Sharing Lessons Learned and Good Practice in Offshore Transmission

A Report for The Crown Estate

Report No.: 112843-UKBR-R-01-F
Date: 29/04/14

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Task and objective: Identify lessons learned to date in offshore transmission and consider the best means of sharing good practice on an enduring basis.

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Reference to part of this report which may lead to misinterpretation is not permissible.

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GLOSSARY

AC – Alternating Current

AEP – Annual Energy Production

BSI – British Standards Institute

Capex – Capital Expenditure

CIGRE - International Council on Large Electric Systems

CRTF – Cost Reduction Task Force

DC – Direct Current

DTS – Distributed Temperature Sensing

ENTSO-E – European Network of Transmission System Operators for Electricity

EMR – Electricity Market Reform

EPC – Engineer, Procure and Construct

FCR – Fixed Charge Rate

FEED – Front End Engineering Design

FID – Final Investment Decision

HVDC – High Voltage Direct Current

IEC – International Electrotechnical Commission

ISO – International Organisation for Standardisation

ITPR – Integrated Transmission, Planning and Regulation project

LCOE – Levelised Cost of Energy

LFAC – Low Frequency Alternating Current

MITS – Main Interconnected Transmission System

OEM – Original Equipment Manufacturer

OFTO – Offshore Transmission Owner

Opex – Operational Expenditure

OWPB – Offshore Wind Programme Board

OWIC – Offshore Wind Industry Council

SAP – Senior Authorised Person

TCE – The Crown Estate

TSO – Transmission System Operator

VSC – Voltage Source Converter

XLPE – Cross Linked Polyethylene

1 EXECUTIVE SUMMARY

The Crown Estate commissioned this report to address one of the recommendations on offshore transmission from 2012's Offshore Wind Cost Reduction Task Force (CRTF) report; namely to explore the extent to which better sharing of knowledge and good practice in the sector would improve 'learning by doing' for future projects, and consequently contribute to reducing the levelised cost of energy (LCOE) for offshore wind.

DNV GL has tackled this by considering three key aspects: (i) identifying what lessons have been learned to date in the development, construction and operation of offshore transmission infrastructure; (ii) assessing alternative ways of improving knowledge sharing in the sector and recommending an approach for doing so, and (iii) seeking to quantify the potential impacts of such an approach in terms of LCOE reduction.

As part of the study, a broad range of industry stakeholders were interviewed between December 2013 and March 2014 in order to understand what issues had been encountered on projects to date. Interviews were conducted with a range of levels of staff within these organisations – from project directors to lead engineers to grid connection managers – to get a balanced view on where issues have arisen. This information, coupled with reviews of relevant literature and in-house knowledge, has provided the evidence base to support these findings.

Lessons learned

Overall, our work has found that the transmission element of offshore wind projects has suffered from, and been adversely impacted by, a range of challenges and issues across the development cycle – from consenting and early stage design through to installation, and operations & maintenance. Not all projects have experienced the same issues, but it does seem to be the case that most projects have been affected in some way, typically manifesting in the cable delivery and installation phase or the installation and operation of the offshore substations and converter stations. The result has been either unexpected cost escalation or extra risk mitigation actions (and in some cases, both). Whilst the collection of lessons learned is essentially a retrospective exercise, and the sector is naturally maturing, a number of progressive learnings have emerged.

A key finding was that many of the problems identified have a root cause in the way projects have been managed and delivered, rather than technical challenges – although technical challenges clearly exist as well. Much of the feedback we received suggested decisions taken at the design stage 'locked in' challenges for later stages of the project lifecycle, with the sector needing to do more to consider the lifecycle impacts of design and procurement decisions. This suggests significant future effort may be best directed toward ensuring the design of the offshore transmission infrastructure is as well-developed as possible prior to key project decision points.

Other evidence suggests that the application of risk management frameworks does not seem to have kept pace with the scale and complexity of larger projects, with developers still searching for the right balance between up-front investment (at risk) and effective delivery of the project over the full lifecycle. Evidence also suggests that the allocation of risk between developers and contractors has often not been appropriately balanced, with more consideration needed to ensure that risk is managed by the party best able to do so. Further development of programme, contingency and mitigation planning also seems to be required.

Although project management has emerged as an important theme, the report has also identified a wide range of good practice in other areas. Table 1-1 summaries some of the key good practice points across the life cycle identified in relation to both project management and other areas.

Lifecycle Stage	Project Management & Delivery	Technical and Other Areas
Consenting	• Consider lifecycle impacts of consenting decisions	• Use risk based burial indices to define consent condition on burial depth • Collect sufficient survey data along entire cable route
Design	• Develop a robust risk management framework • Involve supply chains in the design phase	• Consider system standardisation of capacity ratings and voltage levels • Use reference design(s) for offshore substations if possible • Overplant, subject to Cost Benefit Analysis • Optimise approach to rating of cables and transformers
Procurement	• Focus on interfaces • Ensure risk is identified appropriately and managed by the entity best able to do so • Ensure clear OFTO split in contracts • Consider use of 'reasonable endeavours' clause in contracts	• Seek to increase competition in supply chains
Manufacture	• Avoid design changes during fabrication • Ensure close and competent supervision of suppliers and contractors	
Installation	• Plan with realistic programme, with appropriate mitigations and contingencies • Ensure development team are on site • Use experienced contractors	• 'Fingerprint' export cable with as-laid documentation
Asset Transfer	• Ensure robust process for collecting as-built drawings, records, etc.	• Undertake full suite of surveys and tests before handover
O&M	• Develop robust asset management system • Plan for cable failure prevention, root cause analysis and cable repair	

Table 1-1: Summary of good practice identified in this report

Sharing good practice

In an emerging industry, it is to be expected that not everything goes to plan and there are many lessons to be learned. There is evidence though of the sector learning from past mistakes, with information being shared through industry forums, conferences and events. There are also a wide range of initiatives being taken forward, and by a variety of different stakeholders, to address specific challenges – be these technical, commercial or regulatory. A summary of recent initiatives is set out below:

- The Crown Estate completed a high level investigation into the need, implementability and potential benefits of standardisation at a system level on voltage and power ratings and discussed a modular approach to offshore transmission systems,
- DNV GL has recently published the "Subsea power cables in shallow water renewable energy applications" guideline,
- The Carbon Trust are developing an offshore wind Cable Burial Protection Index and seeking to better mitigate burial risk,
- The OWPB Contracting Strategies Group is shortlisting different risk management approaches to contracting, and working out the best means of bringing the supply chain into the development process earlier,
- Ofgem has recently proposed to undertake more detailed cost benchmarking for offshore transmission, which should improve visibility and comparability of key data,
- Leading developers and OEMs are preparing reference designs, with various industry forums looking at different aspects of standardisation.

This paints a relatively healthy picture of progress. However, it is clear from our research that not all stakeholders are fully aware of or benefitting from this activity – which may go some way to explaining the reoccurrence of the same problems across projects. Given this, there is scope for introducing a more structured approach to the way in which the offshore transmission sector shares its learning and knowledge moving forward. To this end, we recommend an industry-wide 'knowledge hub' is established. Fundamentally, this hub would be a focal point for:

- collating industry learning and experience from a variety of sources,
- sharing this more broadly with the sector, and
- intelligently using the information to identify where further work is necessary, and engaging with stakeholders to take this forward

This 'knowledge hub' is represented graphically below:

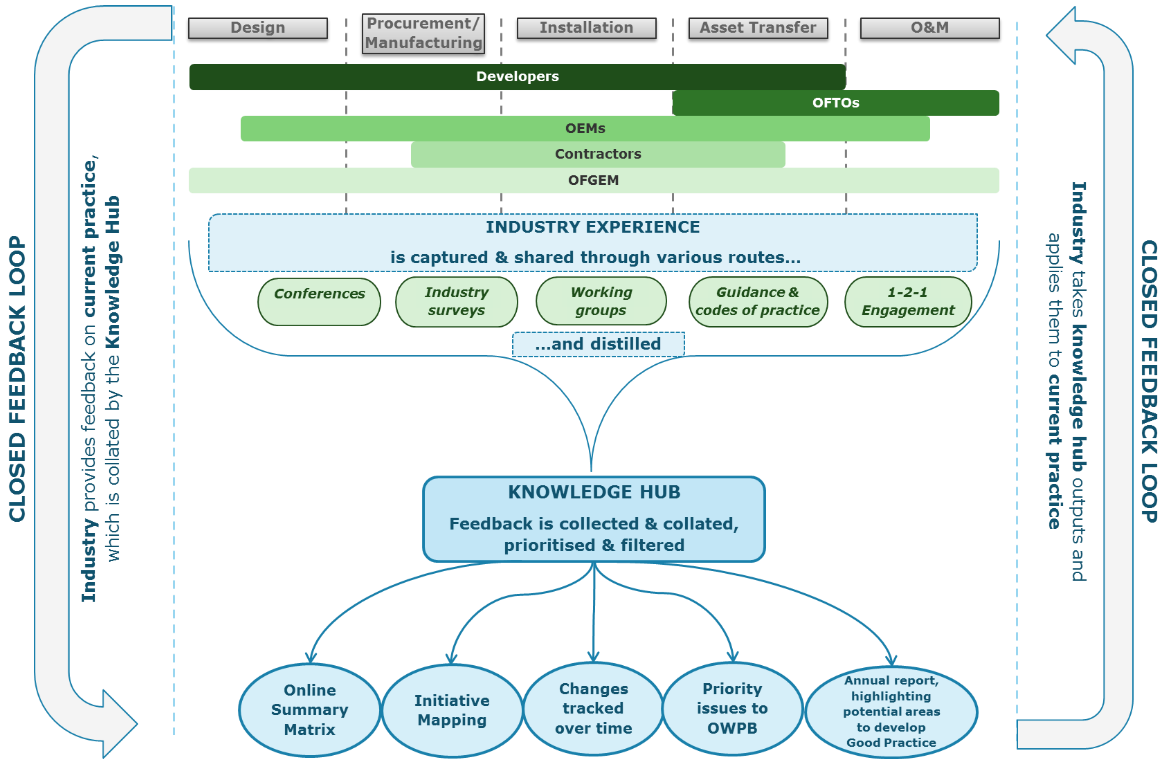


Table 1-2: Schematic of the Offshore Transmission Knowledge Hub

The principle activities of this hub would be to coordinate, collect and collate lessons learned; proactively capturing lessons learned within the sector at minimal cost to industry participants, while developing a central store of information which would, over time, grow into a useful resource. The hub would drive coordination, with greater visibility over which organisations are tackling which issues. Such an approach has been used across a range of industries and countries, typically yielding a net positive benefit, and would be effective at capturing learning across Europe.

Detailed development of this 'knowledge hub' is outside of the scope of this project. Nevertheless, this report identifies proposed outputs, information flows and also considers cost drivers.

Why improve knowledge sharing?

Further evidence for an improved approach to knowledge sharing is provided by a quantitative assessment of the potential reductions in LCOE of offshore wind projects, from initiatives identified in this report. A high level analysis suggests that there could be a saving of up to 22% in the transmission capital expenditure on a 500MW reference project and other associated operational cost savings. Taken together, these equate to around 6% reduction in the LCOE of offshore wind farm projects.

This figure has been calculated by making assumptions around the potential cost savings that may be attributable to certain activities and then applying these on an additive basis (which may not be the case in practice, even if all were applicable). It is therefore highly simplified and should be read as such. However, it does suggest that sharing knowledge and lessons across the offshore transmission sector more effectively than is done at present could have a material effect on the overall LCOE of offshore wind farm projects.

2 INTRODUCTION

The Offshore Wind Cost Reduction Taskforce (CRTF) report[1] made a number of recommendations in a range of areas to help the offshore wind industry achieve a levelised cost of energy (LCOE) of £100/MWh for projects reaching final investment decisions (FID) in 2020. The CRTF report included four recommendations related to the offshore transmission sector. One of these was to explore the extent to which the sector could improve the way it shares knowledge, lessons learned and overall good practice, and estimated that this, plus standardisation, could lead to an up to 20% reduction in transmission Capex.

The Crown Estate is leading work in this area and has commissioned DNV GL to:

i. identify lessons learned to date in the development, construction and operation of offshore transmission infrastructure;

ii. recommend an approach for industry to share good practice on an enduring basis and

iii. quantify the potential impacts of such an approach in terms of LCOE.

This report is the culmination of this work, which provides evidence and draws conclusions based on a number of sources. Primary research was undertaken through semi-structured interviews with 19 industry stakeholders (comprising developers, OFTOs, OEMs and contractors, among others); further details on those that took part and the questionnaire used are in Appendices 4 and 5 respectively. DNV GL believe this represents a significant proportion (more than 50%) of the major players in the offshore transmission sector and therefore consider the results representative of the sector as a whole. The interviews were complemented with internal DNV GL institutional experience and a literature review of eight recent conference proceedings and public domain reports. When considering ways in which the sector could adopt a more structured approach to sharing knowledge and good practice, DNV GL also undertook a review of similar schemes in other industry sectors, in addition to drawing on feedback collated via the interviews.

Scope of the project

For the purpose of this report, scope has been bounded by the assets which will ultimately become owned and operated by Offshore Transmission Owners (OFTO), i.e. the offshore substation (and offshore converter station), export cable and onshore infrastructure (cable and substation/converter station). Array cables within the offshore wind farm are not considered in detail and neither is any onshore transmission infrastructure within the Main Interconnected Transmission System (MITS).

Furthermore, the focus of the work was on technical considerations as opposed to the merits of different regulatory options. However, interviewees commented on the regulatory frameworks during our dialogue and this is included where appropriate in this report.

Structure of this report

This report is divided into three main parts, as summarised below.

[1] Offshore Wind Cost Reduction Task Force Report, June 2012

Part 1 – Lessons learned to date

The first part of this project was to undertake a retrospective review of lessons learned to date, with the results detailed in two interlinked sections. **Section 3** of this report provides an overview of the findings, drawing out big picture issues and providing a summary analysis of the lessons as a whole. Many offshore wind projects have experienced similar impacts in terms of delays and cost overruns, and in order to avoid repetition within the report, an overview of these impacts is provided. The root causes of these impacts on delivery of export cables and offshore substations is provided through fishbone diagrams. **Section 4** discusses each lifecycle stage in turn, providing commentary around the lessons learned.

A challenge when considering 'lessons learned' is whether the lesson has already been learned - i.e. the particular issue was a problem but the industry has now dealt with it – or whether it is still a problem today. Furthermore, some of the issues identified may be more relevant to future offshore wind projects than others, for example as a result of the scale of the project or technology choice. Where possible, this report provides commentary on whether a lesson is historic, current or relevant to future projects. However, for completeness, this report includes as many lessons as possible, thereby allowing the reader to decide whether or not that lesson remains relevant to their organisation or project.

Part 2 – Sharing good practice

Section 5 seeks to identify how the offshore transmission sector could share good practice on an enduring basis. This begins by mapping out existing initiatives in the sector and considering what may be needed, based upon interview responses and a review of experience from other sectors. The report also makes a key recommendation for enabling the offshore transmission sector to better share knowledge and learn lessons, through establishing a central 'knowledge hub'. Whilst it appears there are a various ways in which stakeholders do share knowledge, a more formalised approach would have the effect of better coordinating information flow and make a material contribution to reducing costs.

Part 3 – Quantifying cost reduction potential

Section 6 seeks to quantify the cost reduction benefit of the various lessons identified in Section 4, while providing support for the overall benefits of sharing good practice on an enduring basis. It does this through the development of a simple cost model and assessment of the cost reduction potential of a range of initiatives.

3 LESSONS LEARNED - OVERVIEW

This section provides an overview of the lessons learned to date in the development, construction and operation of offshore transmission infrastructure, capturing big picture items which may be lost in the discussion around the individual lifecycle stages. To avoid repetition, an overview of the impacts experienced by offshore wind related transmission projects is provided along with an assessment of the various root causes that have led to those impacts.

3.1 Summary results

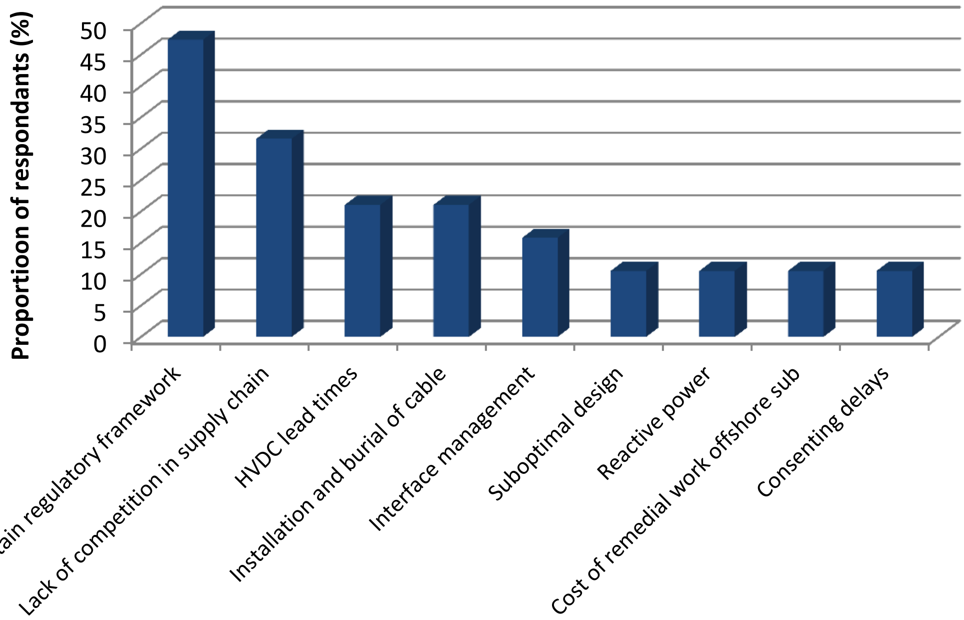
3.1.1 Key concerns

The top nine problems cited most often by interviewees are shown in Figure 3-1. The single most cited problem (by 50% of interviewees) was the uncertain regulatory and policy framework which makes the design and operation of wind farms and the associated offshore transmission infrastructure challenging. This uncertainty covers a range of issues including the impacts of Electricity Market Reform, the OFTO regulatory regime and tender process, the wider regulatory policy landscape (including Integrated Transmission Planning and Regulation - ITPR[2]) at a domestic level and European level measures, such as the incoming European Network Codes. DNV GL suggests that this uncertainty hinders cost reduction efforts, with developers having to factor in contingencies and increasing uncertainty around future delivery.

The second most cited problem was the lack of competition in the supply chain, which is particularly acute for HVDC systems. Third most cited were the long lead times for HVDC equipment. Installation and burial of the export cable and management of interfaces were fourth and fifth respectively. Interestingly, very few interviewees raised strong concerns relating to the onshore assets. DNV GL suggests that this distribution of the areas of concern flagged is reasonably representative of the problems faced by the industry, given the marine environment presents significantly more challenging circumstances compared to onshore operations.

2 https://www.ofgem.gov.uk/electricity/transmission-networks/integrated-transmission-planning-and-regulation

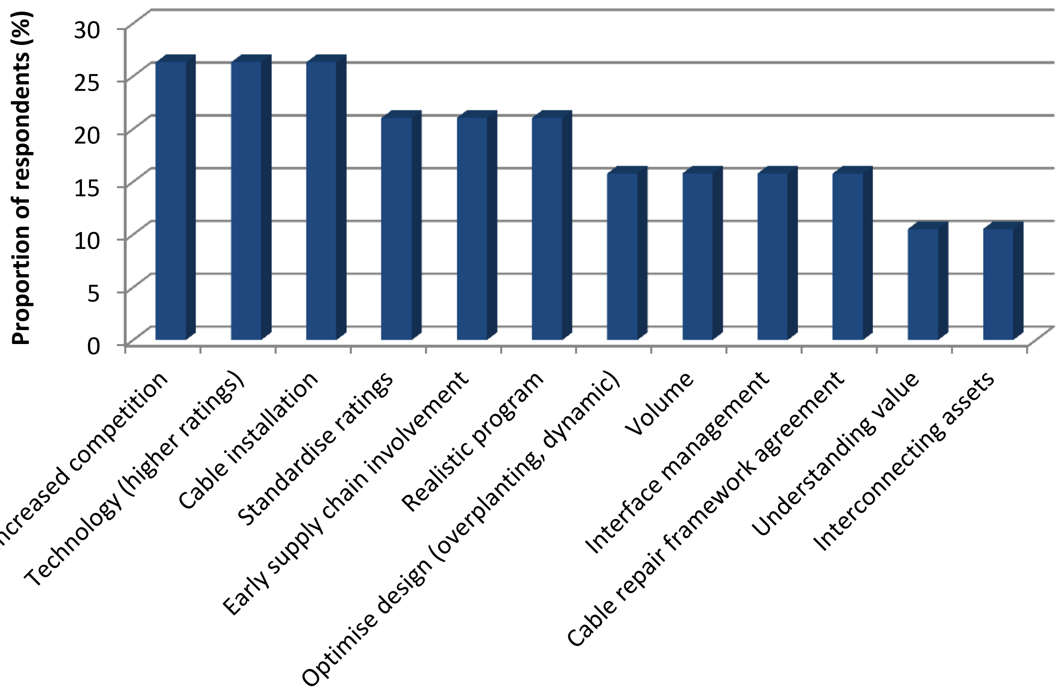
Figure 3-1 Problems cited most often by interviewees



3.1.2 Cost reduction potential

Interviewees were also asked to consider where they thought the greatest potential for cost reduction was, with the top 12 results shown in Figure 3-2. DNV GL considers these an accurate representation of the 'big picture' issues within offshore transmission.

