	Castings and forgings	G	↑	3	3	3	3	4	3
Turbine supply	Blades	G		2	3	3	3	4	2
Turbine supply	Offshore wind turbines	R		2	2	2	3	4	2
Project	Survey vessels	G		2	2	3	3	3	2
Project	Wind farm design	G	↑	3	4	2	2	3	3

[29] Arrows indicate how the traffic light grading has changed since *Towards Round 3: the offshore wind supply chain in 2012*, published in June 2012 (↑ situation improved, ↓ situation worsened). No arrow indicates no change or new or amended category title since 2012.

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