Figure 3-2 Proportion of interviewees who cited potential options for cost reduction



3.2 The impacts

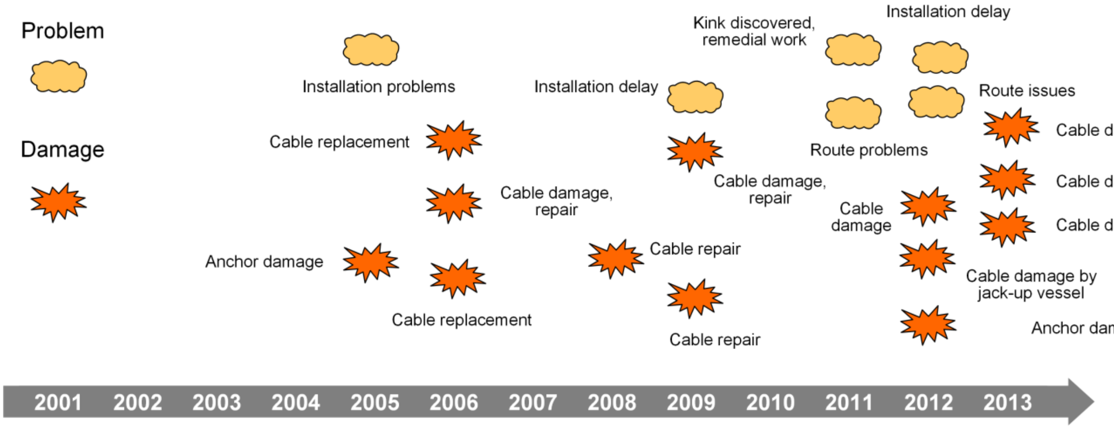
Whilst Section 3.1.1 identifies where interviewees considered the broad topic area in which problems have occurred, this does not necessarily illustrate where the biggest impacts have been felt. In this regard, aspects of export cabling have been particularly problematic. This was picked up in a recent Ofgem report which said: "The installation of the submarine cable is the most challenging part of constructing the transmission assets and therefore carries the biggest risk… All the projects to date have had issues regarding the cable installation, albeit to different degrees"[3]. Whilst challenges with export cables have been well documented, DNV GL is also aware that there have been some substantial issues with the offshore substations/converter stations as well.

To avoid repetition in the report, the following paragraphs provide a summary of the range of impacts which DNV GL understand have been experienced with export cables and offshore substations/converter stations across the sector, with subsequent sections then considering the causes of these impacts. It is important to note that this is a summary of impacts *across the industry* and therefore presents a more pessimistic picture than would be the case for any individual project. Care should be taken when drawing conclusions for individual ongoing or future projects.

3.2.1 Export cable

There have been a range of well-documented problems with export cables across the industry over at least the last decade. These include: manufacturing defects, poor storage, challenges in burying the cable to specified depth, project delays and cost overruns, mismanagement between supply of the cable and installation contractors, unsuccessful horizontal directional drilling (HDD), damage from jack-up vessels, poor landfall design, and poor termination workmanship at the offshore substation. The chart below gives a panoramic picture of some of the issues noted from the public domain sources.

Figure 3-3 Export cable issues experienced by offshore wind farm projects



Impacts from cabling problems such as these have included:

- significant remedial work requiring replacement cables, storage sites, additional vessel costs and project management costs,
- delay to start-up of the wind farm,
- lost wind farm generation revenue due to cable damage,

[3] Ofgem – "Offshore Transmission Cost Assessment: Development proposals" 4/12/13

- transfer value determined by Ofgem being less than the actual costs of developing the transmission infrastructure (paid for by the developer under the Generator Build model),
- delay in transferring assets to the OFTO,
- regular ongoing remedial work, and
- claims and counter claims.

A number of interviewees noted that the "cabling has resulted in around 80% of insurance claims to date" (although this includes array cables). The industry has responded to these issues. For instance, CIGRE published "Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to 500 (550) kV" in February 2012 and a DNV GL led Joint Industry Project resulted in publication of the guideline "Subsea power cables in shallow water renewable energy applications"[4] in February 2014. The Carbon Trust is also undertaking work in this area – see Section 5.2.

3.2.2 Offshore substation and offshore converter station

DNV GL understand that there are a significant number of issues with the offshore substation and offshore converter station that are less well-documented publicly, partly due to the commercial structures which often allow the developer and OEM to resolve issues without the need to report in the public domain or involve insurers.

Despite this more opaque nature, documented issues associated with the offshore substation and/or converter station include:

- transformer failure (e.g. Nysted[5]),
- non-conformities to design specifications,
- design flaws,
- manufacturing defects,
- corrosion,
- installation delays (e.g. DolWin Alpha[6]),
- access and egress issues,
- fire (e.g. Horns Rev II[7]),
- termination interface issues, and
- poorly designed boundary points.

Impacts from offshore substation and converter station problems such as these have included:

- delays and knock on impacts,
- cost overruns,
- standby and additional vessel cost,
- significant offshore snagging,
- exceeding weather windows,
- significant ongoing remedial work, and
- downtime.

3.3 Root causes

Many of the issues identified above have manifested once the offshore assets were installed or operational. However, DNV GL suggests that there are multiple root causes of these issues.

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[4] DNV-RP-J301, see www.dnvgl.com/rules-standards/default.aspx#2
[5] Moller, T. (2007). Danish offshore plant down, Windpower Monthly, 01 Jul 2007.
[6] www.offshorewindindustry.com/node/22826, accessed 05 Mar 2014.
[7] Dong Energy (2009). Mindre brand i kondensator batteri på transformerplatformen, www.dongenergy.com, accessed 09 Jun 2009.

To highlight the complexity of delivering these projects on time and budget, the 'fishbone' diagrams below seek to summarise the root causes that have impacted the successful delivery of export cables and offshore substations/converter stations. These graphics were developed on the basis of the information provided to us during the interviews, and supplemented by DNV GL experience. They consider the sector as a whole, and not a single project.

On the left of the diagrams the various causes are shown. The black text shows individual causes, which are categorised into larger 'themes' highlighted in bold blue text. These themes ultimately lead to effects on the right hand side, either on the export cable or the offshore substation and converter station. The root causes identified are picked up in the project lifecycle stage discussions in the following sections with the relevant section detailed in the numbered brackets.

Figure 3-4 Fishbone diagram showing the root causes of export cabling issues

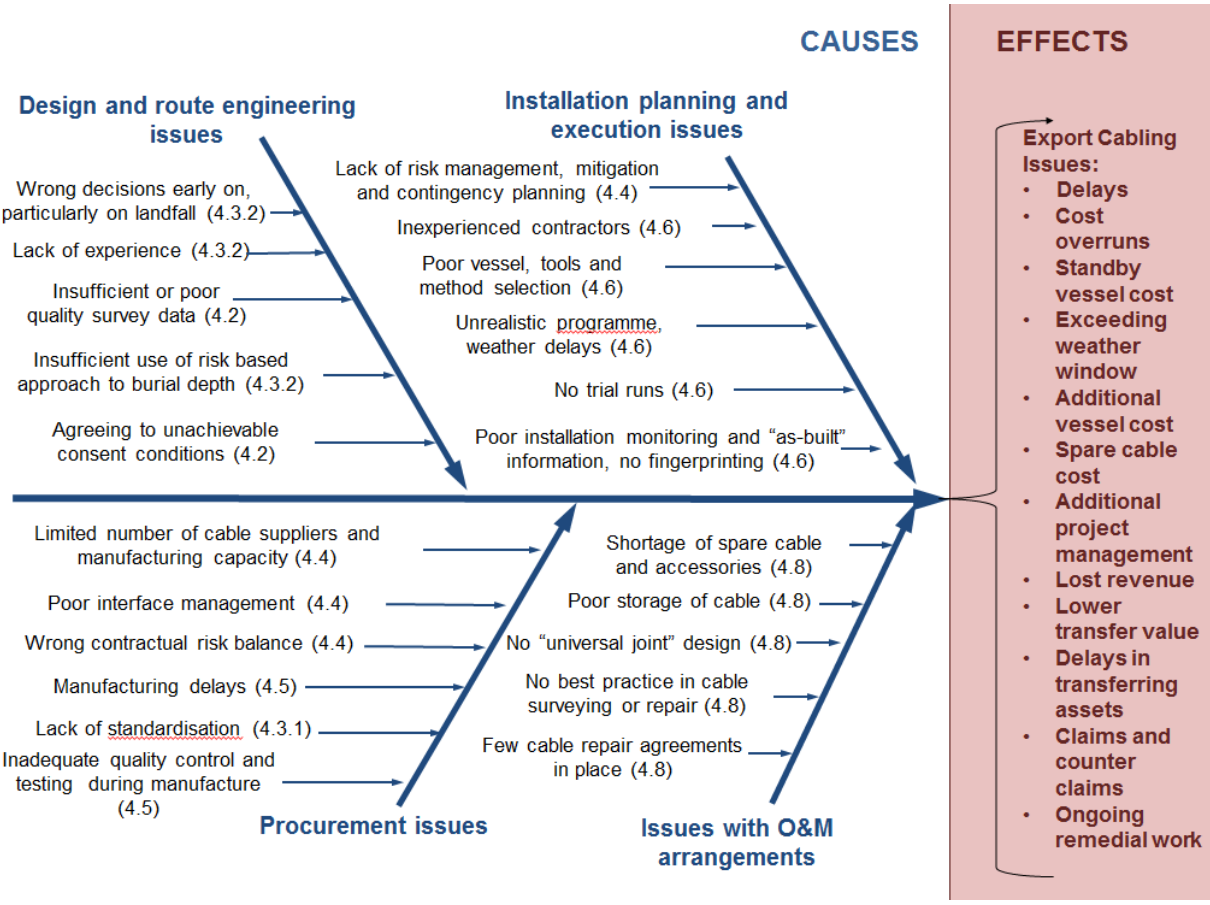
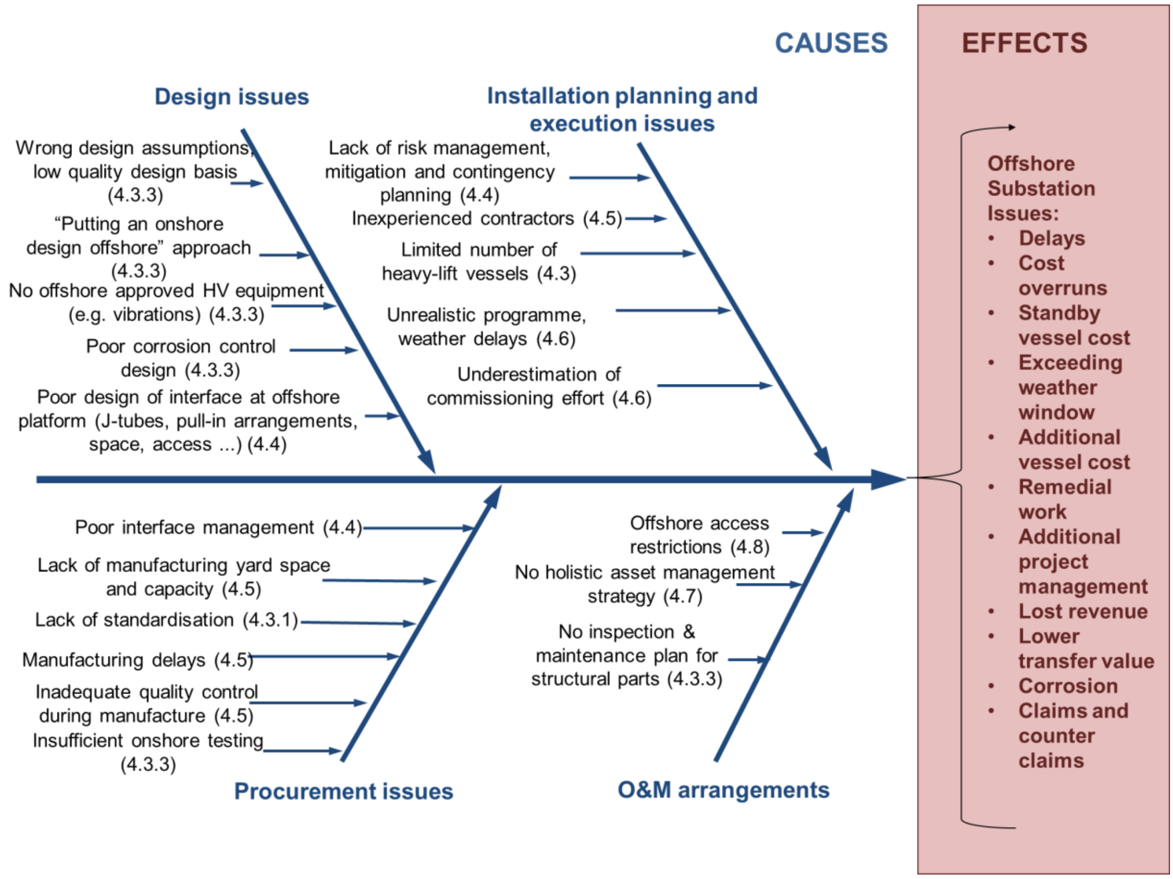


Figure 3-5 Fishbone diagram showing the root causes of offshore substation/converter stations issues



DNV GL suggests that these diagrams highlight the importance of doing the right work up front, with the industry still seeking to identify how much to invest initially (at risk) to effectively de-risk the following project phases. Although the focus is often on minimising Capex, the industry should take much greater account of lifecycle costs and choose 'value' over 'price'. Operational data will play an important role in this, allowing operational teams to push for design changes which may increase Capex but reduce costs overall. For instance, data on export cable failures is likely to provide support for interconnecting separate electrical systems within a wind farm to increase redundancy (but slightly increasing Capex).

4 LESSONS LEARNED BY PROJECT LIFECYCLE STAGE

This section reviews lessons learned through each lifecycle stage of offshore transmission infrastructure. As far as possible, we have captured the specific points as elicited through our research, although in some cases issues have been aggregated for the purposes of reporting. Nevertheless, DNV GL believes that the following provides an accurate description of the most pressing issues that the offshore transmission sector has faced to date.

The tables at the end of each sub-section set out in high level terms potential responses – or areas of good practice – to the lessons learned identified, which may help reduce the likelihood and/or impact of issues on future projects.

4.1 Methodology

Information was collated from interviewing 19 organisations in the sector including a range of developers, OEMs, contractors and transmission companies, who represent a significant proportion of the major players active in the UK. This primary research was supplemented through a review of proceedings from eight conferences and public domain reports and making use of DNV GL institutional knowledge. DNV GL has sought to make it clear where an assertion is based upon the interviews, conference proceedings or DNV GL understanding and analysis.

4.2 Lessons Learned in Consenting and Surveying

Consenting is a critical element of the development process with great potential to add value to the project within the early stages. As with any major construction project, aligning incentives between the consenting, construction and operational phases is a challenge, and some interview respondents noted that too much focus has been given to consenting issues to the detriment of constructability or operability. For instance, one respondent noted that a developer had chosen an option with a shorter onshore cable route (with fewer land owners), leading to a much longer submarine cable route which posed a higher risk during construction and operation. A number of respondents noted the importance of retaining flexibility throughout the consenting process to allow optimised design or installation solutions.

Various interviewees stated that some consent conditions have caused serious problems for offshore transmission. In particular, major issues have occurred when developers have agreed to a fixed cable burial depth (of say 2m) along the cable length as a consent condition. DNV GL understands that this may now be somewhat historic and the UK sector is taking steps towards risk based burial indices[8], but interviewees noted that recently commissioned wind farms have still suffered from this issue. Committing to fixed burial depths is problematic because ground conditions are likely to vary substantially along the route. Even with substantial survey and route planning, last-minute challenges and obstacles may materialise during the installation phase. At the same time, DNV GL notes that measurement of burial depth involves large uncertainties, with error bars of at least 10cm. Furthermore, burial depth assessments may not be possible once the depth is greater than 2m. Lastly, a number of interviewees consider a fixed burial depth as fairly arbitrary in areas with mobile sediments such as sand waves.

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[8] Risk based indices take account of factors such as ground conditions, fishing traffic, risk of anchor strike, etc. to derive a more nuanced burial depth along the length including the consideration of rock placement or mattresses. The Carbon Trust Cable Installation Group has commissioned a project to develop a refined offshore wind Cable Burial Protection Index.

"I remember at the 2005 RenewableUK conference where somebody from North Hoyle recommended not to commit to a fixed cable burial depth – yet we are still doing it today."

- OFTO

Another key lesson noted by a number of parties is the importance of collecting sufficient geophysical and geotechnical survey data for the cable route and landfall area. All wind farm developers undertake surveys but DNV GL understands that too often the strategy and specification have not been aligned with the requirements for cable routing and burial, leading to installation problems later on.

For instance, shallow water sections including landfall cannot always be covered by the main survey vessel (with special low draft vessels required) and this can result in poor data in this crucial area. Furthermore, geotechnical surveys for foundation purposes commonly do not yield any useful data for cable routing purposes. Changes to cable routes and the potential of major storm events to impact the bathymetry also need to be considered when specifying the scope and area of investigation.

"You can almost never have enough [survey data] – this ends up on the lessons learned chart for a lot of the projects out there."

- Developer

In terms of costs, DNV GL understands that a geophysical and geotechnical survey campaign along the cable route can cost in the order of £200-600k depending on length, location and other factors. This is a necessary investment, although much more challenging to spend at risk early in the development process. However, even with a well-executed survey campaign, one contractor noted that due to the uncertain nature of soil conditions in general, the results from collected and analysed soil data cannot provide 100% certainty about the actual soil conditions that will be experienced during the execution of the project. Appropriate mitigation and contingencies should therefore be considered, including need for back up vessels/burial tools, appropriate contractual risk and data sharing and a strong risk management framework. Further information on survey specification can be found in documents such as DNV GL's Subsea Power Cables in Shallow Water Renewable Energy Applications Guidance Note (DNV-RP-J301)[9] and an upcoming Society for Underwater Technology Offshore Site Investigation and Geotechnics Group[10] guideline, expected to be published in spring 2014.

Table 4-1 Summary of consenting lessons learned

Whole system	Consider lifecycle
Export cable	Use risk based burial indices to define consent conditions on burial depth Collect appropriate survey data along the entire cable route

9 https://exchange.dnv.com/publishing/Codes/download.asp?url=2014-02/rp-j301.pdf
10 http://sig.sut.org.uk/sutosig.htm

4.3 Lessons Learned in Design

The largest number of lessons were identified for the design phase, as design covers a wide range of issues, from the overall electrical layout of the transmission infrastructure to the minutiae of cable hang-offs at the offshore substation. Issues affecting the overall design of the offshore transmission system are considered first, followed by the export cable and offshore substation / converter station.

4.3.1 Design of offshore transmission system

A key issue identified by some developers was that the electrical design element was the most difficult aspect of the whole wind farm design process, with a huge number of variables and different outputs to optimise against (cost, availability, redundancy, supply chain limitations, etc.). As a result, one respondent noted that although the transmission infrastructure represents only 15-25% of the offshore wind project Capex, it requires a disproportionately higher design effort. Given these challenges, a number of respondents highlighted the importance of bringing in the supply chain at the design stage or even earlier to provide an additional level of understanding as to the specific technical capabilities of equipment, survey requirements and/or means of optimising the design. The literature review also highlighted the need to bring in operational personnel at an early stage.[11]

4.3.1.1 OFTO regime

The introduction of the OFTO regime in Great Britain was cited by a number of developers as a major difficulty for early Round 1 and Round 2 developers who had not expected, or had no clarity over the process, to sell off the transmission element of their projects. Developers are now fully aware of this requirement with a defined process in place, and take steps to design in a clear boundary between generation and transmission assets. For instance, one developer explained that they had split the transmission element and wind farm into two separate virtual projects to allow better cost separation, justification for design options and independence in the operations phase.

"You have to be aware of the fact that you might not actually get to operate the transmission asset…and plan for this within the design process."

– Developer

Some respondents noted the potential for the OFTO tender process to lead to more conservatism in design while others noted that the process does entail added time, complexity and management resource. Having said this, few mentioned fundamental change was needed, which suggests a general acceptance of the regime. The challenge is now to make the process as effective as possible to reduce cost and risk implications for offshore wind farm developers. An interesting development is Ofgem's recent consultation on a proposal to introduce cost benchmarking[12], which should provide increased visibility on relative costs across the sector.

[11] Lutz Falta – 'Operation experience with the manned platform for GT1' – 24.08.2013 presentation at 2nd International Offshore Wind Power Substations, Germany

[12] https://www.ofgem.gov.uk/ofgem-publications/84971/offshoretransmissioncostassessment281113.pdf

4.3.1.2 Standardisation

A key point discussed by almost every interviewee was standardisation, with a wide range of opinions of its relative merits. On the whole most interviewees believed increased standardisation of transmission modules would be beneficial in terms of realising cost reduction, with OFTOs particularly in favour of this. Given the term 'standardisation' can mean a multitude of different things (e.g. covering both component standardisation *and* system standardisation), the dialogue during the interviews varied on this point. These differences of interpretation are explored in further detail in Appendix 1. Despite this, two aspects of standardisation were recurrent themes: a) design of offshore substations and offshore converter substations and b) cable ratings. Each is considered below.

On the design of offshore substations and offshore converter substations, key issues noted during the interviews were that:

- Virtually all substations built to date have been bespoke designs, which is likely to maintain higher costs as the benefits of repeat design do not flow through to future projects, and there is limited compatibility between projects.
- Potentially as a reaction to this, at least one developer (DONG Energy[13]) is moving towards a relatively standardised design which may help provide a stimulus to the wider market. Other developers designing future wind farms also stated in the interviews that they were no longer accepting fully bespoke designs for substation topsides.
- Siemens have stated they have developed a reference design[14] and are also seeking to standardise on HVDC converter stations of 900MW and 320kV for the German market[15].
- Interviewees noted that benefits could arise from developing a set of reference designs for substations. Reference designs would allow parties to start from the same point and then adjust the design to take account of site specific circumstances when appropriate. The reference designs would consider issues like: what should the standard transformer dimension be, what should the voltage rating be, how many are needed, where would they be located on a substation, how should they be connected, how much can they be overloaded, can ester based systems be used, how many export cables are used etc[16]. Such an approach would not need to be a formal technical standard, but instead an industry guideline or a best practice note.
- The benefits of standardisation should be seen across the lifecycle – from consenting through to operations, for instance when considering the provision of spares.
- A number of past, current and potential future initiatives were highlighted by interviewees, including:
    - The Crown Estate who organised a piece of work promoting modular approach (standardisation on voltage and power ratings) in 2011;
    - DNV Offshore Substation standard (DNV-OS-J201) and Joint Industry Project to undertake technology assessment for HVDC systems;
    - RenewableUK's Offshore Grid Group who have formed a small working group to consider benefits of standardisation and where this could be more effectively introduced;
    - CIGRE who have a DC-connected substation working group after an authoritative technical brochure for offshore AC substations[17] was produced in 2011;

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13 Mats Vilkolm – DONG Energy "New ways of working in Offshore wind" Nov 2013 EWEA Offshore conference

14 Matthew Knight: "Hard won lessons from offshore grid connections" 22nd May 2013 All Energy

15 It is acknowledged that this reference design may not be suitable for projects in UK waters, but included by way of example.

16 This list is illustrative based on the feedback from the interviews. In practice it would be expected that any guideline or guidance note would include issues such as structural design and auxiliary systems.

17 CIGRE: Guidelines for the design and construction of AC offshore substations for wind power plants. Working Group B3.26, Technical Brochure 483, December 2011.

- Interviewees also suggested that there may be a role for Ofgem to develop or at least encourage the development of 'best practice' guidelines through its cost assessment guidance;
- The Carbon Trust is looking at how to optimise AC and DC systems including optimisation of substation design.

On submarine cables, the key issue that came through the interviews was standardising cable voltage and capacity ratings, with a number of interviewees pointing to the lack of compatibility between different wind farms and the implications this has for spares provision. This lack of compatibility is confirmed by the fact there is a wide range of voltages used to connect wind farms to the UK transmission system.[18] Generally there seemed little optimism that standardisation would happen on cable ratings in the near term due to the lack of a clear means of doing so.[19]

4.3.1.3 Overplanting

A number of developers noted that to date, offshore transmission links have been typically sized conservatively, without due consideration of the actual generation profile of the wind farms and optimisation of the assets (for instance transmitting more than rated capacity or curtailing off power for short periods). It was noted a better balance could therefore be struck by optimising the transmission capacity against the installed capacity of wind farms in what is known as 'overplanting'[20]. Internal modelling work by DNV GL suggests that this approach can reduce the LCOE of projects, by increasing the generating capacity by around 8% (through a greater number of wind turbines) for the same transmission asset (although this depends on project specific factors).[21] This is particularly important for larger projects that are located further from shore.

Dynamic rating is a related but separate initiative to overplanting and is discussed further in section 4.3.2. Overplanting increases the average load factor on cable and equipment and thus reduces the scope for dynamic ratings. Overplanting and dynamic rating should be considered in conjunction with each other as part of the overall design.

4.3.1.4 Reactive power compensation

Another area which interviewees suggested could potentially be further optimised was reactive power compensation requirements, with some respondents noting that the current requirements were too conservative. This was partly because there are already requirements on both the wind turbine – with newer turbines having much greater reactive power capability - and the onshore substation. One developer noted that reactive power control equipment onshore can cost around £10million for a 300MW wind farm, suggesting that significant savings could be made across the network, with another developer estimating that the industry could save around £90 million in total capital savings by 2020. A developer suggested that it may be beneficial to revisit Grid Code requirements to make better use of wind turbine generator reactive power capability, although with OFTOs, a commercial agreement may be required between the generator and OFTO to provide reactive power services. From a system operator perspective, some degree of coordination around

[18] To date, projects have been connected at AC voltages including 132kV, 150kV, 155kV, etc in the UK and 110kV -170kV in Germany, not to mention the various DC voltages in Germany.

[19] This report has not considered in quantitative terms benefits from standardising cable ratings.

[20] The term 'overplanting' refers to optimising the relative sizes of total wind farm capacity, offshore substation capacity, connection to shore, and grid connection capacity. As an example, for a wind farm with about 95% availability and 40% load factor, there will be only a small number of hours in the year when all turbines are fully available and at full output, which means the electrical system capacity and grid connection capacity can be lower. A complex optimisation involving consideration of curtailment, electrical losses, failure rates, repair times, and coincidence of high output with low temperatures and high natural cooling would be required. For information, based on an assessment by The Crown Estate (using actual half hourly output data from 12 large UK offshore wind farms as of March 2014), a 10% overplanting of the windfarm may lead to a curtailment of 0.1%~1.6% (i.e. a reduction in the MWh energy yield). This lost generation opportunity needs to be balanced against the reduced cost of the transmission infrastructure.

[21] See Section 6.2 for more detail

reactive power compensation requirements between developers is likely to be required. The Carbon Trust stated that they are considering options for reactive compensation as part of their AC Optimisation study.

4.3.1.5 Other aspects of offshore transmission system design

Two respondents noted the importance of obtaining project-specific details on key design parameters before contract signing, for instance around wind turbine models, harmonics, horizontal directional drilling (locations, ground conditions), grid code compliance; all of which are needed to properly optimise the electrical system and may only be provided after design decisions are made. An interviewee noted that this lack of detail has led to delays or incorrect ordering of plant.

DNV GL note the importance of ensuring that the responsibility for electrical design of the transmission system is clearly defined and understood, and that this responsibility is assumed continuously through design, fabrication, installation, commissioning and operation phases, with comprehensive management of change and well managed transfer of responsibility.

Relatively few respondents discussed the process by which National Grid determines the onshore connection point, although some developers noted the importance of a close and productive relationship with National Grid to ensure the right, cost effective and de-risked connection.

Looking forward, an open question within the design process for many developers is whether to use AC or DC for transmission. A couple of developers noted significant challenges with adopting DC solutions, citing a relative lack of track record (of VSC type large capacity DC systems) and long and variable lead times. It was noted that DC solutions had an added complexity given interactions with EMR timescales (see Section 4.3.1.6). Further, the German HVDC experience was mentioned by almost all parties and has negatively impacted the enthusiasm of developers towards this technology – see the box below for an overview of the experience from Germany.

Challenges with HVDC have led some interviewees to consider the potential of a low frequency AC (LFAC) option (e.g. at $16^{2}/_{3}$ Hz), which for offshore transmission is currently only at a research stage. Internal DNV GL modelling work indicates that electrical losses may be substantially lower for LFAC compared to 50 Hz AC transmission and the maximum achievable transmission distance could be significantly longer than for 50 Hz AC. Whilst little evidence is in the public domain, using LFAC transmission could lead to potentially significant cost saving compared to more conventional technologies, particularly if the wind turbines produce power at LFAC and the offshore HVDC converter station and auxiliary AC substation are replaced by one LFAC offshore substation.

HVDC experience in Germany

Many interviewees discussed the high-profile HVDC grid connection issues experienced in Germany which have included delays, cost overruns and a mismatch between completion of the wind farm and export system. A range of potential causes were identified including:

- *Innovative application of the new Voltage Source Converter (VSC) technology*
- *Limited supply chain capacity, with only two European suppliers in the market currently (increasing to three in 2014)*
- *Sheer size of the HVDC converter platforms (11,000~17,000 tonnes topsides weight) which is at the upper end of what has been installed to date in the oil and gas sector. This led to very restricted installation options (and high installation risk and high cost); this risk being magnified given that only two vessels in the world are able to lift over 10,000 tonnes. The other option available for these large platforms (and the only one for the largest platforms) has been to use innovative self-installing platforms. The fabrication of these structures presents another huge challenge with few European yards being big enough to do so.*
- *Insufficient capitalisation (i.e. balance sheet) of TenneT (one of the TSOs)*
- *Bespoke design of each substation*
- *Design changes during the fabrication process*
- *Limited resource at licensing authority BSH combined with active design approval role.*
- *Increased demand for interconnection restricting the cable supply market further, (although it is noted that offshore wind HVDC transmission and HVDC interconnection do not necessarily use identical technologies).*

The major delays reported on these German projects have led to multi-million euro compensation claims. It has been widely reported that Siemens and ABB (main equipment suppliers in the German HVDC market), and also some developers, have been financially affected by these, posting losses partly as a result of these issues. One interviewee noted that UK projects are likely to pay for mistakes in Germany, with a significant risk premium being added to any future HVDC links for offshore wind.

4.3.1.6 Electricity Market Reform and HVDC systems

Two developers and an OEM noted major concerns with the apparent incompatibility of the delivery timescales laid down under the Electricity Market Reform (EMR) and that which is required for HVDC systems. Specifically, the latest developers can commission and receive strike prices, under the first EMR Delivery Plan, is March 2019. However, they are unlikely to know whether they have successfully obtained a Contract for Difference (CfD) until late 2014/early 2015. Given the around four year lead times currently quoted for HVDC transmission systems, this would require the developer to either a) order the HVDC transmission required before reaching Final Investment Decision (FID) (termed Significant Financial Commitment under EMR) or b) have done sufficient development to reach FID almost immediately after being allocated CfDs, which would be difficult to do because of the large uncertainty as to whether a project would receive a CfD contract. Given delays in Germany, the risk of delay would also need to be considered with large uncertainty as to how DECC would utilise contract termination or erosion rights in the case of delay. The significant cost of HVDC transmission systems (potentially increasing the transmission element of the project Capex to over 25%) amplifies these challenges and suggests real difficulties in delivering HVDC links under this framework.

4.3.2 Design and routing of export cables

Issues with route engineering and the design of export cables were a common theme throughout the interviews. DNV GL would suggest most projects to date have not spent long enough designing the cable route, having too little offshore experience within the project team. In particular, consideration of the landfall has often been inadequate, causing difficulties as this almost always requires a tailored solution and can be costly. For instance, on London Array the shore landings cost approximately 13% of the total cable installation costs[22]. Along the cable route, many respondents noted the importance of risk-based indices for assessing cable burial depth with The Carbon Trust currently seeking to develop a fit-for-purpose Cable Burial Protection Index. This would take into account factors such as ground conditions, sediment type, shipping and fishing to determine an appropriate burial approach.

Many interviewees noted the potential for cost savings through dynamic or real-time rating of cables, with cables to date usually sized for the maximum installed capacity, despite the wind farm rarely operating at full power unless some ‘overplanting’ has already been incorporated in the wind farm design. Interviewees were aware that there is currently no design standard for wind power loading, with the closest being an IEC standard around daily load cycles (IEC 60853-2). The result is that export cables are potentially underutilised, with one developer estimating that the capital cost of the cable could be reduced by 10%. The fact that there is no IEC standard does pose a challenge to this approach, with IEC standards taking years to develop. Without such a standard, developers noted concern over whether OFTOs would accept cables to be operated to non-IEC conditions and whether National Grid as the System Operator could support on security requirements.

DNV GL note that dynamic rating must be complemented by distributed temperature sensing (DTS) in cables which gives a greater understanding of the actual cable condition. To date significant contingency may be included to ensure that cable temperature limits are not exceeded causing permanent damage to the cable or provoking uncertainties in relation to cable life, warranties and insurance. However, through greater monitoring of the cable DNV GL suggest that this contingency could be reduced with the potential to operate the cable at higher ratings for short periods of time. DNV GL note that DTS provides less certainty over very long cable lengths and may be less effective with AC onshore. Consequently introducing DTS in cable systems (both onshore and offshore) should be considered as part of an integrated design stage and not later once the cable is delivered or installed.

Cable manufacturers pointed to the potential benefits of XLPE insulation, aluminium conductors and mixed armouring to save cost, although these may require prequalification testing.

Similarly, dynamic rating of transformers could be addressed[23].

To overcome these challenges in relation to the implementability of dynamic rating, developers suggested that Ofgem offer interim guidance on this issue and there was general support for cross-industry action to explore the options in more detail – see Appendix 1.

[22] Arnoud Roels, VSMC: ‘Experience with cable landfalls during the London Array project’ – 13/05/13 – International Offshore Cabling Conference 2013

[23] Kevin Wilson, ABB ‘The application of Continuous Emergency Rated (CER) transformers for offshore wind farms’ 22nd May 2013 All Energy

4.3.3 Design of offshore substations / converter stations

Issues with offshore substations and converter stations were discussed often during the interviews. One lesson learned that came through strongly during the interviews was not to build offshore substations on monopiles if significant wave interaction can be expected. DNV GL note that wave loading on the monopile creates significant accelerations, deflections and resonance which can result in failure of mechanical and electrical components, leading to outages and repair work. Mitigation options include building in damping systems and using jacket structures (which appear to be increasingly favoured).

Linked to this, DNV GL note that medium voltage and high voltage equipment used on offshore substations is not necessarily qualified for use in an offshore environment because only lower voltages are commonly used for equipment in ships and offshore oil and gas installations. With regard to vibrations, DNV GL understand that HV equipment is commonly tested considering transportation to the installation site and the potential of earthquakes. These accelerations spectra are very different from those induced by continuous wave interaction over a 20 to 25 year life span. DNV GL would suggest that long-term experience needs to be obtained and specific approval procedures may need to be developed. With the possibility of component failure, offshore substations and converter stations should always be designed with major component replacement in mind, which is backed by a CIGRE report from 2011[24].

Another issue raised by OEMs was corrosion of the offshore substations and converter stations (particularly on early designs), installed with inadequate cathodic protection or paint coating leading to significant and ongoing corrective work. The industry has learned lessons and designs have improved, although there remain some concerns about corrosion over the full lifecycle of the assets. Corrosion protection costs can also be significant with TenneT suggesting 21% of the maintenance costs on an offshore substation are spent on corrosion protection[25]. The design should also consider the practicality of applying coatings once the substation and converter station is operational, with access being a major challenge. The underside of the platform may have to be considered and operators should understand how to deal with sea water on deck. A clear plan should be developed at the design phase for determining how and when remedial works would be undertaken.

In Germany, a developer noted that the crane is a single point of failure for platform supply and substantial thought needs to be given to logistical requirements before specification and purchase. For instance, the platform crane was designed for a 10ft container and 8t max load when in practice a 20ft container needed to be lifted requiring additional equipment[26].

66kV array cables were mentioned by respondents as offering cost reduction potential. A 66kV solution may also allow a higher fault level design with a simpler arrangement (keeping the fault level within the capability of 33kV equipment in the turbines can be challenging). Array cables are outside the scope of the study but the relevance of 66kV here is the potential to allow smaller, close to shore wind farms to connect directly to land without the need for an offshore substation.

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[24] CIGRE (2011). Guidelines for the design and construction of AC offshore substations for wind power plants, Technical Brochure 483, December 2011.

[25] Christoph vor dem Brocke – TenneT – 'Considering O&M in the design – Lessons Learned and examples' 24.08.2013 presentation at 2nd International Offshore Wind Power Substations, Germany

[26] Lutz Falta – Global Tech 1 – 'Operation experience with the manned platform for GT1' 24.08.2013 presentation at 2nd International Offshore Wind Power Substations, Germany

Table 4-2 Summary of Lessons Learned in Design

Whole system	Consider system standardisation of capacity ratings and voltage levels Overplant, subject to Cost Benefit Analysis Optimise approach to rating of cables and transformers Optimise reactive power requirements Provide early detail on design parameters Bring in supply chain early Important to consider OFTO regime requirements in contracts
Offshore substation and converter station	Develop a set of reference designs Avoid monopiles if significant wave interaction can be expected Consider corrosion prevention
Export Cable	Design in better condition monitoring systems

4.4 Lessons Learned in Procurement

Along with design, procurement was one of the areas of focus amongst interviewees. The degree of competition, number of experienced players and the capacity of the supply chain to deliver were cited as major concerns. More specifically, focus was drawn to cables, cable installation vessels (including inter-tidal operations) and crew. One interviewee suggested learning from National Grid, who is seeking to facilitate greater competition in one segment of the transmission market by working with a supplier (Hyundai) to help type test onshore transformers. Looking ahead, interviewees considered HVDC systems would be a serious area of concern given the limited capacity in the market, competing demands (e.g. from interconnectors) and long and variable lead times.

Risk and contract management was seen as a critically important area with one interviewer noting that: 'risk management frameworks have not kept pace with the size and scale of the developments, with risk strategies for major items being naïve and needing much more input from other sectors'. Furthermore, the balance of risk between developers and contractors was cited often as placing too much risk on parties not able to manage it and a need for both parties to have early and frank discussions over what each are committing to. One interviewee noted that to date developers have had an over expectation, perhaps driven by a lack of offshore experience, or an unclear assumed position. On the supply chain side interviewees noted that there has, with some contractors, been a lack of experience and naivety about the risks involved in working in the offshore environment. DNV GL understand that insufficient consideration of risk or unclear risk allocation, particularly within the cable installation phase, can also lead to difficulties in Ofgem taking a view as to whether costs have been efficiently incurred.

Other interviewees noted that the sector is still learning about cost and value, with developers still seeking to squeeze contractors too far, pointing to the oil and gas sector which has apparently learned that sometimes you have to pay more upfront to get the right results.

Interface management was a challenge identified by several interviewees. In particular, interfaces need to be identified, specified, responsibility allocated at an early stage of the project and subsequently tracked. Failure to do so will result in variations or the need to place additional contracts at a late stage. One developer noted that they have a specialist interface management team who, in addition to defining technical specifications and meeting contractors, are responsible for a tool which tracks and manages interfaces throughout the life of the project. Experience from Germany suggests that it is useful to define design, supply and installation responsibilities in a scope split matrix, use drawings and sketches to ensure a common understanding, organise interface workshops and keep a master document register for all contractors[27]. Key interfaces can be between equipment, stakeholders or both and include:

- Cable manufacture, transport, storage and installation
- Cable terminations on offshore substations including design of I or J tubes
- Landfall connection points
- Fabrication of substation substructure / topsides and programme for installation
- Survey data
- Commissioning and hand over to operations

Definition of key terms is also important with "high availability, redundancies, safe operation mode, continuous operation etc. having slightly different but important meanings in shipyards, power distribution and the wind industry"[28].

One option to reduce interfaces was to have fewer (and larger) contract packages but there were a range of opinions on the relative merits of EPC versus multi-contracting. For those developers capable of managing many complex interfaces, multi-contracting is usually favoured to help retain control of the project. From a contractors' perspective there appeared to be an appetite for larger packages. DNV GL consider that this will continue to be a project-specific decision with a trend towards larger packages as parties become more comfortable with the risks.

There was general agreement that earlier involvement of the supply chain was an important aspect with a couple of respondents noting that having the supply chain involved with the Front End Engineering Design (FEED) study, before contract selection and/or contract award, will help driving better technical solutions. There are different approaches to running this including:

- shortlist and competitive FEED process,
- compensated arrangements, or
- allocating preferred bidders before running the FEED.

The OWPB Contracting Group is exploring this issue in more detail[29].

"It is the supply chain who learn lessons on projects and then apply these to the next'."

– Developer

One developer noted the importance of having contractual access to designers, fabricators & installers and ensuring that these parties are not two or three steps down the supply chain as sub-contractors. Without this access the developer found it difficult to influence the design, fabrication and/or installation of the project. This is particularly important where the main contractors are themselves not specialists in design and fabrication (of certain elements) and hence not well placed to manage their subcontractors in all of these areas.

A small number of interviewees proposed that the inclusion of a 'reasonable endeavours' term, which was initially used by TenneT in Germany, may be a progressive development regarding cable burial. This term states that the contractor will agree with the client up front the approach used to bury the cable, including burial tools and any mitigations. A certain number of burial attempts will

[27] Vincent Buchert – EnBW –'Experience with offshore cabling projects – Planning the implementation phase of Baltic 2' 13.05.13 International Offshore Cabling conference 2013

[28] Lutz Falta – Global Tech 1 – 'Operation experience with the manned platform for GT1' 24.08.2013 presentation at 2nd International Offshore Wind Power Substations, Germany

[29] http://www.thecrownestate.co.uk/media/553197/owpb-annual-report-2013.pdf

be agreed and if the contractor meets these obligations but ultimately fails to bury the cable to the specified depth, then they are considered to have taken reasonable endeavours to do so and responsibility for resolving remaining issues, if any, is passed back to the client. Developments such as this should be considered alongside other initiatives referenced in this report which may be acting in tandem to address similar issues, such as the development of risk-based approaches to cable burial.

DNV GL suggest that spare cable lengths need to be ordered together with the lengths required for the project, as a cable manufacturer cannot, in general, produce small lengths at the very short notice a repair campaign will typically entail. If spare cable lengths are not procured then cable repair times are likely to be significant. Clearly, this would need to be balanced with the efficiency requirements placed on developers including accessibility to any spare pools during Ofgem's cost assessment process as part of the OFTO tender process.

Table 4-3 Summary of Lessons Learned in Procurement

Whole system	Seek to expand supply chain capacity by considering alternative suppliers Effectively manage interfaces Ensure risk is identified appropriately and managed by the entity best able to do so Choose best value not cheapest Ensure clear OFTO split in contracts Ensure contractual access to sub-contractors Consider use of 'reasonable endeavours' clauses in contracts

4.5 Lessons Learned in Manufacture

Manufacturing issues were rarely identified during the interviews as being prominent, but a number of issues came to light in subsequent discussions.

For instance, a number of interviewees noted that offshore substations had been manufactured with non-conformities and were non-compliant with UK electrical standards. One interviewee noted that on some projects offshore substations had been installed before fabrication was complete. The results were substantial (and expensive) offshore work to finalise fabrication, with offshore works costing up to 10 times more than onshore. Some choices will be influenced by season and forecasted weather windows, but a better approach to some of the issues is the use of competent supervision of suppliers and contractors to ensure that issues are picked up and resolved as early as possible, and certainly prior to equipment being shipped and installed offshore.

Another point noted was that design changes during fabrication (particularly in Germany) caused major delays. There have also been high-profile delays when experienced manufacturers sought to scale up fabrication capacity for cables or substation/converter station topsides. For example, Nexans is understood to have lost about €50 million in sales as production was pushed back for two to three months.[30]

Table 4-4 Summary of lessons learned in Manufacture

Offshore Substation and converter station	Ensure close and competent supervision of supplier and contractors Avoid design changes during fabrication
Export Cable	Use sound procurement processes Agree on detailed testing programme and perform quality assurance

[30] http://www.bloomberg.com/news/2012-04-25/nexans-stock-declines-on-submarine-cable-production-delay.html

4.6 Lessons Learned in Installation

Once the project moves offshore, the challenging marine environment increases complexity and risk. Delays and cost escalation are more the norm than the exception.

Whilst submarine cable installation is in many ways a mature sector (with a history dating back over 150 years), the application to offshore wind is relatively new and as such has caused a number of challenges. A key finding from our work has been confirmation that case-specific solutions nearly always need to be developed in order to handle the ground conditions on site, particularly at landfall, albeit common techniques are developing to deal with these.

A common theme from interviewees was that problems tended to arise more from project planning and management, possibly resulting from a lack of experience on the developer side. Some interviewees noted this was starting to change, with a greater focus on cabling and useful industry efforts to share information. Reflecting on experience, one interviewee set out their 'wishlist' for future cable installation which included having better vessel availability; putting in place a clearer contract for the cable installation package; undertaking more up front work on the cable route survey; not agreeing to fixed burial depths and for industry to work on a standard cable burial assessment framework. Separately, a German developer noted benefits in seeking to incentivise weather costs through statistical analysis of weather downtime, and with gain and risk sharing above and below this point.[31]

In terms of mitigations, an installer noted benefits from breaking down the longest path in the schedule by separating the shore landing and shallow water cable installation from the rest of the installation. This in turn would reduce the payload for the main cable installation vessel and increase the number of suitable vessels. Furthermore the developer could consider independently pulling cables in at the offshore substation and shore landings to reduce dependency and vessel times[32].

Fewer issues were raised around the offshore substation/converter station beyond that the transport and installation represents a major challenge. This issue was particular acute in Germany. Cable pull-in has been challenging on some occasions and commissioning time for the offshore substation/converter station has generally been underestimated. This poses additional health & safety risks as offshore substations/converter stations are often declared 'unmanned' with corresponding (lack of) provisions for emergency situations.

Another common theme from interviewees was the importance of using experienced contractors, although their number is limited. This should be combined with strong offshore Quality Assurance processes because, as stated before, resolving problems will be multiple times more expensive offshore. It is important to get things right the first time, with strong client representatives who have the authority to ensure works are completed to a satisfactory level being an important element of this.

A key lesson identified by experienced developers was the need for a realistic programme, particularly building in sufficient contingency around critical path items. Given the large financial investment, there is strong pressure to deliver projects earlier and thereby improve project IRR. However in practice this can lead to project delays and consequential knock-on costs or increased

[31] Vincent Buchert – EnBW –'Experience with offshore cabling projects – Planning the implementation phase of Baltic 2' 13.05.13 International Offshore Cabling conference 2013

[32] Arnoud Roels, VSMC: 'Experience with cable landfalls during the London Array project' – 13/05/13 – International Offshore Cabling Conference 2013

costs associated with employing more resource (e.g. vessels) to maintain the programme. Risk mitigation and contingency planning are therefore absolutely critical.

It was also noted that schedule pressure can drive inappropriate decisions and behaviour. For example, in one case, a decision was taken to install an offshore substation topside before it was finished in order to maintain the programme and also ensure vessel availability. However, this decision led to expensive offshore remedial work being needed at a later point. In retrospect, a key finding here was that a short delay in the topside installation may have been better from an overall cost perspective, but was not considered an option at the time due to installation vessel charter and availability.

One developer noted the simple point that the development team, including management, should be on site during installation and commissioning to allow effective consideration of on-the-ground issues. In particular the electrical designer and responsible persons/entity with the authority to take alteration decisions needs to be on site (on the offshore substation/converter station) during installation and commissioning, as significant delays can occur if decisions on change processes are made by land based staff working only 'office hours'. One contractor suggested that the offshore wind sector could learn from the oil and gas sector in this regard.

Looking ahead, wind farms further offshore will need to provide offshore accommodation for the SAP/responsible person for electrical design (as opposed to travelling out from shore, which has typically been the experience for near shore wind farms). A key learning from the Global Tech 1 wind farm was that the number of persons required for the installation and commissioning phase was several more than expected, and there was insufficient cabin space provided[33]. Factors such as this should be built in at the early design stage.

Table 4-5 Summary of lessons learned in Installation

Whole System	Develop a realistic programme, including sufficient contingency Ensure development team able to take decisions, including management and electrical designer, are on site Use experienced installation contractors (although their number is limited)
Offshore Substation and converter station	Ensure close and competent supervision of supplier and contractors Provide sufficient cabin space for installations far offshore
Export Cable	'Fingerprint' export cable with as-laid documentation Consider risk mitigations and contingencies, e.g. additional vessel availability

4.7 Lessons Learned in Asset Transfer

Under UK law, all offshore generation projects in GB that are connected at 132kV or above must transfer their transmission infrastructure to an OFTO post commissioning. For early projects, this requirement introduced a significant level of uncertainty. However, as the OFTO regime is now more established (and with nine systems built and transferred to OFTOs, and six others at various stages in Ofgem's competitive tender process) experience has grown and the process is now better understood at an industry level.

[33] Lutz Falta – Global Tech 1 – 'Operation experience with the manned platform for GT1' & 24.08.2013 presentations at 2nd International Offshore Wind Power Substations, Germany

However, it was clear from the interviews that developers still feel uncertain about the cost assessment process which Ofgem uses to determine efficient costs of the transmission infrastructure. In particular, there is an inherent risk that projects will not recover all of their investment if it is not deemed 'economic and efficient', which has been the case on a number of projects to date[34]. Interviewees noted that historically, proving with the necessary documentary evidence why decisions were made at the time was a challenge, particularly in cases where the transmission infrastructure may not have been designed to be separated out from the generation infrastructure. However, with the experience of the OFTO regime, developers are now much more aware of the need to document design decisions and interviewees noted the importance of ensuring that contract scope and value can be split easily.

It was suggested that Ofgem's cost assessment process could potentially be a very powerful way of driving good practice, particularly as the information included in the Cost Assessment reports provides a clear view on the treatment of costs. A suggestion came forward that greater explanation of the rationale for decisions would benefit the industry and improve decision-making. Linked to this, DNV GL consider Ofgem have an opportunity to help drive good practice and potentially standardisation through its cost benchmarking proposals (See Section 5.2 for further detail).

A key element of the asset transfer is who the OFTO chooses as the O&M provider, with the wind farm developer frequently undertaking this role on behalf of the OFTO. This is not surprising given the strong incentive that generators have to see the transmission infrastructure operated with minimal downtime and that they already have onsite personnel and equipment. Interviewees noted that generators have tended to offer below cost prices for these services in order to secure O&M provision within the developer's remit. Despite these advantages, it appears that two OFTOs have chosen not to use the relevant generators for at least part of the O&M contract. On one occasion we understand that this was decided based on the OFTO achieving synergies across other projects and also developing investor friendly contracts that resulted in the OFTO being able to offer a wider scope of works than the generators at a lower expenditure. Outside of this example other OFTOs raised concerns about the lack of third party competition in the maintenance market while one developer (DONG Energy) has called for Independent Service Providers to enter the market[35]. ISPs are common in the oil and gas sector, operating offshore assets on behalf of the owner. They could save cost in the wind sector through specialisation, low overheads and leveraging synergies across projects.

Through the interviews with OFTOs, it became apparent that there were a number of areas which the interviewees felt could be improved to enhance the asset transfer. These have been captured in the following 'OFTO wish list for developers':

[34] Wind Power Monthly "Regulator penalises DONG Energy and SSE Renewables" 1st September 2011

[35] Martin Welna, DONG Energy – 'The need for the emergence of large scale offshore ISPs to service offshore wind' EWEA Offshore Nov 21st 2013

OFTOs' Wish List to Offshore Wind Developers

- *Understand that a quicker and easier transfer lowers cost to a project*
- *Project financing of OFTOs will mean there are stringent due diligence requirements and reporting processes both before and after asset transfer. In these structures, unlimited liability caps are a challenge.*
- *Ensure full record of cable burial depth and bathymetric surveys post construction and details of survey technique so that future surveys can have a baseline to compare data accurately*
- *Ensure all testing and commissioning of the assets is complete and documented (including for instance, voltage withstand testing on the cable and thermal cycling to prove cable integrity).*
- *Ensure robust processes for collection of as-built drawings, commissioning records, O&M manuals and method statements*
- *Provide a single document outlining indemnity and liability payments, property and rents payable, security requirements to avoid all OFTOs having to trawl through the data room*
- *Be clear about the issue of separation of OFTO and wind farm operations, and design for minimisation of loss of availability – considering array string interconnection and rating of bus-couplers / bus-sections offshore.*
- *Ensure adequate industry standard warranties are obtained. Short term or limited warranty coverage may impact the time taken to return the transmission asset to service following a fault.*
- *Ensure component labelling and numbering convention (particularly within substation and converter station) is consistent with what the host transmission system is using.*

Table 4-6 Summary of lessons learned in Asset Transfer

Whole System	Undertake full suite of surveys and tests before handover Ensure robust process for collecting as-built drawings, records etc. to facilitate efficient OFTO due diligence Seek greater explanation of the rationale of Ofgem's cost assessment to help improve project specifications and execution.

4.8 Lessons Learned in Operations & Maintenance

Although the majority of cabling issues have been associated with the installation phase, DNV GL are aware of a number of cable failures once the transmission system has become operational. Repair times in such instances have been lengthy in one case taking 5 months, with lead times for spare cables and joints being particularly challenging. In instances where there is a single cable connecting the offshore wind farm, downtime means that the generator cannot export output to market. This risk is mitigated to some extent with designs that have more than a single export cable, which enable the wind farm to keep operating, albeit at reduced capacity.

DNV GL understand that a full export cable repair spread costs in the order of £10 million including vessel day rates, mobilisation and demobilisation costs, spare cable, joints, project management and skilled labour. From the interviews, it is evident that cable failures remain a significant concern. A number of interviewees suggested that the sector should move towards more formal industry wide maintenance agreement approach (see pull out box below).

On substations/converter stations, TenneT note that downtimes on HVDC platforms in Germany cost on average around €1.6 million per day with the maximum being €3.2 million per day.[36]

To date all the transmission assets associated with offshore wind in the UK have been built and owned/operated during the commissioning years by wind developers under the Generator Build model. Given the relative immaturity of the OFTO regime (it commenced in 2009 with the first OFTO licence granted in 2011), OFTOs have had limited exposure to cable repair to date. Nevertheless, we understand OFTOs are considering the optimal approaches to managing this risk, including entering into call-off contracts with key suppliers.

OFTOs noted that a lack of industry best practice and standardisation was driving up costs. In particular, costs for strategic spares were high, driven by each wind farm having bespoke sets and little compatibility. Cable surveying was another area where a lack of standardisation was leading to higher costs, with OFTOs noting the importance of being able to compare across different survey techniques and over time. OFTOs also suggested that much more could be done to monitor the cable through temperature sensing and vibration analysis, although both need to be designed in.

A number of OFTOs discussed the ability to flex warranties. With operational experience it may be possible to reduce offshore visits without compromising the asset integrity. However, continuous availability of operational data is vital.

Corrosion has been a major issue in offshore substations/converter stations, particularly in the early wind farms. In most cases, the root cause is not appreciating the extreme environmental conditions and making incorrect design choices. However, with experience from the marine and oil and gas sectors, suitable corrosion protection measures are available for both substructure and topsides.

German and Belgian experience highlights the need to collect good quality failure data and to optimise the condition monitoring and strategic spares strategy[37]. Specific consideration should be given to remote control and remote reset capabilities, as well as earthing design.

Scour has also been noted as an issue on some sites in Germany, although it is a generic problem in most locations in the North Sea and affects cable installation and design due to the dynamic effects.[38]

An interesting development is the SPARTA[39] project which seeks to improve the operational performance of wind turbines by sharing anonymised performance and maintenance data and developing benchmarks. It will be the first time that developers share such data in offshore wind and suggests potential for such a scheme to expand to other areas such as offshore transmission.

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36 Christoph vor dem Brocke – Tennet – 'Considering O&M in the design – Lessons Learned and examples' 24.08.2013 presentation at 2nd International Offshore Wind Power Substations, Germany

37 Lutz Falta – Global Tech 1 – 'Operation experience with the manned platform for GT1' & Jean Beauverger, CG Systems 'Optimisation of substations and their transformers to the offshore environment' 24.08.2013 presentations at 2nd International Offshore Wind Power Substations, Germany

38 Christoph vor dem Brocke – TenneT– 'Considering O&M in the design – Lessons Learned and examples' 24.08.2013 presentation at 2nd International Offshore Wind Power Substations, Germany

39 SPARTA was initiated by The Crown Estate and DNV GL in 2013 and officially launched by The Crown Estate, ORE Catapult and wind farm owner/operators in January 2014: http://www.thecrownestate.co.uk/news-media/news/2014/sparta-project-to-drive-offshore-wind-cost-reduction/

Cable Repair Maintenance Agreements

Interviewees regularly cited the formal industry wide cable repair agreement in place within the telecommunication sector (Atlantic Cable Maintenance Agreement, ACMA) as a possible example for cable maintenance in the offshore transmission sector. The ACMA agreement mandates that in the case of a fault, a cable repair vessel leaves port within a set time period (24 hours) and needs to be on site within a certain period. Various KPIs exist for the repair itself. This scheme is paid for by contributions from a large number of cable operators and a pre-requisite for membership is that the cable is suitable for repair employing a universal joint.

Many interviewees believed that the offshore transmission sector should be moving towards a similar model to ensure faster cable repair times, building on the experience from the telecoms sector. Some expressed scepticism however, primarily relating to the cost - with developers considering it cheaper to insure. Other issues noted were the:

- *lack of universal jointing methods for export cables (with fibre optics a particular concern),*
- *a lack of awareness from developers on potential downtime costs, and*
- *challenging commercial issues including whether warranties would be valid if one manufacturer's cable had been spliced with another*

One interviewee also noted that the telecoms sector is more culturally attuned to sharing, with "plug and play" design standards and a focus on interoperability.

In the short term, developers and OFTOs will need to plan and develop their own individual repair arrangements. In the longer term, despite some scepticism, there may be benefit in exploring industry wide repair frameworks as a proactive and strategic way of optimising O&M performance.

Table 4-7 Summary of lessons learned in Operations & Maintenance

Export Cable	Robustly plan for cable repair and failure prevention Explore cable repair framework agreements Develop industry wide good practice in cable surveying

4.9 Lessons Learned in Decommissioning

Very few points were raised around decommissioning, which is not surprising given the status of development. The one comment made was that there appears to be a wide range of cost estimates for decommissioning between OFTOs. Nevertheless, given decommissioning requirements for offshore transmission infrastructure are either included in The Crown Estate leases or as per the decommissioning plan agreed with the Secretary of State under the Electricity Act there should be adequate arrangements and protection in place to ensure that decommissioning obligations, requirements and associated security are managed adequately. DNV GL expect learnings to develop in this area as wind farms start to reach the end of their economic life and decisions are required on the ongoing needs for the offshore transmission infrastructure.

4.10 Summary of good practice identified throughout the lifecycle stages

This section of the report has described the lessons learned across offshore transmission projects to date. Based on the information gathered and assessed, it has been possible to identify certain areas of good practice that should help to mitigate some of the issues arising in the future, as summarised in table 4-8.

Table 4-8: Good practice on offshore transmission emerging from this report

Lifecycle Stage	Project Management & Delivery	Technical and Other Areas
Consenting	• Consider lifecycle impacts of consenting decisions	• Use risk based burial indices to define consent condition on burial depth • Collect sufficient survey data along entire cable route
Design	• Develop a robust risk management framework • Involve supply chains in the design phase • Consider lifecycle costs	• Consider system standardisation of capacity ratings and voltage levels • Use reference design(s) for offshore substations if possible • Overplant, subject to Cost Benefit Analysis • Optimise approach to rating of cables and transformers • Optimise reactive power compensation • Avoid monopiles in areas with significant wave interaction • Design in better condition monitoring systems • Make effort to design out corrosion
Procurement	• Focus on interfaces • Ensure risk is identified appropriately and managed by the entity best able to do so • Choose best value not cheapest • Ensure clear OFTO split in contracts • Consider use of 'reasonable endeavours' clause in contracts • Ensure contractual access to subcontractors	• Seek to increase competition in supply chains
Manufacture	• Avoid design changes during fabrication • Ensure close and competent supervision of suppliers and contractors	
Installation	• Plan with realistic programme, with appropriate mitigations and contingencies • Ensure development team are on site	• 'Fingerprint' export cable with as-laid documentation

	• Use experienced contractors	
Asset Transfer	• Ensure robust process for collecting as-built drawings, records, etc.	• Undertake full suite of surveys and tests before handover
Operations & Maintenance	• Plan for cable failure prevention, root cause analysis and cable repair • Use a risk based inspection programme • Explore cable repair framework agreements	• Develop industry wide good practice in cable surveying

5 SHARING GOOD PRACTICE

This section of the report considers ways in which the offshore transmission sector could more effectively share learnings and knowledge on an enduring basis, and recommends a more structured approach of doing so, taking into account factors such as the structure of the sector, its relative maturity and the extent of initiatives either already ongoing or planned.

DNV GL note that there are a range of ways in which the sector does already share knowledge and learning, but that there are also clear gaps – particularly in terms of how lessons are collected, curated and coordinated. To this end, we set out a recommendation on the development of a 'knowledge hub' to provide a more structured approach to the sharing of lessons learned. DNV GL also highlight a number of potential additional work packages which the industry should consider taking forward.

"How can we become better at sharing good practice?"

5.1 Methodology

To inform this part of the project, DNV GL has used three primary sources of information – direct feedback from the interviews undertaken, a detailed consideration of the ways in which the sector already shares knowledge, and a review of a sample of similar schemes in operation across different (but similar) sectors. We have used these sources of information to inform our thinking on what is required for the offshore transmission sector at this time.

5.2 Existing and Proposed Initiatives

Through the course of the project it became apparent that there are a range of initiatives ongoing which bring together relevant stakeholders in industry and have the effect of sharing good practice – whether this is a direct objective or a beneficial by-product of the initiative. A summary of those initiatives that DNV GL are aware of at the time of writing this report are outlined in Table 5-1, with the following section discussing those most relevant to this report in more detail.[40]

Table 5-1 List of existing and proposed initiatives in offshore transmission

Organisation	Initiative(s)
DECC	- Funding of demonstrator project to understand benefits of online electrical monitoring, including partial discharge, for offshore transmission[41].
Ofgem	- Offshore Transmission: Guidance for Cost Assessment - OFTO Transfer Cost Assessment Reports - Cost Benchmarking consultation - Harmonics working group - Design parameters working group - Network Innovation Competition (NIC) projects

[40] In practice, there are likely to be other initiatives not captured in this table and later discussion, particularly outside of the UK
[41] http://www.hvpd.co.uk/news/2013-04-decc-technology.html

CIGRE	- Various working groups looking at all aspects of transmission. Relevant ones include: o High voltage equipment o HVDC and power electronics o Insulated cables o Transformers o Materials and emerging test techniques o Substations - CIGRE Technical Brochure 379, "Update of service experience of HV underground and submarine cable systems", April 2009[42] - CIGRE Technical Brochure 490, "Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to 500 (550) kV", February 2012. - Update of mechanical testing recommendations for subsea power cables, expected to be published in 2014 - CIGRE Technical Brochure 483, "Guidelines for the design and construction of AC offshore substations for wind power plants", December 2011 - CIGRE Technical Brochure, "Special considerations for AC collector systems and substations associated with HVDC connected wind power plants", working group B3.36, expected to be published in 2014
IEC[43]	- Consolidation of industry practice into minimum standardised approaches and internationalisation
DNV GL	- DNV-RP-J301, "Subsea power cables in shallow water renewable energy applications", February 2014 (following Joint Industry Project) - Joint Industry Project on HVDC qualification - Offshore substation standard - DNV-OS-J201 and GL guideline
The Crown Estate	- Investigation into the need, implementability and potential benefits of a 'Modular Approach to Offshore Transmission Systems' discussing standardisation at the system level
Carbon Trust	- Cable Installation working group o Cable burial and risk mitigation project – ▪ assess burial equipment capabilities and limitations ▪ develop fit for purpose cable BPI o Share developer experience o J-tubeless cable entry system o Free-hanging cables (for floating) - Electrical working group o Optimising AC system design ▪ Identify, review and evaluate technologies with cost reduction potential o Optimising DC system design ▪ Combining AC and DC platforms ▪ Going from 66kV AC to 400kV DC
Insurers European Wind Turbine Committee	- Draft Offshore Code of Practice for Offshore Wind Projects. At present this is focused on array cables but has some applicability to export cables[44]

42 http://www.landsnet.is/Uploads/document/L%C3%ADnur%20og%20strengir/Sk%C3%BDrslur/CIGR%C3%89%20TB-379%20Update%20of%20service%20experience%20of%20HV%20underground%20and%20submarine%20cable%20systems.pdf

43 CENELEC also produces standards but these tend to be very similar to IEC and so have been considered together.

44 Andrew Norris – Swiss Re 'Introducing the Offshore Code of Practice for Offshore Wind Projects' Offshore Cabling, Bremen May 12th 2013.

OWPB	- Grid Group o Design standardisation o Sharing good practice - Contracting Strategies Group (DNV GL understand this is mainly focused on the wind farm but the work should have applicability to offshore transmission) o Exploring pre and post FID engagement strategies o Defining alliancing approaches o Shortlist of contracting approaches to help support appropriate risk transfer and collaboration
Conferences	- Numerous industry conferences exist often focused on lessons learned e.g. EWEA, RenewableUK, Windpower Monthly, International Cabling, International Substation Design, etc. - Range of more technical conferences e.g. Annual Wind Integration Workshop, CIGRE sessions
Working groups and industry forums	- RenewableUK Grid Group and Offshore Grid Group - Electricity Networks Association OFTO Forum - Subsea Cables UK Renewables sub-group - Society of Underwater Technology OSIC group - CIGRE (covered above) - OWPB Grid Group

5.2.1 Discussion of key initiatives

The following subsection provides further detail on some of the initiatives referred to in the table above, with particular focus on those tackling the major lessons identified in Sections 3 and 4.

5.2.1.1 Knowledge sharing, risk management and earlier supply chain involvement

The Offshore Wind Programme Board (OWPB) has been established to identify and remove barriers to the deployment of offshore wind and also oversee cost reduction initiatives. It has created eight work streams, with the Grid and Contracting groups of most relevance to this report. The Grid group is focussing on issues around causes of delay and where cost reductions could be made, and is providing key advice to this initiative on lessons learned/good practice as well as others, such as on standardisation. The Contracting group are seeking to develop the best means of engaging with suppliers both pre- and post-FID and shortlisting contracting approaches which help support appropriate risk transfer and collaboration. This group is therefore tackling some of the biggest issues identified in Section 4.4, including the approach to managing risk, contractual risk balance and a lack of supply chain involvement in design. DNV GL suggest that this group could consider wider adoption of ISO 33000 series which provides principles and generic guidelines on risk management.

5.2.1.2 Data

Although not explicitly referenced in Section 3 and 4, it became apparent during the interviews that there was a lack of quantitative data within the sector. Ofgem's recent consultation on publicly sharing anonymised cost data from the asset transfer process[45], thereby allowing the benchmarking of projects, is an important step forward in this regard. Ofgem's initial view was that "it may be possible to conduct benchmarking for various components for future projects, based on a combination of comparative data and project specific factors. This should provide a useful and

[45] 'Offshore Transmission Cost Assessment: Development Proposals': https://www.ofgem.gov.uk/ofgem-publications/84971/offshoretransmissioncostassessment281113.pdf

transparent reference point for both developers and Ofgem, and would help focus the cost assessment scrutiny." DNV GL believe that this should be extremely useful in sharing good practice because Ofgem will be able to access and share anonymised high quality cost data, previously a real challenge for the sector to obtain. The benefits should therefore be seen across the lifecycle stages up to the point at which the asset transfers. In addition, Ofgem has initiated two working groups, one looking at optimising harmonics design and the other working with OEMs to provide earlier resolution on data issues crucial to design.

With regards to failure data, CIGRE undertakes a review of high voltage (≥ 60 kV) cable failure data every five years, with the most recent report published in 2009 when offshore wind was still in its infancy. In a future edition, we would expect offshore transmission to be a greater focus and accordingly include more data.

5.2.1.3 Cable Installation

The Carbon Trust is active in the transmission sector, primarily through the Offshore Wind Accelerator, which is a joint research & development project with nine leading offshore wind developers. Its cable installation working group has recently kicked off a project looking to better assess cable burial risk and mitigations. This seeks to assess burial equipment capabilities and limitations and develop a fit for purpose offshore wind cable Burial Protection Index. Given the learnings identified in Section 4.2, this is a very welcome initiative and should help tackle one of the root causes of cable installation problems.

DNV GL has recently released the conclusion from the "CableRisk" Joint Industry Project in the form of a publicly available guideline "Subsea power cables in shallow water renewable energy applications" (DNV-RP-J301). This could be a major reference in tackling cable installation issues.

An interesting development from Germany is the Offshore Code of Practice which various insurers have developed to try and reduce risk and liabilities by strengthening the role of the Marine Warranty Surveyor (MWS). It covers wind turbines, array cables and offshore substations, but not the export cable. The document is currently out for consultation (in German) and expected to be published later in 2014. Although focused on the generating asset there are likely to be lessons for the successful delivery of export cables. Good practice developed in Germany is likely to be exported to the UK through the insurance market, developers and suppliers who work across Europe, although detailed issues around experience and certification of the MWS for example will need to be considered in the UK context.

5.2.1.4 Optimising electrical design

The Carbon Trust's electrical working group has recently kicked off projects looking to optimise electrical design for both AC and DC transmission systems, with a long list of opportunities currently being scoped out. Feedback from the interviewees from this report suggests there is good potential for cost reduction through optimisation of reactive compensation requirements and cable and transformer ratings.

DNV GL is also leading a JIP to develop a recommended practice for Technology Qualification for offshore HVDC technologies. This hopes to drive faster, more efficient and more reliable deployment of HVDC systems by integrating ongoing activities and experiences with a proven risk management approach.

5.3 Mapping of initiatives

Many of the initiatives described above target those areas identified as problems in Sections 3 and 4. To provide a summary overview, Figure 5-1 maps out the different initiatives in terms of the various lifecycle phases which they are targeting.

At the top of the chart, the green bars represent the actors with the position of the bar highlighting which stages they are involved in. The various initiatives are below this, with the box 'fill' showing whether the scheme is operational (in the context envisioned here), at the proposal or consultation stage. Through this mapping exercise it became apparent that sharing good practice involves a number of different approaches, from informal qualitative lessons to highly quantitative benchmarking studies and standards. We have identified four broad categories within which most initiatives can be grouped:

1. Qualitative Feedback of Lessons

- This approach seeks to provide relatively informal, qualitative feedback to the wider industry from the latest experience gained on projects. Often this will be through conference presentations, workshops and working groups and may not have a fundamental sharing objective (unlike specific R&D projects). The lessons could be considered 'anecdotal', as they are often based on opinions as opposed to debated and established facts. Although some will consider this less valuable to the sector as a whole, there is significant, often difficult to measure benefit, in the sharing of experience on projects on a regular basis. This approach is often the most responsive, with these forums open to allow informal discussion on what is the most pressing issue of the day.

2. Quantitative data collection and benchmarking

- The second approach seeks to share good practice through the collection of quantitative data and metrics that allow benchmarking and comparison across projects. These data are harder to collect but in turn should add greater value. More mature sectors will typically develop robust and reliable benchmarks.

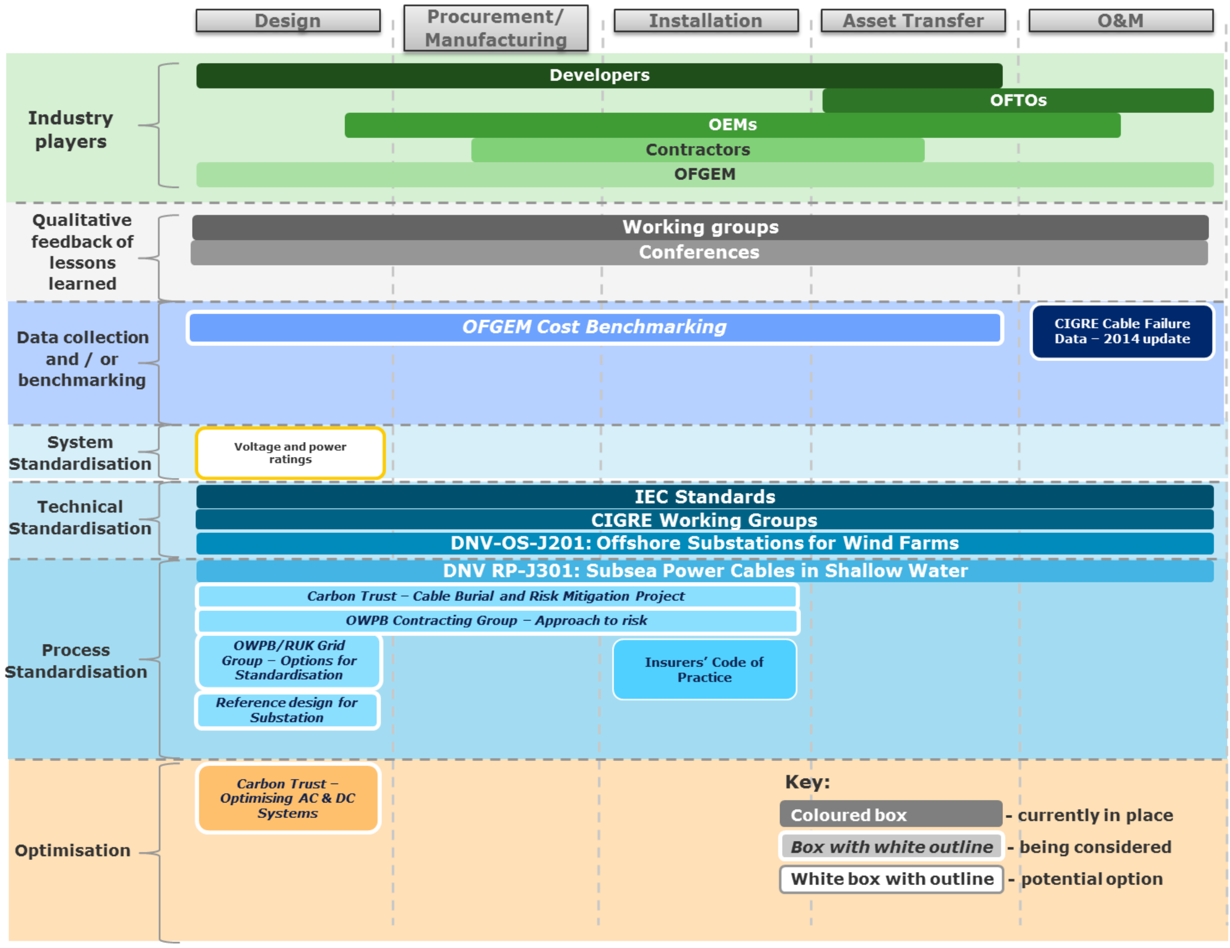
3. Standardisation

- This approach highlights those initiatives which are seeking to standardise various aspects of offshore transmission. Standardisation covers a range of initiatives in relation to standardisation at the system and functional level, standardisation of processes and standardisation at component and technical level.

4. Optimisation

- This approach seeks to develop better existing systems, assets or procedures, often involving technical or process innovation and research and development. Optimisation can later lead to standardisation but has slightly distinct meanings in that context.

Figure 5-1: Map of existing and proposed industry initiatives seeking to share good practice



This initial mapping exercise identifies that there are a number of initiatives already ongoing or being considered within the sector, which have the effect of sharing knowledge or developing good practice. There appears to be good coverage across the lifecycle, with a concentration of initiatives focussing on the design phase. The operational phase could perhaps benefit from more focus although this is arguably due to the limited operational experience to date.

However, there are a number of additional areas which warrant further consideration, most notably the development of a 'knowledge hub'.

5.4 A 'knowledge hub'

Our work on this project suggests that there are a range of outlets for sharing lessons learned and knowledge, yet it has become apparent that the way this works in practice is unstructured. This may undermine the efficiency of knowledge sharing across all stakeholders and reduce the overall benefits (in terms of cost reduction and risk mitigation) that knowledge sharing brings. This section sets out a rationale for introducing a more structured approach and recommends a model, or 'knowledge hub', appropriate to the needs of the offshore transmission sector.

5.4.1 The need for such a scheme

As this report has highlighted, the offshore transmission sector is still relatively immature, and is a sector that has experienced a range of challenges in terms of cost control and risk management. Different projects have experienced similar or the same issues and the sector is still seeking the right balance between up-front investment at risk and overall project management and delivery. Onshore transmission professionals, marine installation contractors and utility scale developers have had to work together, with corresponding cultural differences and approaches, suggesting that the sector is still developing an 'offshore wind' way of doing things.

At the same time, the dominance of the Generator Build approach in the UK means that there are a large number of developers developing offshore transmission assets with little coordination across projects or sharing of knowledge. This is in contrast to the German experience where two TSOs develop, own and operate the offshore transmission infrastructure. This report does not pass comment on the relative merits of the UK and German approaches to offshore transmission, which both have strengths and weaknesses that have been explored in a range of other forums. However, the nature of the UK approach means that there is an inherent risk of less knowledge sharing and learning lessons from previous experience (given this involves cross-developer dialogue) than would be the case where one or two entities develop the infrastructure.

Knowledge management and learning is particularly important given the long development timescales for offshore wind that can result in the loss of knowledge as project teams disband. Most (if not all) projects have a 'lessons learned' database, but there is nothing similar at an industry level. As a result, industry players may not know where to go for advice on a particular issue, leading to mistakes being repeated. This is especially relevant for smaller lessons which individually may not be that significant but taken cumulatively become important.

Further, a coordinated approach to knowledge sharing across an industry is not uncommon. As part of our research for this project, we have reviewed a number of schemes across a range of industries and countries, to assess impacts of improved knowledge sharing. The two most relevant schemes were the Norwegian FPSO (Floating Production, Storage and Offloading) Experience Transfer Network and SKYbrary (an aviation sector initiative) which demonstrate that a structured approach can improve the way an industry either manages cost or improves risk mitigation (or both). A short summary of these is highlighted in Table 5-2 below. Further detail on these and others considered is included in Appendix 2.

Table 5-2 Examples of schemes to share good practice in other sectors

Norwegian FPSO Experience Transfer Network	**Summary** - The FPSO (Floating Production, Storage and Offloading) Experience Transfer Network is set up under the sponsorship of the Norwegian Oil and Gas Association Operations Committee. The committee recognised in 2001 the need to capture lessons learned during several FPSO projects during the 1990s, and to gather experience from operating FPSOs on the Norwegian Continental Shelf. **Aim** - To enable FPSO operators to learn from each other to improve operations and influence future designs **Outputs** – a) to gather lessons learned from existing Norwegian FPSOs b) to develop an Norwegian Oil and Gas Association website for the sharing of FPSO lessons (The website seeks to provide the user access to a wide range of FPSO

	lessons learned, links to other important FPSO websites and enables entry of lessons learned by users interested in building a knowledge base for future designers and operators.) c) to establish links with the UKOOA d) to hold a seminar on topics of relevance to FPSO operators **Impact** – The coordinator of the scheme (and former Operations Manager for BP's Schiehallion FPSO)stated via email that: " *The 'Lessons Learned' documents from the project receive around 50,000 hits a year, and are referred to and even directly quoted in contracts.* *Skarv BP and Alvheim are projects which benefitted directly from these lessons learned: they are now operational and performing exceptionally well*.
SKYbrary	**Summary** - SKYbrary is an electronic repository of safety knowledge related to Air Traffic Management and aviation safety in general. It is also a portal that enables users to access the safety data made available on the websites of various aviation organisations - regulators, service providers, industry. **Outputs** - SKYbrary contains knowledge articles divided into 4 major domains: operational issues, human performance, enhancing safety and safety regulations. A total of 3500 knowledge articles were published over the years and are kept up to date by means of review cycles. All authors are experts in their domains. Authoring is restricted to experts. All content is publicly available. **Impact** - 1.5 million visits per year which includes 150,000 visits monthly by 100,000 unique visitors, visiting 300,000 pages, spending 2.25 minutes on average per visit and reading 2.5 pages per visit. 20,000+ subscribers to the weekly newsletter which result in in 5000 - 8000 visits. Toolkits were visited over 50,000 times each[46]

Given the characteristics of the offshore transmission sector noted above, and based on the experiences documented in this report, DNV GL considers there is a strong case for establishing a more structured approach to proactively capturing lessons learned. At its simplest level, this should help build up a knowledge bank and reduce instances of mistakes being repeated across projects. It should also help target key areas where further research is needed in order for the sector to contribute to overall cost reduction of the offshore wind industry and help track progress over time.

Positively, this report shows that when targeted appropriately industry participants are willing to share lessons and good practice.

5.4.2 The proposed solution

Having considered the range of initiatives ongoing, the potential gaps and that there is a potential lack of coordination across the industry, DNV GL consider the most appropriate way forward would be for a single organisation to take responsibility for developing and managing on an ongoing basis a 'knowledge hub' for the offshore transmission sector. In coming to this conclusion, we have considered a range of possible alternatives – a summary of these is set out in Appendix 3. Of the approaches considered, the 'hub' concept has a number of distinct advantages including:

- Low cost

[46] Email from SKYbrary team to DNV GL dated 24th Jan 2014

- Facilitates the sharing of lessons at minimal cost to industry participants
- Ease of setting up
- Degree of buy in from sector already

Further detail on the rationale for this approach is set out in section 5.4.3 below.

The details of how this ‘hub’ would operate in practice would need to be considered carefully as part of a formal business case, but in essence the ‘hub’ could:

a) Proactively seek to capture lessons learned which emerge from industry experience, for example through:
   - Attending and capturing learnings from industry conferences;
   - Engaging with working groups so that if a lesson is identified the secretariat informs the knowledge hub who speaks to the relevant individuals and captures the learnings; or
   - One-to-one engagement.

b) Undertaking annual reviews of the sector through semi-structured interviews (in a manner similar to this project).

c) Keep track of all initiatives seeking to develop or share good practice within offshore transmission and provide links and details on a website.

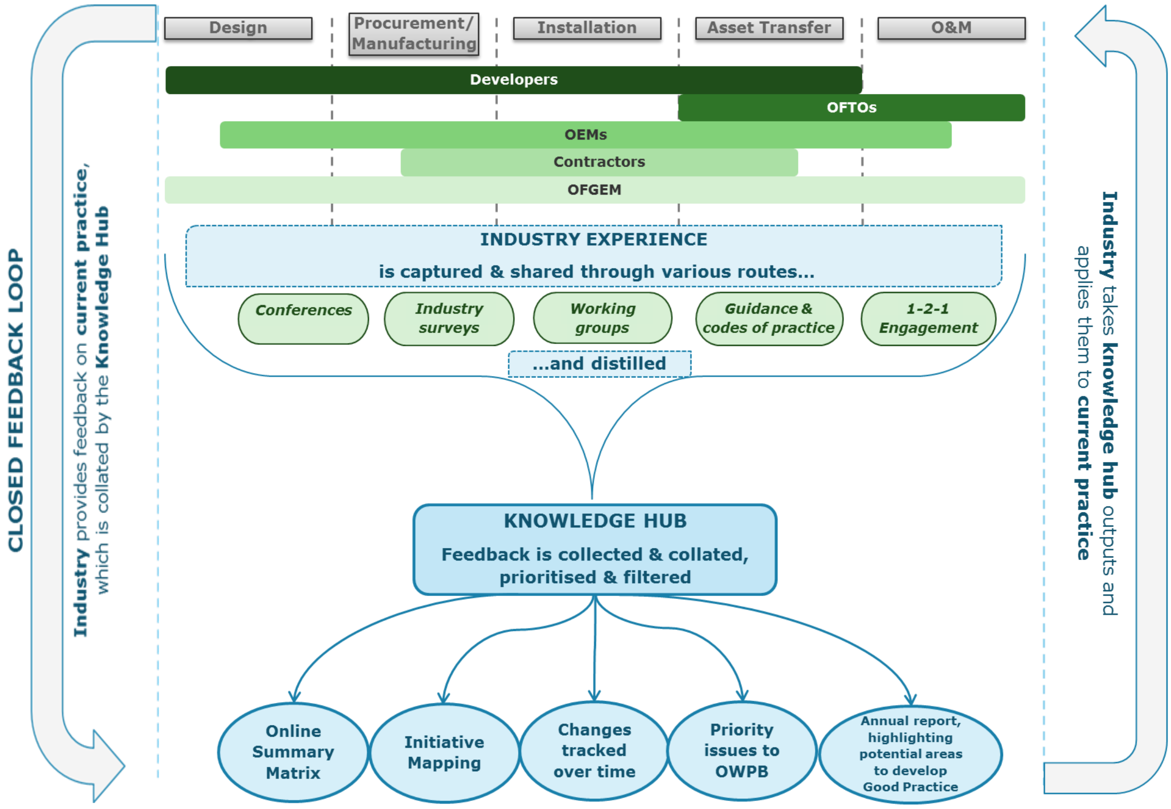
d) Collate a central online repository of lessons learned which would take Table 1-1 as a starting point and refine and develop it over time (as done by the Norwegian FPSO Experience Transfer Network – see Appendix 2).

e) Intelligently filter the data to identify and prioritise emerging issues which require action, and use information to inform and advise senior industry groups (such as the Offshore Wind Programme Board and Offshore Wind Industry Council) as necessary, in order to gain momentum toward resolution of these issues.

The knowledge hub will therefore facilitate the sharing of lessons by complementing existing initiatives, minimising the costs and maximising the incentive to contribute.

Figure 5-2 provides an overview of how such a hub could work.

Figure 5-2 Overview of the knowledge hub



5.4.3 Rationale for the scheme

This approach will help increase the rate of learning in the sector by proactively collecting, collating and sharing lessons learned and through the development of a widely accessible knowledge base. It should facilitate the sharing of lessons through minimising the time and resource costs on industry participants of doing so. Through becoming a trusted organisation that undertakes regular one to one interviews on the basis of anonymity, it should facilitate high levels of input (as opposed to group sessions where individuals are more reticent to discuss learnings in front of their competitors). This report shows the benefit of such an approach, with the industry willing to make time available for interview and providing considered answers.

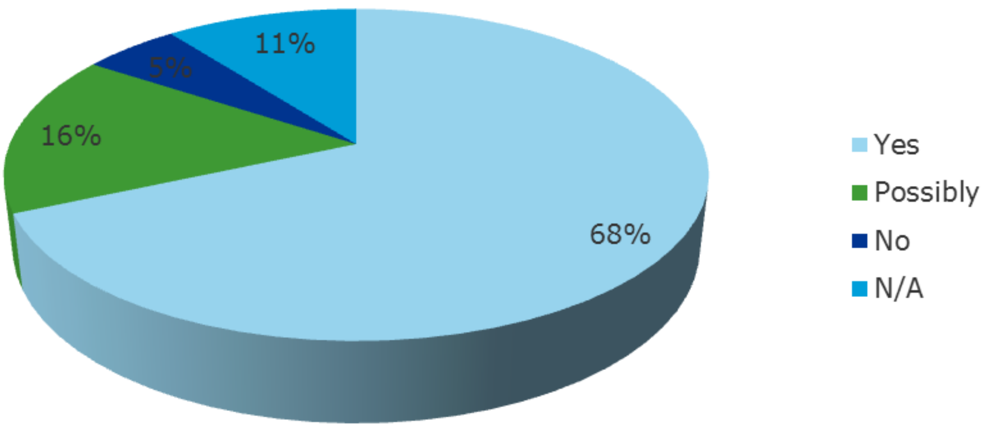
In addition, the knowledge hub will help drive coordination across the offshore transmission sector by ensuring wider dissemination of information across stakeholders and the identification of any future research requirements. It will complement existing initiatives, acting in a light touch manner, and helping to ensure that the right organisations are tackling the priorities, with any potential synergies and overlaps identified. The knowledge hub will do so by giving clear visibility to different initiatives and facilitating contact between them, enhancing the overall network.

This report has not considered the costs of such a scheme in detail, focussing instead on a proposed way forward. However, the knowledge hub should be relatively low cost, with minimal set up costs and the focus being on drawing together existing learnings and leveraging existing resources.

The bar for success for such a scheme should be quite low and therefore very achievable. Offshore wind requires a huge amount of investment, which means that even a small change in a developer's plans can result in a large cost saving in reality. This benefit may not necessarily be directly visible (i.e. the organisation which changed something may not actually say that the scheme led them to do so). But as one interviewee noted: 'Offshore wind is not easy – any help from others is always gratefully received'. The knowledge hub could also help position the UK as the centre of learning for offshore wind.

Our industry engagement shows there is already a degree of buy in from the sector towards greater sharing of lessons. Figure 5-3 shows the proportion of respondents that responded who stated that sharing good practice would benefit their organisation. In our dialogue and follow up in developing this report, a more structured approach was broadly supported (subject to detailed consideration of outputs, costs and timing, etc.).

Figure 5-3 Proportion of respondents who thought sharing good practice would benefit their company:



Overall the scheme would help developers design and install better transmission assets, by increasing the flow of information from projects further ahead in the development cycle (in particular the operational phase) and by identifying and tackling common issues across projects. For OFTOs, the scheme would offer the ability to share learnings in a more structured fashion and providing a route by which design choices could be influenced, ultimately resulting in a better asset to transfer and operate, lowering cost.

5.4.4 Costs

This report has not considered what the costs could be for developing and running the knowledge hub – this is a matter for any resultant business case to consider. However, the broad categories of costs to consider include:

- Detailed design of the scheme
- Further industry engagement ('buy in' is essential)
- Set up
- Awareness raising campaign
- Ongoing capturing of lessons learned
- Operating and maintaining resources
- Producing relevant outputs and dissemination
- Managing review/feedback loops

5.4.5 SWOT Analysis

Figure 5-4 assesses the strengths, weaknesses, opportunities and threats of the knowledge hub. It highlights that for the scheme to be successful it needs industry buy in and credibility, with the move to competitive allocation of CfDs a potential threat. On the upside there appear to be good opportunities for this scheme to build links with other countries in Europe, and if successful potentially expand into others area of offshore wind. However, overall the benefits appear to outweigh the costs.

Figure 5-4 SWOT analysis

5.5 Additional Potential Initiatives

In addition to the knowledge hub, the following is an overview of initiatives that DNV GL considers may be needed to progress over the coming years. These are recommended based on the feedback from the interviews and other research supporting this study. Each will require a detailed business case to flesh out scope and need at the time, but this list provides a starting point for future work – potentially considered under the knowledge hub.

Table 5-3: Overview of potential initiatives identified in this report

System standardisation	To date, transmission for offshore wind farms has been built with a variety of voltage and capacity ratings which limits compatibility and drives up costs. Technical standards bodies (like IEC, BSI, etc.) or technical guidance bodies (like CIGRE, etc.) only spell out what should be done in terms of material and component design for a given voltage level. They do not specify what the voltage should be in offshore transmission. In other words, system voltage level is an input rather than output in many technical standards. Yet failure to agree a set of common voltage levels will likely increase cost over the lifetime of the asset, because limited compatibility between wind farms will increase spares cost provision and may limit standard asset management approaches. A possibly effective way to promote and implement standardisation may be via regulators' guidance on cost assessment of offshore transmission infrastructure (in the case of GB) or via central planning bodies' plans (for example TSOs or ENTSO-E).
Collection of detailed operational cost and failure data	Good quality failure data is extremely useful in developing benchmarks and therefore driving better designs and operating models. Benchmarking is favoured by Ofgem for network regulation and is common in more mature industries. CIGRE provides failure data on a 5-10 year basis, but there is likely to be benefit in developing systems which provide more regular updates, potentially at a higher resolution. With SPARTA, there appears to be an opportunity to do just that, and subject to the pilot project being a success, there may be a case for it to expand to cover offshore transmission as well. DNV GL understand that an equivalent scheme in oil and gas (OREDA) was developed on a similar basis i.e. with additional modules being added over time.
Optimisation of reactive power requirements	A number of interviewees suggested that reactive power requirements were overly conservative, with too little optimisation across the system. Interviewees suggested the underlying assumptions upon which the Grid Code requirements were based may no longer be as valid and may be worth revisiting. The Carbon Trust are exploring different technical approaches to optimising reactive power requirements and beyond this any regulatory change would require substantial engagement with relevant parties including Ofgem and National Grid.
	As noted elsewhere in this report, the industry is seeking to identify the right

Overplanting	balance between optimising the transmission capacity against installed capacity in what is known as 'overplanting'. Internal modelling work at DNV GL suggest that the generating capacity can be increased by around 8% (through a greater number of wind turbines) for the same transmission asset (although this depends on project specific factors), with the corresponding benefit in AEP outweighing the increase in Capex and Opex. The Carbon Trust AC Optimisation study may consider this issue but if not there may be benefit in exploring it at industry level, perhaps through a Joint Industry Project.
Base and dynamic cable rating	Estimates for the current-carrying capacity of cables tend to be conservative and export cables in subsea applications are rarely fully utilised (unless 'Overplanting' has been applied). Cable design is often carried out in accordance with IEC 60287 series of standards to determine the limit of the continuous rated current (100% load factor) at maximum allowed conductor temperature (e.g. +90°C) for the assumed surrounding conditions. Cyclic HV cable rating is covered in IEC 60853-2 but only applies "to cables buried in the ground, either directly or in ducts, when carrying a load which varies cyclically over a 24 h period, the shape of each daily cycle being substantially the same". A generally agreed approach for renewable energy applications which takes due consideration of site specific wind patterns and predicted loading of the cable is yet to be developed. With assets being traded, it will also be required that stakeholders apply the same methodology for an appropriate rating so that a valuation would be carried out on similar terms. A suitably chosen base rating of the cable could be supplemented by "dynamic" rating of the cable, where its capacity at a specific time is dependent on the recent history and the current conditions around the cable. There appears to be benefit in developing a UK-led 'white paper' for base and dynamic cable rating in offshore renewable applications for soonest application. With more experience becoming available, this could be turned into standard practice in the longer term, e.g. by publication through CIGRE or IEC. Separately, a detailed base and dynamic rating approach may also be developed for offshore transformers.
Optimising asset management	To date, DNV GL consider the operational strategy of developers to be relatively immature, with insufficient focus on asset management. A system approach in line with BSI PAS 55 or newly published ISO 55000 series can be considered good practice[47]. Another issue mentioned by a number of OFTOs was trying to gain a better understanding of how and when vendors' warranties could possibly be disregarded, because they may be overly conservative.

[47] ISO 55000 series details requirements specification for an integrated, effective management system for asset management

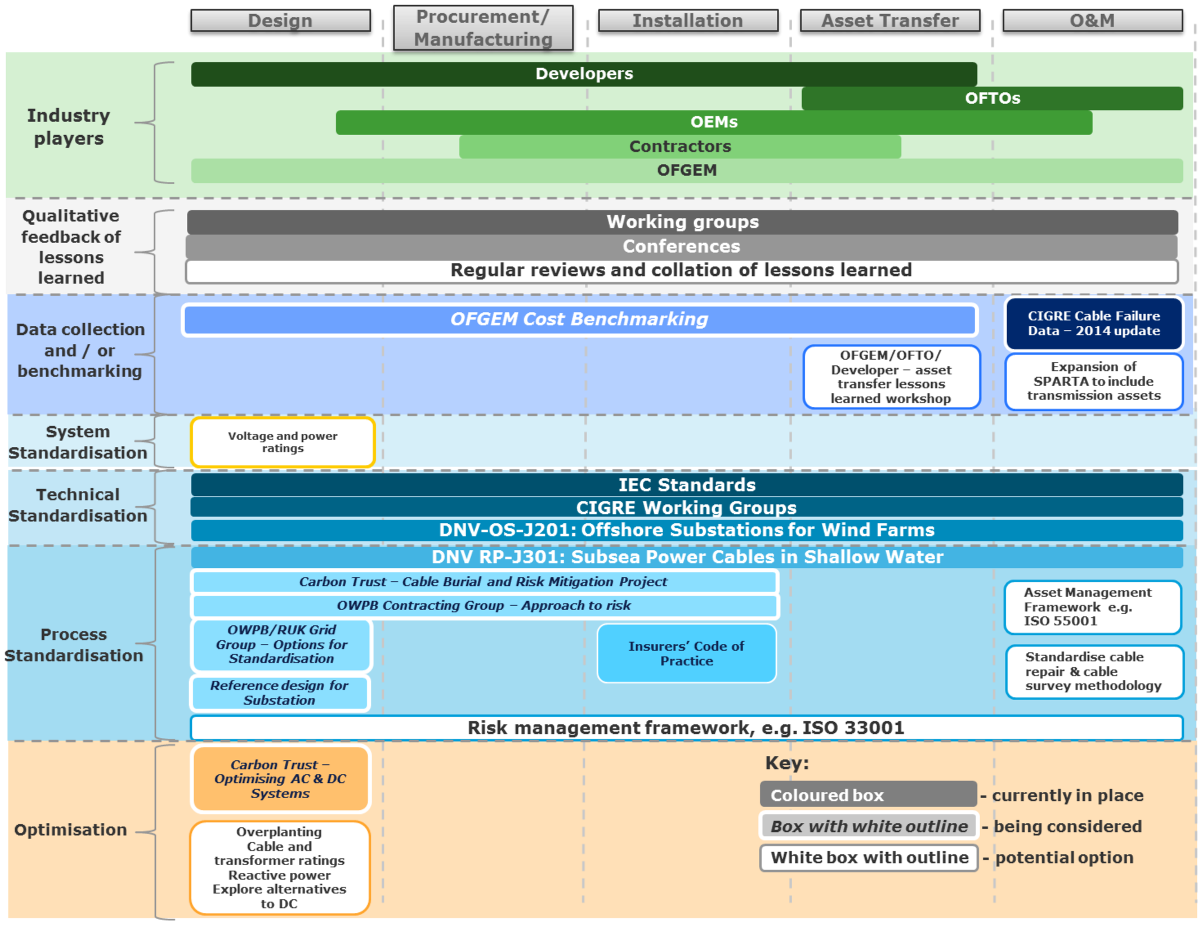
$16^{2}/_{3}$ Hz	With costs, lead times and delays associated with HVDC continuing to increase, the industry is beginning to consider alternatives with recent interest in low frequency AC (LFAC, such as $16^{2}/_{3}$ Hz), particularly in Germany. Internal DNV GL work indicates that electrical losses may be substantially lower for LFAC than for 50 Hz AC transmission and the maximum transmission distance is significantly higher than that of 50 Hz AC. Moreover, economic calculations indicate that the LFAC concept may be cost-efficient compared to high voltage DC (HVDC) transmission, possibly also increasing system reliability. The sector could therefore consider the best means of developing this option for offshore wind.
Standardising cable surveying and repair approaches	A number of OFTOs highlighted the lack of an industry approach to cable surveying, monitoring and repair once commissioned. The data collected is often not comparable, limiting its usefulness. There appears to be scope for a joint industry project to resolve this issue.
Lessons learned asset transfer workshop	Ofgem produce a cost assessment report for every asset transferred to an OFTO. This details the evolution of the transfer price and the rationale for changes. It also provides a lot of learning and experience and is considered by interviewees as a useful resource. However, there would appear to be benefit of holding a lessons learned workshop between Ofgem, OFTO and the developer after asset transfer to discuss any learning from the process. This should be in public to help future OFTOs and developers improve their own asset transfer process.

5.6 Future approach to sharing good practice

Figure 5-5 builds on the earlier 'map' (Figure 5-1) by adding in the proposed initiatives identified above.

DNV GL consider that the knowledge hub can complement all of the initiatives identified in this updated map, by coordinating, collecting and collating information into useful resources. Looking ahead, this approach should also be used to identify further specific work packages and targeted interventions (such as on design optimisation, system standardisation, overplanting, reactive power requirements and alternatives to DC). Overall, this approach has many benefits and should help realise the contribution knowledge sharing can bring to reducing both risk and cost of offshore transmission – and ultimately offshore wind.

Figure 5-5 Map of existing and potential industry initiatives and potential work packages identified by this report



6 QUANTIFYING POTENTIAL BENEFITS FROM SHARING GOOD PRACTICE

To help provide support for a good practice sharing scheme in offshore transmission and reinforce cost saving estimates in the CRTF report, this section quantifies potential benefits from a number of the lessons and initiatives identified earlier in the report.

The cost estimates in this section are indicative of the cost reduction potential and will be subject to significant uncertainty. Many simplifying assumptions have been made and further work would be required to refine and validate the work. However, the following should provide a useful indication of the order of cost savings.

6.1 Methodology

In order to assess the cost reduction potential of different initiatives DNV GL completed a three stage process:

1. Derive technical characteristics for a reference project and assumptions
2. Use DNV GL model to derive Capex, Opex and AEP baseline estimates. In particular break down Capex into the transmission element and provide cost breakdown for each element e.g. export cable supply
3. Consider lessons learned initiatives and consider quantified impact on Capex, Opex and AEP. Figures are likely to be mainly quoted for transmission Capex with the total value provided for LCOE

DNV GL also looked at potential impacts in terms of cost reduction from introducing the knowledge hub described in section 5, by researching impacts from across a range of other schemes in other sectors. Despite clear evidence of qualitative benefits, it is extremely difficult to identify specific cost savings driven by these other schemes. For this reason, we have focussed on the cost reduction potential from the specific initiatives, although qualitative benefits of the knowledge hub are set out in section 5.

6.1.1 Assumptions and choice of reference project

For our analysis, we adopted a reference project from The Crown Estate's Cost Reduction Pathways Study[48]. Site B was chosen as the reference site due to its similarity to the projects which DNV GL expects to see installed out to 2020. The technical characteristics are as follows:

Table 6-1 Technical characteristics of the reference project

35m water depth
40km export cable to onshore connection point
9.4m/s mean wind speed at the hub height
540MW wind farm
90 x 6MW turbines
500MW substation and transmission[49]

A number of simplifying assumptions were made:

48 Offshore Wind Cost Reduction Pathways Study, http://www.thecrownestate.co.uk/media/305094/offshore-wind-cost-reduction-pathways-study.pdf

49 Using a 500MW substation and transmission for a 540MW wind farm is an illustration of the application of 'Overplanting' concept.

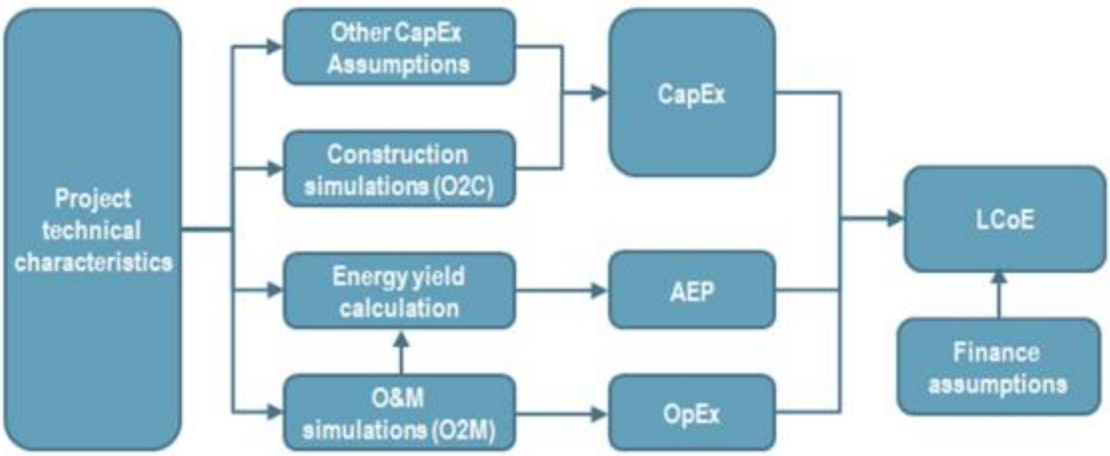
- Volume of deployment is not considered. This approach assesses the cost of a project today and then considers the potential reductions that may be achieved through different initiatives on that same project. Volume is clearly critical to cost reduction, but the impact is uncertain and would distract from direct consideration of the initiatives within this project.
- Transmission costs are included as Capex, i.e. as the generator perceives it at Final Investment Decision. In practice transmission costs are recouped from the OFTO and then paid for through TNUoS charges and become Opex. In practice this may impact on the terms on which the transmission element is financed. However for the purposes of this model transmission costs are included as Capex with finance considered across the wind farm (and not disaggregated into the generation asset and transmission asset).
- As a simplifying assumption, wider TNUoS charges are not included.

6.1.2 Cost baseline

DNV GL have developed an Offshore Wind Cost model which takes publicly available data on distance to onshore connection point, water depth and wind resources and plugs them into a detailed bottom up model consisting of a number of different elements. These include individual Support Structures, Electrical Systems and Installation Capex models, an Opex model and an Annual Energy Production (AEP) model.

The model is summarised in the graphic below:

Figure 6-1 Schematic diagram of DNV GL's LCOE model



For the purposes of this study, LCOE is calculated as follows:

$$\mathrm{LCoE} = \frac{(\mathrm{FCR} \times \mathit{Total}\ \mathrm{CapEx}) + (\mathrm{OpEx})}{\mathrm{AEP}}$$

Where;

- LCoE = Levelised Cost of Energy (£/MWh)
- Total CapEx = Capital Expenditure (£)
- FCR = Fixed Charge Rate (%)
- Total OpEx = Operating Expenditure (£ / annum)
- AEP = Net Annual Energy Production (MWh / annum)

It is important to note that this method of calculating the LCoE relies on a nominal charge rate, called the fixed charge rate (FCR), which is used to annualise the costs of offshore wind to a single year.[50]

On the basis of this model and using the technical assumptions determined in Section 6.1.1, the cost breakdown of an offshore wind farm (including its export transmission) can be derived and is shown in Figure 6-2. We have deliberately not identified actual costs for this reference project because we considered this would detract from the message around potential percentage reductions.

A further cost breakdown of an export transmission is given in Figure 6-3.

Figure 6-2 Proportion of offshore wind levelised costs

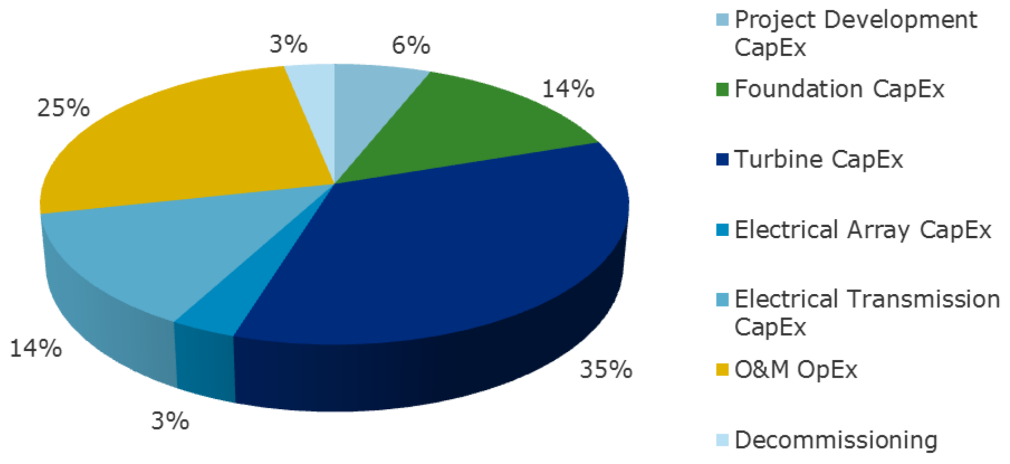
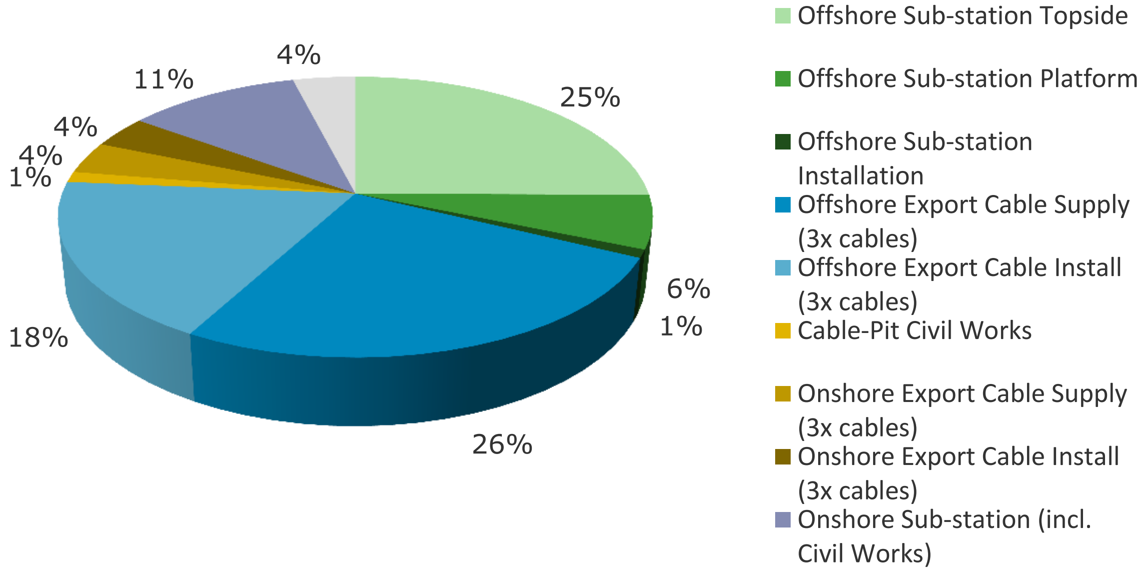


Figure 6-3 Share of offshore transmission Capex by activity[51]



50 Previous work for the Crown Estate showed that using a FCR as opposed to a DCF led to very little difference in LCOE between Discounted Cash Flow and Fixed Charge Rate approaches, even across a range of projects with different characteristics. It should therefore be seen as a simplifying assumption, but one that makes relatively little impact on the results.

51 Grid connection cost is a bank guarantee provided to the TSO for local works, which is redeemed through TNUoS charges

6.2 Cost reduction potential

Table 6-2 provides indicative estimates of the cost reduction potential from a range of the initiatives described in this study and the impact on the reference project. Many of these initiatives are challenging to quantify given their nature, and so caution must be used when quoting the specific values. However, the potential order of magnitude of the saving is a useful metric to understand relative potential value of the activity – where some can be considered more significant than others.

In addition, this study has focused on the transmission Capex element and in practice many of these initiatives will have implications on the operational performance and energy production of the wind farm. The actual cost saving will therefore be reduced. It is also important to distinguish between cost – how much something actually costs to make or deliver – and price – the amount companies are willing to pay for that good or service.

How to read Table 6-2

To identify the potential cost saving of different initiatives, DNV GL first considered whether there was any evidence available in the public domain of the cost saving potential of the different initiatives and if not then used internal expert knowledge to assess the potential impacts.

Next an input assumption was derived, for instance, on the basis of experience from the oil and gas sector, DNV GL assume that collation, collection and coordination of industry knowledge can lead to a 5% reduction in transmission Capex. Initiatives resulting in a saving on transmission Capex were summed to provide the total reduction.

For those initiatives which impacted Opex or AEP, the formula in Section 6.1.2 was used to assess the reduction against the baseline, and a total LCOE reduction identified.

Table 6-2: Indicative cost reduction potential of selected initiatives

Life-cycle stage	Initiative	Evidence (based on DNV GL judgement unless explicitly stated)	Input Assumption used	Potential impact	Other factors to consider
All	Collation, collection and coordination of industry knowledge	Examples considered in this report demonstrate that in oil and gas, a first tier supplier can save 5% of total cost through supply chain knowledge sharing.[52] Internal knowledge management schemes in the oil and gas sector "was one of the keys to reduce operating costs by 21%" (ex- Chairman of Chevron)[53]. Industry level schemes may not be able to achieve this level but this example highlights the potential benefit.	Take 5% of total transmission Capex	5% reduction in transmission Capex	Potential for OpEx saving. Scheme would need buy in and credibility amongst industry players to achieve these level of savings.
Design	System standardisation	Benefits accrue throughout lifecycle but difficult to quantify. System standardisation likely to reduce risk (through replication), reduce design effort and aid manufacturing. Strategic spares provision should reduce Opex. It will also enhance the applicability of reference designs of substations (and converter stations) and common ratings of cables.	Take 10% from Opex associated with transmission system, and take 1% of total transmission Capex	0.2% reduction in LCOE	Likely to be some further Capex benefit although there is the potential that voltage rating may not be optimal for all projects.
Design	Reference designs for substations	Benefits accrue throughout lifecycle but difficult to quantify. Standard designs should reduce risk and lead to lower contingencies. DNV GL assume about 10% contingency for manufacturing. Bespoke designs can also increase price by up to 30%. Therefore DNV GL assume potential to reduce cost by 10% for offshore substation.	Take 10% of offshore substation supply cost	3% reduction in transmission Capex	Overlap with system standardisation. Reduction in contingency will take time to realise. However this considers only one element of the benefits of standardisation, benefits would accrue in consenting, installation, procurement and operations. The benefits are therefore likely to be greater.

52 http://eprints.brighton.ac.uk/79/1/Putting_Supply_Chains_into_Practice.pdf

53 http://www.providersedge.com/docs/km_articles/Applying_KM_to_Oil_and_Gas_Industry_Challenges.pdf

Design	Overplanting of wind farm	DNV GL modelling suggests a 540MW wind farm could be serviced by 500MW export infrastructure. The saving from lower transmission capacity outweighs generation lost due to curtailment leading to a reduction in LCOE.	Compare LCOE under the two scenarios	1.3% reduction in LCOE	Very dependent on project specific assumptions. Likely to be some impact on transmission losses and cable life which has not been captured.
Design	Appropriate base rating, supplemented by dynamic rating of cables and transformers	Interviewers suggest 10% cost reduction in cables and transformers possible.	Take 10% of cable supply cost	3% reduction in transmission Capex	Dynamic loading may increase losses, impact cable life, insurance costs and increase monitoring requirements.
Design	Reactive power requirements	£10-20 million cost for a 540MW wind farm. Potential for SVC requirements to be optimised across the system which could result in savings at a project level of approximately 10% of onshore substation.	Take 10% from onshore substation costs	1% reduction in transmission Capex	May increase losses. More of a movement of where cost falls (i.e. SO or generator) and better optimisation at system level and so unlikely that every wind farm would see this saving.
Procurement & Supply Chain	Bringing in the supply chain earlier into the development process	Earlier involvement of the supply chain helps a) reduce risk and b) allows greater optimisation of design. In terms of risk, DNV GL propose a saving of around 2-3% of transmission Capex.	Take 2-3% from transmission Capex	2% reduction in transmission Capex	There may also be some benefit in generation availability if the system is optimised more effectively.
Procurement & Supply Chain	Increased competition	In DNV GL experience increasing the number of bidders from 2 to 5 has led to price reductions of around 10% in supply.	Take 10% from supply of offshore substations and export cables (sufficient competition onshore)	5% reduction in transmission Capex	Competition is critical to achieving price reduction although quantifying saving is extremely difficult.

Installation	Avoiding damage to or failures of cables during construction	DNV GL understand a full cable repair campaign may cost in the order of £10 million.	Take £10 million from transmission Capex	3% reduction in transmission Capex	Although contingency is included in model, it is not this significant. This is therefore less of a cost reduction and more avoidance of cost overruns (not accounted for by the model).
O&M	Robustly plan for cable failure prevention, root cause analysis and cable repair	DNV GL understand that submarine cables have been out of service for up to 5 months, while with appropriate repair frameworks in place a repair could be completed within 2 months. Assuming that a 540MW wind farm (500MW transmission) loses both export cables through external forces, then having the cable repair agreement in place could save 3 months of AEP.	Improve AEP by 1.2%	1% reduction in LCOE	There will be costs of having a call-off contract in place which are not accounted for and so the overall saving will be reduced. This is a relatively simplistic assessment of LCOE impact, with the timing of the potential fault important to overall cost reduction.
Total potential impact: 22% reduction in transmission Capex, plus additional 2.5% reduction in LCOE					

6.3 Summary

Summing the results above suggests a total cost reduction potential of 22% of transmission Capex, most of which is realised from better upfront design and project planning. This figure should be treated with caution however. In particular:

- The analysis has considered a very narrow cost reduction potential, with only a qualitative assessment of wider implications of such a change. A more refined quantitative approach based on observed results may produce different, and potentially lower, results.
- It is unlikely that all the cost reduction potential would apply to a single project, but would rather manifest across the sector as a whole.
- The analysis looked at one reference project. As projects move further offshore, both the absolute and the relative cost of the transmission element is likely to increase (e.g. as a result of using HVDC), thereby impacting the cost reduction potential.
- Quantifying the broad range of initiatives here is challenging, with various assumptions having to be made which would need to be tested in more detail.

Bearing these caveats in mind, we ran the 22% transmission Capex saving through DNV GL's LCOE model. This results in a 3.5% reduction in the LCOE of offshore wind.[54] Combining this with the LCOE reductions of 2.5% from system standardisation, overplanting and cable repair frameworks (i.e. Opex savings), gives an overall wind farm LCOE reduction potential of around 6%.

Whilst this should be treated with due caution, DNV GL conclude that applying lessons learned to future projects provides a material opportunity to reduce costs of offshore transmission and offshore wind.

[54] A 22% reduction in transmission Capex results in a greater levelised cost saving than results from simply multiplying this reduction by the 14% of total cost (in Figure 6-2) because of the time value of money. (i.e. future costs are worth less today). This can be seen through the application of the FCR.

APPENDIX 1 – FURTHER DETAIL ON TWO POTENTIAL INITIATIVES TO TAKE FORWARD

This appendix provides further detail on two of the initiatives highlighted in section 5.5 as requiring further attention and consideration.

1. Standardisation and a Modular Approach[55]

Standardisation can be distinguished into three levels:

- Standardisation at component and technical level. This is largely a technical and design issue.
- Standardisation at the system and functional level, mainly in relation to transmission voltage and substation power ratings. Functionalities may include fault behaviour, system protection schemes and control devices. This is largely a regulatory or management issue.
- Standardisation of processes including processes and methodologies of project management, design, installation, operation and maintenance.

It is more urgent and important to introduce standardisation at the system and functional level and about processes rather than on detailed parameters and technical solutions. If every offshore substation, converter station and every offshore transmission cable has a bespoke voltage and power rating, it would forego significant cost savings and other benefits including supply chain and safety related benefits.

Currently the UK market is characterised by non-standard offshore transmission infrastructure – offshore wind developers have largely adopted bespoke solutions and multiple designs (in terms of MW capacity and voltage). In Germany, despite that it has a different regulatory model, the same issue pervades – multiple designs across projects have been adopted (e.g. the first four offshore HVDC transmission schemes for offshore wind farms have all used a different voltage including ±150kV, ±250kV, ±300kV and ±320kV). It is encouraging that the new German offshore transmission plan includes standardised assets which may move toward a 900MW standard block size of substations and converter stations.

It is important to avoid confusion between standardisation, and innovation and competition. There may be concerns that early standardisation will hinder innovation and competition. This is true for standardisation at component level but the standardisation at system and functional level will increase number of suppliers and guarantee inter-operability between different designs thus promoting innovation and competition.

It is also worth avoiding confusion of different duties of the standard bodies. Technical standards bodies (like IEC, BSI, etc.) or technical guidance bodies (like CIGRE, etc.) only spell out what should be done in terms of material and component design for a given voltage level. They do not specify what the system voltage should be. In other words, system voltage level is an input rather than output in any technical standards. It would be unrealistic to expect a body which issues technical standards to define the voltage level and transmission capacity to be used in specific countries or situations.

A possibly more effective way to promote and implement standardisation may be via regulators' guidance on cost assessment of offshore transmission infrastructure (in the case of GB) or via central planning bodies' plans (in the case of other European countries). This is because a reasonable degree

[55] An excerpt from 'Offshore Transmission Associated with Connecting Offshore Generation', prepared by Chuan Zhang for IET On-Line Reference Work (expected to go live later in 2014)

of standardisation will bring the following benefits (all of which should be recognised by the regulators' cost assessment guidance):

- economies of scale and Capex reductions;
- safer operation and better operational performance and improved interoperability of assets;
- increased availability of strategic spares;
- improved skill sets / training around standardised designs and modules; and
- less pressure on supply chain as less variation in design.

Furthermore standardisation of voltages can help to minimise the voltage conversion required and hence minimise capital costs and losses. For future DC interconnection this could avoid the need and cost of DC–DC converter to convert from one DC voltage to another.

2. Appropriate Ratings of Cables and Power Transformers

The temperature in the cable core depends on the losses within the cable due to the power transmitted, the construction of the cable, and the conditions of the cable surrounding such as temperature and thermal conductivity.

From the cable's point of view, the limiting parameter is the maximum temperature allowed in the insulation which is, for instance, 90°C for XLPE and EPR. Typically, the maximum current carrying capacity for a cable is defined based on project specific data, thermal calculations, loading patterns and experience, including a number of assumptions. Taking into account the uncertainties, the estimates tend to be conservative and export cables in subsea applications may be rarely fully utilised.

Cable design is often carried out in accordance with IEC 60287[56] series of standards to determine the limit of the continuous rated current (100% load factor) at maximum allowed conductor temperature (e.g. 90°C) for the assumed surrounding conditions. Cyclic HV cable rating is covered in IEC 60853-2[57] but only applies "to cables buried in the ground, either directly or in ducts, when carrying a load which varies cyclically over a 24 hour period, the shape of each daily cycle being substantially the same". A generally agreed approach for renewable energy applications which takes due consideration of site specific wind patterns and predicted loading of the cable is yet to be developed. With assets being traded, it will also be required that stakeholders apply the same methodology for an appropriate rating so that a valuation would be carried out on similar terms. A suitably chosen base rating of the cable could be supplemented by "dynamic" rating of the cable, where its capacity at a specific time is dependent on the recent history and the current conditions in / around the cable.

A pre-requisite for dynamic rating is that the cable temperature can be monitored in real time. This is commonly achieved by using optical fibre based distributed temperature sensing (DTS) system. Availability of optical fibres is considered to be standard for today's offshore wind farm export cables and use of DTS is widespread[58]. However for onshore AC cases, as the DTS is normally not embedded inside the cables but is run alongside the cables thus providing data of limited use, separate consideration would be required if dynamic ratings are to be applied beyond the subsea section.

[56] International Electrotechnical Commission (IEC) (2006). Electric cables - Calculation of the current rating - Part 1-1: Current rating equations (100 % load factor) and calculation of losses - General, IEC 60287-1-1, 2nd edition.

[57] IEC (1989). Calculation of the cyclic and emergency current rating of cables - Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages, IEC 60853-2, 1st edition.

[58] Kjaer, S.V., Schwartzberg, D., Christiansen, W. and Zinglersen, M.Z. (2011). Determination of hotspots in submarine power cables in offshore wind farms using distributed temperature sensing technology, 10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Farms, Aarhus, Denmark, 25-26 October, 2011.

Separately, a detailed base and dynamic rating approach may also be developed for offshore transformers.

In conclusion, there appears to benefit in developing a UK-led ‘white paper’ (an implementation proposal and needs case) for base and dynamic rating in offshore renewable applications for soonest application. With more experience becoming available, this could be turned into standard practice in the longer term, e.g. by publication through CIGRE or IEC.

APPENDIX 2 - REVIEW OF KNOWLEDGE SHARING SCHEMES IN OTHER SECTORS

In developing the scope of the knowledge hub, DNV GL reviewed the following schemes in other sectors. The aim of this was to understand the characteristics of these schemes and what made them successful (or not):

- Norwegian FPSO Experience Transfer Network
- CIGRE
- Offshore REliability Data (OREDA)
- SKYbrary

Key learnings from these other schemes

- Sharing good practice has generally been successful in other sectors.
- For instance the Norwegian Offshore Oil and Gas FPSO Experience Transfer Network Lessons Learned document: "receives around 50,000 hits a year, and is referred to and even directly quoted in contracts", according to the scheme's facilitator.
- OREDA has led to:
    - Standards for reliability data collection. An ISO Standard based on the OREDA concept was issued in 2006 (ISO 14 224: 'Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment');
    - Guidelines and software for data collection and data analysis; and
    - Publication of reliability data. Five public editions of a Reliability Data Handbook have been issued (1984, 1992, 1997, 2002, 2009), which is sold in more than 50 countries world-wide.
- There is a need for someone to own the scheme. Individuals within companies are usually too busy with other commitments to share lessons of their own accord – a framework needs to be put in place to facilitate the exchange of valuable information
- The competitive landscape will drive how willing people are to share information. It is very unlikely that people will share if they are in direct competition with each other. Different phases of the lifecycle will have different competitive pressures which will impact how open people are.
- There needs to be a clear benefit to participating in the scheme. Considering and sharing lessons requires another claim on people's time and to ensure that it is worth this time commitment, people need to see the benefits to themselves or their organisation. The incentive needs to be clear. This also means considering the balance between cost and benefits to make it easy for people to respond while maximising the benefit.
- Only the decision makers can enact the lessons – can be problematic to get to these people.
- Data is vital.
- There needs to be clarity on aims. The term 'best practice' can be seen negatively.

- The funding model depends on whether benefits are primarily to participants or to wider industry. For instance when financial contributions are required, it is usually easier to sell the concept within organisations if the benefits which emerge from the project are only made available to the participants of the joint industry project and not released (at least initially) into the public domain. This helps overcome potential free riders.
- There are two different approaches in lessons learned schemes:
    - Driving the collection of lessons around certain themes (usually through sub-committees or work packages) with these themes determined by a central committee. CIGRE is an example of this type of highly stratified approach. The benefit can be real change and added value but potentially over long timescales and through a relatively rigid approach.
    - Putting a framework in place which collates, curates and responds to those lessons which emerge from the industry experience. This is more reactive but in turn, flexible. It can still drive change but needs the appropriate means of resolving lessons which emerge. The Norwegian FPSO transfer network is an example of this approach.

Norwegian FPSO Experience Transfer Network

Summary	The FPSO (Floating Production, Storage and Offloading) Experience Transfer network is set up under the sponsorship of the Norwegian Oil and Gas Association Operations Committee. The committee recognized in 2001 the need to capture lessons learned during several FPSO projects during the 1990s, and to gather experience from 20 operating years with FPSOs on the Norwegian Continental Shelf.
Objective	To enable FPSO operators to learn from each other to improve operations and influence future designs".
Representation	The workgroup has representation from the operators of the five Norwegian FPSOs, and two of the operators who have a close interest in FPSOs. A representative from the PSA also participates to assist with legislative and safety issues. The group is supported by an Norwegian Oil and Gas Association sponsored facilitator and meets regularly.
Outputs	• to gather lessons learned from existing Norwegian FPSOs • to develop an Norwegian Oil and Gas Association website for the sharing of FPSO lessons (This website seeks to provide the user access to a wide range of FPSO lessons learned, links to other important FPSO websites and enables entry of lessons learned by users interested in building a knowledge base for future designers and operators.) • to establish links with the UKOOA • to hold a seminar on topics of relevance to FPSO operators
Measured Impact	David Llwellyn – facilitator for the scheme and formerly Operations Manager for BP's Schiehallion FPSO: "*What's special is the encouragement we get from the government to work together: the regulators are encouraging us through ratings to learn from each other.* *The 'Lessons Learned' documented from the project receive around 50,000 hits a year, and are refereed to and even directly quoted in contracts.* *In this way, Skarv BP and Alvheim are projects which benefitted directly from these lessons learned: they are now operational and performing exceptionally well".*

Figure A-1 Summary matrix of lessons learned in the Norwegian FPSO Knowledge Transfer Network

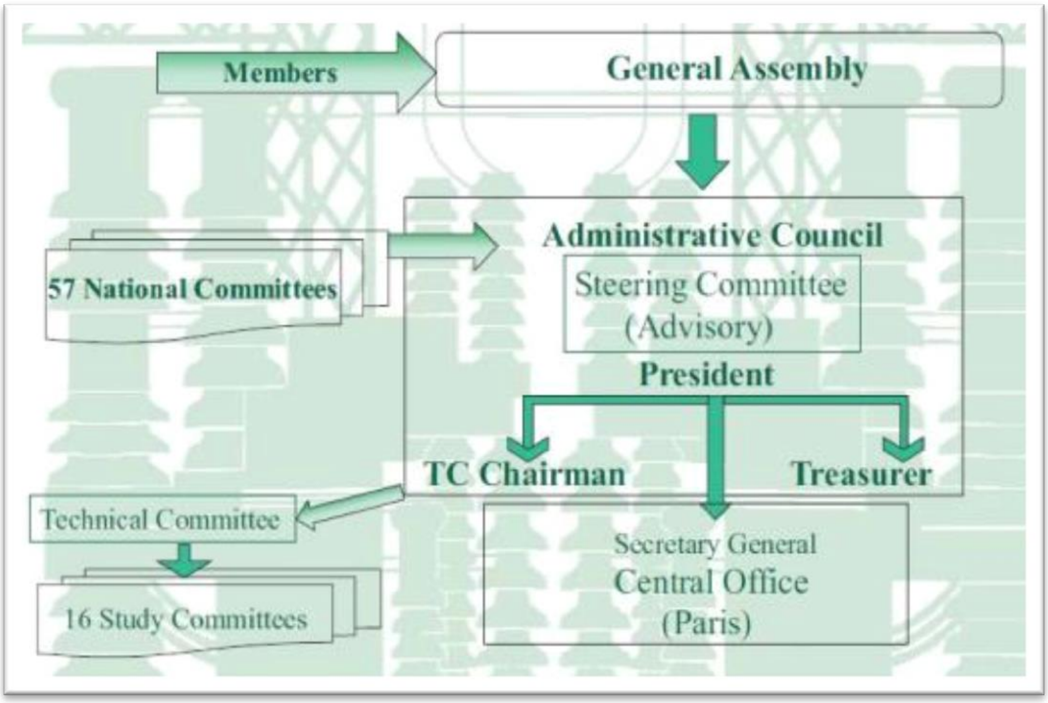
Lessons overview

	SELECT	DESIGN	CONSTRUCT	COMMISSION	INSTALL	OPERATE
HSE		• Fire protection • Risk Management	• Site Safety • HSE			• Risk Management • Safety - General
OPERATIONS	• Organisation • Accomandation Size	• Workshops • Mechanical handling • Helicopters • Commercial	• Organisation	• Materials Control • Handovers • Commercial • Organisation • Documentation		• Crew Performance • Uptime Performance • Accommodation • Other • Role of Vendors/OEM • Standby vessel
SUBSEA		• Flow Assurance • Interfaces • Installation • Controls • Risers	• Corrosion • Technical • Installation • Planning	• Commissioning • Interfaces • Multi-function support vessel		
PROJECT MANAGEMENT	• Planning • Organization • Contracts • Risk Management • Commercial • Relationships • FEED • Technical	• Documentation • System engineering • Regulatory compliance • Organisation • Contingency • Design Input from Operations • Engineering • Knowledge Management • Interfaces • Planning	• Construction Management • Planning • Project steering • Project Input from other groups • Capex Over Runs • Documentation • QA/QC	• Risk Management • Offshore hook-up		

International Council on Large Electric Systems (CIGRE)

Summary	Founded in 1921, CIGRE, the Council on Large Electric Systems, is an international non-profit association for promoting collaboration with experts from all around the world by sharing knowledge and joining forces to improve electric power systems of today and tomorrow.
Objective	CIGRE calls on international experts to exchange knowledge, share best practices and join forces for the power system of today and tomorrow. CIGRE aims to: • Allow engineers and specialists from all around the world to exchange information and enhance their knowledge related to power systems, • Add value to the knowledge and information exchanged by synthesizing state-of-the-art world practices, • Make the synthesis of CIGRE's work available to the decision-makers of the industry (CEOs, directors, managers, and regulators).
Representation	CIGRE counts more than 2,500 experts from all around the world working actively together in structured work programmes coordinated by the CIGRE 16 Study Committees, overseen by the Technical Committee. Each Study Committee covers a specific technical domain dealing with power systems. Their main objectives are to design and deploy the power system for the future, optimize existing equipment and power systems, respect the environment and facilitate access to information.
Outputs	CIGRE provides technical knowledge through: **Events:** Session: CIGRE flagship event held in even number years, brings together over 3,200 senior executives, experts and specialists to interact, discuss and network. A Technical Exhibition is held in parallel. The Session and its exhibition gather around 6,600 decision makers and experts from the worldwide Power Industry. Symposia in odd numbered years, in different countries, brings together over 300 delegates. Symposia tend to focus on specific subjects of topical interests. Regional meetings and colloquiums, held to discuss specific issues specific to a country or a region. **Publications:** **Publications** (6800 references, including reports, tutorials, technical brochures, etc) are available from e-cigre, the CIGRE Technical Library and Bookstore (on sale for all, download for members only). Some 50 technical brochures are issued every year.
Measured Impact	CIGRE’s publications are normally referred to as authoritative guides or evidence by the transmission sector. A typical example is Guidelines for the design and construction of AC offshore substations for wind power plants, Technical Brochure 483, December 2011.

Figure A-2 Overview of CIGRE



Offshore REliability Data (OREDA)

Summary	In the early 1980s a number of oil companies operating in the North Sea and the Adriatic started a collaborative project. The idea was to survey the reliability of important equipment under 'real life' operational conditions. The Norwegian Petroleum Directorate (now: Petroleum Safety Authority) initiated the OREDA Project in 1981.
Objective	OREDA's main purpose is to collect and exchange reliability data among the participating companies and act as The Forum for co-ordination and management of reliability data collection within the oil and gas industry.
Representation	OREDA® is a project organisation sponsored by eight oil and gas companies with worldwide operations.
Outputs	OREDA has established a comprehensive databank with reliability and maintenance data for exploration and production equipment from a wide variety of geographic areas, installations, equipment types and operating conditions. Offshore subsea and topside equipment are primarily covered, but onshore equipment is also included. The OREDA® data are stored in a database, and specialised OREDA® software has been developed to collect, retrieve and analyse the information. Currently the database contains data from > 265 installations, 16 000 equipment units with 38000 failure and 68 000 maintenance records. The databank also includes subsea fields with almost 2000 well-years' operating experience.
Measured Impact	In addition to the build-up of a large reliability databank, and the use of data by the participating companies, achievements in the OREDA include: • Standards for reliability data collection. An ISO Standard based on the OREDA concept was issued in 2006 (ISO 14 224: "Petroleum, petrochemical and natural gas industries – Collection and exchange of reliability and maintenance data for equipment"). • Guidelines and software for data collection and data analysis • Publication of reliability data. Five public editions of a Reliability Data Handbook have been issued (1984, -92, -97, -02, -09), which is sold in more than 50 countries world-wide. • Data used in analyses for decision support for e.g. concept selection, design optimisation. • Exchange of reliability knowledge between the participating companies, and co-operation with miscellaneous parties such as manufacturers, research institutes etc. • Formalised co-operation with the subsea system suppliers Cameron, FMC Kongsberg Subsea, Aker Solutions and Vetco Gray • Promotion of the OREDA concept and OREDA data application by > 40 papers at various international conferences • Training courses and material for OREDA data users • Data used in various research projects and student theses

SKYbrary

Summary	SKYbrary is an electronic repository of safety knowledge related to Air Traffic Management (ATM) and aviation safety in general. It is also a portal (a common entry point) that enables users to access the safety data made available on the websites of various aviation organisations - regulators, service providers, industry.
Objective	SKYbrary's objective is to become a single point of reference for aviation safety knowledge by making universally available and accessible the safety knowledge accumulated by various aviation organisations, entities and initiatives. The SKYbrary knowledgebase is a dynamic enterprise and has taken several years to develop. To develop further, and maintain the accuracy and relevance of the knowledgebase, will require the support and active participation of all those interested in promoting best practice and knowledge in aviation safety.
Representation	SKYbrary has been initiated by EUROCONTROL
Outputs	SKYbrary contains knowledge articles divided into 4 major domains: operational issues, human performance, enhancing safety and safety regulations. A total of 3500 knowledge articles were published over the years and are kept up to date by means of review cycles. All authors are experts in their domains. Authoring is restricted to experts. All content is publicly available. SKYbrary adopts the concept of Media-wiki products - anyone can comment, propose modification to an existing article, suggest a new topic or submit a draft article. However, there is an important difference that distinguishes SKYbrary from other wikies. A robust content management and control process supported by appropriate user rights management ensures the needed quality, credibility and consistency of stored safety dataSKYbrary is one of the largest outward facing / public knowledge sharing websites and certainly the largest in the aviation industry. SKYbrary contains knowledge articles divided into 4 major domains: operational issues, human performance, enhancing safety and safety regulations. A total of 3500 knowledge articles were published over the years and are kept up to date by means of review cycles. All authors are experts in their domains. Authoring is restricted to experts. All content is publicly available.
Measured Impact	1.5 million visits per year which includes 150,000 visits monthly by 100,000 unique visitors, visiting 300,000 pages, spending 2.25 minutes on average per visit and reading 2.5 pages per visit. 20,000+ subscribers to the weekly newsletter which result in in 5000 - 8000 visits. Toolkits were visited over 50,000 times each SKYbrary also publishes nano-learnings (short stories to learn from) on the social media (Facebook, Twitter, LinkedIn and Google+). Bi-annually a paper print magazine called HindSight is published and distributed free of charge.

APPENDIX 3 - POTENTIAL OPTIONS FOR SHARING GOOD PRACTICE IN THE OFFSHORE TRANSMISSION SECTOR

When considering the best approach to the sharing of lessons learned, DNV GL developed and assessed a long list of potential options which are outlined below:

Type	Pros	Cons	Relevance to this study	Potential examples
Online resource (wiki)	Low cost. Good repository of information. Useful supplement to other options.	Relies on people contributing unilaterally. Relies on people contributing in sufficient detail to be useful to others. It can take considerable effort to write for others outside your project. Need to validate (and possibly filter) contributions.	*Unlikely to be sufficient on its own to add real value but could be a useful supplement to other options, acting as a long lasting and easily accessible repository of information at fairly low cost.*	'Knowledge Network' for the Wave and Tidal sector.
Conference proceedings/ workshops	Lessons already being shared this way. Useful for disseminating information to wide audience. Some effort could add greater value i.e. more robust choosing and vetting of speakers.	Quality can vary Unlikely to add sufficient value on own Can be high level overviews and paint 'rosy picture' omitting the problems altogether.	*Lessons learned will continue to be shared through conferences and act as a useful means of disseminating to a wide audience, however they are likely to be sufficient on own. Conference proceedings should therefore be part of the overall scheme but as a supplement to other options.*	Wide range of industry conferences e.g. Annual Offshore Wind Conference of RenewableUK, conference on offshore transmission, etc
Existing working groups	Works within existing structures and therefore relatively low cost.	Issues as to whether these groups would have enough time in the agenda. Individuals less open than in one to one discussions.	*Unlikely that existing working group would have sufficient time on the agenda to focus on lessons learned, but working groups should be bought into the scheme, perhaps contributing lessons learned on an annual basis.*	RenewableUK Offshore Grid Group
Third party survey of industry	Low effort for industry to respond. Ability to anonymise responses. Allows degree of filtration	Requires experienced resource to undertake survey and therefore financial cost.	*Appears to be best means of eliciting wider information out of the industry and annual survey could form a primary data source, supplemented by other options above and helping*	This study

	and prioritisation. More open in one to one discussions with trusted party.		*to shape joint industry projects (JIPs) for example. However it requires resource to do so.*	
Joint Industry Project (JIP)	Wide variety of projects can fall under this category. Can add significant value and drive real change.	Time and resource intensive. Outputs may, on some occasions, be restricted to participants only, and not open access.	*Arguably best means of driving real change in specific areas but can be time and resource intensive.* *Agreeing correct focus is a challenge.*	DNV's 'CableRisk' JIP which led to 'Subsea power cables in shallow water renewable energy applications' guideline (with open access)
Third party data/infoaggregators	Can collect high quality anonymised data/info. Commercial operators may be more efficient at collecting and analysing data/info. Cost paid for by users.	Need to identify a trustworthy party handling sensitive data and information.	*Good data and information are immensely helpful and with SPARTA project does suggest offshore wind sector can share data.* *Remains a challenge to identify business case and appetite in sector.*	SPARTA for data; CIGRE Technical Brochure 379 for info, 'Update of service experience of HV underground and submarine cable systems'.
Combination of the above	Flexible framework. Allows high profile issues to be identified and dealt with. Allows appropriate dissemination tools to be used for each lesson. Can disseminate both widely (lots of little lessons) and deeply (specific actions in one area).	Perceived further adding to crowded landscape.	*Appears not to be one silver bullet and so flexible approach using tool box of options would be sensible.*	'Knowledge Hub' for Offshore Transmission (as proposed in this study).

APPENDIX 4 - ACKNOWLEDGEMENTS

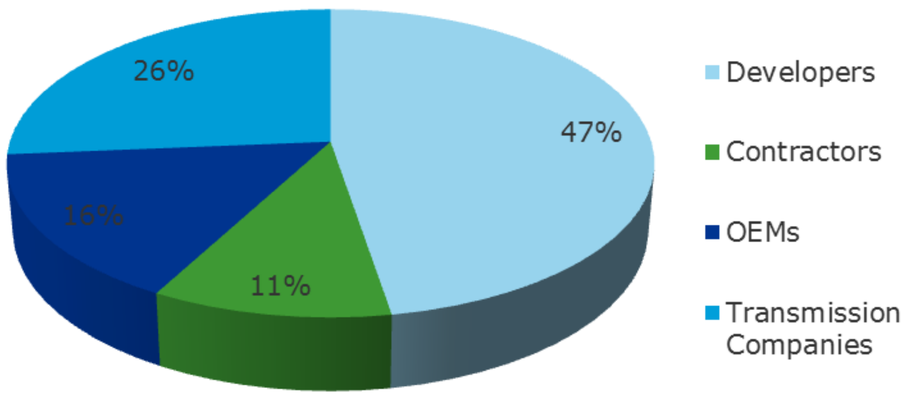
The following companies participated in this study by providing their perspectives and insights on lessons learned in the development, construction and operation of offshore transmission infrastructure and also in ways the sector could share knowledge and lessons more effectively going forward. Their respective contributions are gratefully acknowledged.

In developing this report, we also received comment and input from Ofgem, RenewableUK, the Offshore Renewable Energy Catapult, The Carbon Trust, The Institution of Engineering and Technology and the Offshore Wind Programme Board Grid Group.

Interviewees:

- Centrica
- DONG Energy
- Fluor
- Mainstream Renewable Power
- RWE
- Scottish Power Renewables / Iberdrola
- Statkraft
- Statoil
- Warwick Energy
- Van Oord
- Visser & Smit Marine Contracting (VSMC)
- ABB
- nkt cables
- Siemens T&D
- Balfour Beatty
- Diamond Transmission
- Frontier Power
- National Grid
- Transmission Investment

Figure A-3 Proportion of interviewees



APPENDIX 5 - INTERVIEW QUESTIONNAIRE

Sharing Best Practice in Offshore Transmission to Facilitate Cost Reduction – Questionnaire

The Crown Estate has commissioned DNV GL to identify lessons learned and share best practice in the development and operation of offshore transmission infrastructure, following on from recommendations made in the Cost Reduction Taskforce report.

Key points:

- This document will be used as a guide for ~ 1 hour semi structured interview with yourself and DNV GL staff.
- It is not expected that you complete it beforehand but you can do so if you wish (if, for instance, person is collating inputs from various internal resources).
- We do not expect to cover all the questions and we are keen to focus on those areas of most relevance to you and your organisation.
- The study is mainly focused on technical lessons as opposed to a debate about the potential merits of the OFTO regime – however if there is an important lesson within the regulatory element we are happy to discuss it.

In terms of confidentiality:

- DNV GL staff will not pass on any project-specific or company-specific information gained during the interview. There will be a written record, but circulation will be restricted to DNV GL and TCE staff on a need-to-know basis. Access to the electronic version will be restricted to project staff only, for a period of three years.
- Any information published will not be identifiable with a specific organisation or project.

<table>
<tr><td>1</td><td>What are the main activities undertaken by your organisation, relevant to offshore transmission?

(Tick all that apply)</td><td>
<table>
<tr><th></th><th>Consenting</th><th>Design</th><th>Procurement</th><th>Manufacturing</th><th>Installation</th><th>Commissioning</th><th>Operation, monitoring</th><th>Maintenance, repair</th><th>Asset transfer,</th><th>Decommissioning</th></tr>
<tr><td>Onshore asset</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Offshore asset</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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Notes:</td></tr>
<tr><td>2</td><td>Which projects have you worked / are you working on, and in what roles?</td><td></td></tr>
<tr><td>3</td><td>What problems have you experienced or what do you see as the biggest problems with offshore transmission?

(Identify and explain up to 5, allocating item</td><td></td></tr>
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<td>4</td>
<td>What have you learnt as an organisation that you would consider ‘Best Practice’?

(Identify and explain up to 5, allocating item numbers to cells in table)</td>
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<tr><td>5</td><td>Which lessons offer the best chance of reducing COE for offshore wind?

(Identify and explain up to 5, allocating item numbers to cells in table)</td><td>
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<tr><td></td><td>How would these cost savings be realised (e.g. eliminating errors, adopting best practices and procedures, enabling standardisation of components, a common approach adopted by parties)?</td><td></td></tr>
<tr><td>6</td><td>What lessons can the UK learn from other countries, e.g. in Europe?</td><td></td></tr>
<tr><td></td><td>What lessons can the offshore transmission sector learn from other industries, e.g. oil and gas?</td><td></td></tr>
<tr><td>7</td><td>In ten years' time, what do you think the industry will be doing differently in offshore transmission?</td><td></td></tr>
<tr><td>8</td><td>Do you think that sharing Best Practice in offshore transmission…</td><td>• Is likely to be useful to your organisation?</td></tr>
</table>

		• Is likely to be useful to the industry generally, leading to significant cost reduction?
9	What is the best way for the industry to share Best Practice in future? *(Give examples of experience of participation in Best Practice forums or organisations, including other industries. What works/doesn't work?)*	
	Are there lessons that you have learned from earlier projects that have been successfully applied to later projects? If so, did you perceive any cost reduction? How was this cost reduction measured?	
10	Are there any issues or subject areas in which your organisation would not be willing to share Best Practice?	
11	Are there any questions or areas you think we should also have covered?	

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.